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650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B
Association à but non lucratif enregistrée à la
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Contents

Foreword

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1 Scope

The present document describes the physical channels and signals for 5G-NR.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 38.201: "NR; Physical Layer – General Description"

[3] 3GPP TS 38.202: "NR; Services provided by the physical layer"

[4] 3GPP TS 38.212: "NR; Multiplexing and channel coding"

[5] 3GPP TS 38.213: "NR; Physical layer procedures for control "

[6] 3GPP TS 38.214: "NR; Physical layer procedures for data "

[7] 3GPP TS 38.215: "NR; Physical layer measurements"

[8] 3GPP TS 38.104: "NR; Base Station (BS) radio transmission and reception"

[9] void

[10] 3GPP TS 38.306: "NR; User Equipment (UE) radio access capabilities"

[11] 3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification"

[12] 3GPP TS 38.133: "NR; Requirements for support of radio resource management"

[13] 3GPP TS 38.304: "NR; User Equipment (UE) procedures in Idle mode and RRC Inactive state"

[14] 3GPP TS 38.101-1: "NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone"

3 Definitions of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following definitions apply:

3.2 Symbols

For the purposes of the present document, the following symbols apply:

$(k,l)_{p,\mu}$	Resource element with frequency-domain index k and time-domain index l for antenna port p and subcarrier spacing configuration μ; see clause 4.4.3
$a_{k,l}^{(p,\mu)}$	Value of resource element (k,l) for antenna port p and subcarrier spacing configuration μ; see clause 4.4.3
β	Amplitude scaling for a physical channel/signal

$c(n)$	PN sequence; see clause 5.2.1
Δf	Subcarrier spacing
Δf_{RA}	Subcarrier spacing for random-access preambles
κ	The ratio between T_{s} and T_{c}; see clause 4.1
k	Subcarrier index relative to a reference
l	OFDM symbol index relative to a reference
μ	Subcarrier spacing configuration, $\Delta f = 2^{\mu} \cdot 15\ [kHz]$
$M_{\mathrm{bit}}^{(q)}$	Number of coded bits to transmit on a physical channel [for codeword q]
$M_{\mathrm{symb}}^{(q)}$	Number of modulation symbols to transmit on a physical channel [for codeword q]
$M_{\mathrm{symb}}^{\mathrm{layer}}$	Number of modulation symbols to transmit per layer for a physical channel
$M_{\mathrm{sc}}^{\mathrm{PUSCH}}$	Scheduled bandwidth for uplink transmission, expressed as a number of subcarriers
$M_{\mathrm{RB}}^{\mathrm{PUSCH}}$	Scheduled bandwidth for uplink transmission, expressed as a number of resource blocks
$M_{\mathrm{symb}}^{\mathrm{ap}}$	Number of modulation symbols to transmit per antenna port for a physical channel
υ	Number of transmission layers
$N_{\mathrm{BWP},i}^{\mathrm{size}}$	Size of bandwidth part i; see clause 4.4.4.4
$N_{\mathrm{BWP},i}^{\mathrm{start}}$	Start of bandwidth part i; see clause 4.4.4.4
$N_{\mathrm{CP},l}^{\mu}$	Cyclic prefix length; see clause 5.3.1
$N_{\mathrm{grid},x}^{\mathrm{size},\mu}$	The size of the resource grid; see clauses 4.4.2 and 5.3
$N_{\mathrm{grid},x}^{\mathrm{start},\mu}$	The start of the resource grid; see clause 4.4.2
$N_{\mathrm{group}}^{\mathrm{PT\text{-}RS}}$	The number of PT-RS groups; see clause 6.3.1.4
$N_{\mathrm{ID}}^{\mathrm{cell}}$	Physical layer cell identity; see clause 7.4.2.1
$N_{\mathrm{ID}}^{\mathrm{SL}}$	Physical-layer sidelink identity; see clause 8.4.2.1
$N_{\mathrm{RB}}^{\mathrm{CORESET}}$	Frequency-domain size of a control resource set; see clause 7.3.2.2
$N_{\mathrm{REG}}^{\mathrm{CORESET}}$	Number of resource-element groups in a CORESET; see clause 7.3.2.2
$N_{\mathrm{samp}}^{\mathrm{group}}$	Number of samples per PT-RS group; see clause 6.3.1.4
$N_{\mathrm{sc}}^{\mathrm{RB}}$	Number of subcarriers per resource block, see clause 4.4.4.1
$N_{\mathrm{slot}}^{\mathrm{subframe},\mu}$	Number of slots per subframe for subcarrier spacing configuration μ, see clause 4.3.2
$N_{\mathrm{slot}}^{\mathrm{frame},\mu}$	Number of slots per frame for subcarrier spacing configuration μ, see clause 4.3.2
$N_{\mathrm{symb}}^{\mathrm{CORESET}}$	Time duration of a control resource set; see clause 7.3.2.2
$N_{\mathrm{symb}}^{\mathrm{PUCCH}}$	Length of the PUCCH transmission in OFDM symbols; see clause 6.3.2.1
$N_{\mathrm{symb}}^{\mathrm{subframe},\mu}$	Number of OFDM symbols per subframe for subcarrier spacing configuration μ; see clause 4.3.1
$N_{\mathrm{symb}}^{\mathrm{slot}}$	Number of symbols per slot
N_{TA}	Timing advance between downlink and uplink; see clause 4.3.1
$N_{\mathrm{TA,offset}}$	A fixed offset used to calculate the timing advance; see clause 4.3.1
$N_{\mathrm{TA,adj}}^{\mathrm{common}}$	Network-controlled timing correction; see clause 4.3.1
$N_{\mathrm{TA,adj}}^{\mathrm{UE}}$	UE-derived timing correction; see clause 4.3.1
$N_{\mathrm{Rx\text{-}Tx}}$	Minimum time from reception to transmission for a half-duplex UE; see clause 4.3.2
n_{f}	System frame number (SFN)
n_{CRB}^{μ}	Common resource block number for subcarrier spacing configuration μ, see clause 4.4.4.3
n_{HFN}	Hyper-frame number
n_{PRB}	Physical resource block number; see clause 4.4.4.4
n_{RNTI}	Radio network temporary identifier
n_{s}^{μ}	Slot number within a subframe for subcarrier spacing configuration μ; see clause 4.3.2
$n_{\mathrm{s,f}}^{\mu}$	Slot number within a frame for subcarrier spacing configuration μ; see clause 4.3.2
p	Antenna port number
Q_m	Modulation order
ρ	Number of antenna ports
$\bar{r}_{u,v}(n)$	Low-PAPR base sequence; see clause 5.2.2
$r_{u,v}^{(\alpha,\delta)}(n)$	Low-PAPR sequence; see clause 5.2.2
$s_l^{(p,\mu)}(t)$	The time-continuous signal on antenna port p and subcarrier spacing configuration μ for OFDM symbol l in a subframe; see clause 5.3.1
T_{c}	Basic time unit for NR; see clause 4.1

T_f	Radio frame duration; see clause 4.3.1
T_s	Basic time unit for LTE
T_sf	Subframe duration; see clause 4.3.1
T_slot	Slot duration; see clause 4.3.2
T_TA	Timing advance between downlink and uplink; see clause 4.3.1
W	Precoding matrix for spatial multiplexing

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BWP	Bandwidth Part
CCE	Control Channel Element
CORESET	Control Resource Set
CRB	Common Resource Block
CSI	Channel-State Information
CSI-RS	CSI Reference Signal
DCI	Downlink Control Information
DM-RS	Demodulation Reference Signal
FR1	Frequency Range 1 as defined in TS 38.104 [8]
FR2	Frequency Range 2 as defined in TS 38.104 [8]
IAB	Integrated Access and Backhaul
IAB-MT	IAB Mobile Termination
IE	Information Element
NCR	Network-Controlled repeater
NCR-MT	NCR Mobile Termination
PBCH	Physical Broadcast Channel
PDCCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PRACH	Physical Random-Access Channel
PRB	Physical Resource Block
PSS	Primary Synchronization Signal
PT-RS	Phase-tracking reference signal
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
RAR	Random Access Response
REG	Resource-Element Group
RIM	Remote Interference Management
RIM-RS	Remote Interference Management Reference Signal
SRS	Sounding Reference Signal
SSS	Secondary Synchronization Signal
VRB	Virtual Resource Block

4 Frame structure and physical resources

4.1 General

Throughout this specification, unless otherwise noted, the size of various fields in the time domain is expressed in time units $T_\mathrm{c} = 1/(\Delta f_\mathrm{max} \cdot N_\mathrm{f})$ where $\Delta f_\mathrm{max} = 480 \cdot 10^3$ Hz and $N_\mathrm{f} = 4096$. The constant $\kappa = T_\mathrm{s}/T_\mathrm{c} = 64$ where $T_\mathrm{s} = 1/(\Delta f_\mathrm{ref} \cdot N_\mathrm{f,ref})$, $\Delta f_\mathrm{ref} = 15 \cdot 10^3$ Hz and $N_\mathrm{f,ref} = 2048$.

Throughout this specification, unless otherwise noted, statements using the term "UE" in clauses 4, 5, 6, or 7 are equally applicable to the IAB-MT part of an IAB-node and the NCR-MT part of an NCR node.

4.2 Numerologies

Multiple OFDM numerologies are supported as given by Table 4.2-1 where μ and the cyclic prefix for a downlink or uplink bandwidth part are obtained from the higher-layer parameters *subcarrierSpacing* and *cyclicPrefix*, respectively.

Table 4.2-1: Supported transmission numerologies.

μ	$\Delta f = 2^{\mu} \cdot 15\,[\mathrm{kHz}]$	**Cyclic prefix**
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal
5	480	Normal
6	960	Normal

4.3 Frame structure

4.3.1 Frames and subframes

Downlink, uplink, and sidelink transmissions are organized into frames with $T_{\mathrm{f}} = (\Delta f_{\max} N_{\mathrm{f}} / 100) \cdot T_{\mathrm{c}} = 10\,\mathrm{ms}$ duration, each consisting of ten subframes of $T_{\mathrm{sf}} = (\Delta f_{\max} N_{\mathrm{f}} / 1000) \cdot T_{\mathrm{c}} = 1\,\mathrm{ms}$ duration. The number of consecutive OFDM symbols per subframe is $N_{\mathrm{symb}}^{\mathrm{subframe},\mu} = N_{\mathrm{symb}}^{\mathrm{slot}} N_{\mathrm{slot}}^{\mathrm{subframe},\mu}$. Each frame is divided into two equally-sized half-frames of five subframes each with half-frame 0 consisting of subframes 0 – 4 and half-frame 1 consisting of subframes 5 – 9.

There is one set of frames in the uplink and one set of frames in the downlink on a carrier.

Uplink frame number i for transmission from the UE shall start $T_{\mathrm{TA}} = \left(N_{\mathrm{TA}} + N_{\mathrm{TA,offset}} + N_{\mathrm{TA,adj}}^{\mathrm{common}} + N_{\mathrm{TA,adj}}^{\mathrm{UE}}\right) T_{\mathrm{c}}$ before the start of the corresponding downlink frame at the UE where

- N_{TA} and $N_{\mathrm{TA,offset}}$ are given by clause 4.2 of [5, TS 38.213], except for msgA transmission on PUSCH where $N_{\mathrm{TA}} = 0$ shall be used;
- $N_{\mathrm{TA,adj}}^{\mathrm{common}}$ given by clause 4.2 of [5, TS 38.213] is derived from the higher-layer parameters *ta-Common*, *ta-CommonDrift*, and *ta-CommonDriftVariant* if configured, otherwise $N_{\mathrm{TA,adj}}^{\mathrm{common}} = 0$;
- $N_{\mathrm{TA,adj}}^{\mathrm{UE}}$ given by clause 4.2 of [5, TS 38.213] is computed by the UE based on UE position and serving-satellite-ephemeris-related higher-layers parameters if configured, otherwise $N_{\mathrm{TA,adj}}^{\mathrm{UE}} = 0$.

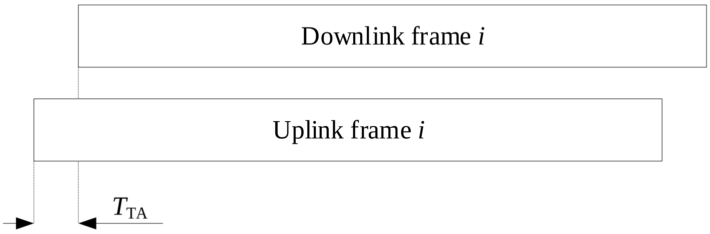

Figure 4.3.1-1: Uplink-downlink timing relation.

4.3.2 Slots

For subcarrier spacing configuration μ , slots are numbered $n_{\mathrm{s}}^{\mu} \in \left\{0, \ldots, N_{\mathrm{slot}}^{\mathrm{subframe},\mu} - 1\right\}$ in increasing order within a subframe and $n_{\mathrm{s,f}}^{\mu} \in \left\{0, \ldots, N_{\mathrm{slot}}^{\mathrm{frame},\mu} - 1\right\}$ in increasing order within a frame. There are $N_{\mathrm{symb}}^{\mathrm{slot}}$ consecutive OFDM symbols in a slot where $N_{\mathrm{symb}}^{\mathrm{slot}}$ depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2. The start of slot n_{s}^{μ} in a subframe is aligned in time with the start of OFDM symbol $n_{\mathrm{s}}^{\mu} N_{\mathrm{symb}}^{\mathrm{slot}}$ in the same subframe.

OFDM symbols in a slot in a downlink or uplink frame can be classified as 'downlink', 'flexible', or 'uplink'. Signaling of slot formats is described in clause 11.1 of [5, TS 38.213].

In a slot in a downlink frame, the UE shall assume that downlink transmissions only occur in 'downlink' or 'flexible' symbols.

In a slot in an uplink frame, the UE shall only transmit in 'uplink' or 'flexible' symbols.

A UE not capable of full-duplex communication and not supporting simultaneous transmission and reception as defined by parameter *simultaneousRxTxInterBandENDC, simultaneousRxTxInterBandCA or simultaneousRxTxSUL* [10, TS 38.306] among all cells within a group of cells is not expected to transmit in the uplink in one cell within the group of cells earlier than $N_{\text{Rx-Tx}}T_{\mathrm{c}}$ after the end of the last received downlink symbol in the same or different cell within the group of cells where $N_{\text{Rx-Tx}}$ is given by Table 4.3.2-3.

A UE not capable of full-duplex communication and not supporting simultaneous transmission and reception as defined by parameter *simultaneousRxTxInterBandENDC*, *simultaneousRxTxInterBandCA or simultaneousRxTxSUL* [10, TS 38.306] among all cells within a group of cells is not expected to receive in the downlink in one cell within the group of cells earlier than $N_{\text{Tx-Rx}}T_{\mathrm{c}}$ after the end of the last transmitted uplink symbol in the same or different cell within the group of cells where $N_{\text{Tx-Rx}}$ is given by Table 4.3.2-3.

For DAPS handover operation, a UE not capable of full-duplex communication is not expected to transmit in the uplink to a cell earlier than $N_{\text{Rx-Tx}}T_{\mathrm{c}}$ after the end of the last received downlink symbol in the different cell where $N_{\text{Rx-Tx}}$ is given by Table 4.3.2-3.

For DAPS handover operation, a UE not capable of full-duplex communication is not expected to receive in the downlink from a cell earlier than $N_{\text{Tx-Rx}}T_{\mathrm{c}}$ after the end of the last transmitted uplink symbol in the different cell where $N_{\text{Tx-Rx}}$ is given by Table 4.3.2-3.

A UE not capable of full-duplex communication is not expected to transmit in the uplink earlier than $N_{\text{Rx-Tx}}T_{\mathrm{c}}$ after the end of the last received downlink symbol in the same cell where $N_{\text{Rx-Tx}}$ is given by Table 4.3.2-3.

A UE not capable of full-duplex communication is not expected to receive in the downlink earlier than $N_{\text{Tx-Rx}}T_{\mathrm{c}}$ after the end of the last transmitted uplink symbol in the same cell where $N_{\text{Tx-Rx}}$ is given by Table 4.3.2-3.

Table 4.3.2-1: Number of OFDM symbols per slot, slots per frame, and slots per subframe for normal cyclic prefix.

μ	$N_{\mathrm{symb}}^{\mathrm{slot}}$	$N_{\mathrm{slot}}^{\mathrm{frame},\mu}$	$N_{\mathrm{slot}}^{\mathrm{subframe},\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16
5	14	320	32
6	14	640	64

Table 4.3.2-2: Number of OFDM symbols per slot, slots per frame, and slots per subframe for extended cyclic prefix.

μ	$N_{\mathrm{symb}}^{\mathrm{slot}}$	$N_{\mathrm{slot}}^{\mathrm{frame},\mu}$	$N_{\mathrm{slot}}^{\mathrm{subframe},\mu}$
2	12	40	4

Table 4.3.2-3: Transition time $N_{\mathrm{Rx\text{-}Tx}}$ and $N_{\mathrm{Tx\text{-}Rx}}$

Transition time	FR1	FR2
$N_{\mathrm{Tx\text{-}Rx}}$	25600	13792
$N_{\mathrm{Rx\text{-}Tx}}$	25600	13792

4.4 Physical resources

4.4.1 Antenna ports

An antenna port is defined such that the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed.

Two antenna ports are said to be quasi co-located if the large-scale properties of the channel over which a symbol on one antenna port is conveyed can be inferred from the channel over which a symbol on the other antenna port is conveyed. The large-scale properties include one or more of delay spread, Doppler spread, Doppler shift, average gain, average delay, and spatial Rx parameters.

4.4.2 Resource grid

For each numerology and carrier, a resource grid of $N_{\mathrm{grid},x}^{\mathrm{size},\mu} N_{\mathrm{sc}}^{\mathrm{RB}}$ subcarriers and $N_{\mathrm{symb}}^{\mathrm{subframe},\mu}$ OFDM symbols is defined, starting at common resource block $N_{\mathrm{grid}}^{\mathrm{start},\mu}$ indicated by higher-layer signalling. There is one set of resource grids per transmission direction (uplink, downlink, or sidelink) with the subscript x set to DL, UL, and SL for downlink, uplink, and sidelink, respectively. When there is no risk for confusion, the subscript x may be dropped. There is one resource grid for a given antenna port p, subcarrier spacing configuration μ, and transmission direction (downlink, uplink, or sidelink).

For uplink and downlink, the carrier bandwidth $N_{\mathrm{grid}}^{\mathrm{size},\mu}$ for subcarrier spacing configuration μ is given by the higher-layer parameter *carrierBandwidth* in the *SCS-SpecificCarrier* IE. The starting position $N_{\mathrm{grid}}^{\mathrm{start},\mu}$ for subcarrier spacing configuration μ is given by the higher-layer parameter *offsetToCarrier* in the *SCS-SpecificCarrier* IE.

The frequency location of a subcarrier refers to the center frequency of that subcarrier.

For the downlink, the higher-layer parameter *txDirectCurrentLocation* in the *SCS-SpecificCarrier* IE indicates the location of the transmitter DC subcarrier in the downlink for each of the numerologies configured in the downlink. Values in the range 0 – 3299 represent the number of the DC subcarrier and the value 3300 indicates that the DC subcarrier is located outside the resource grid.

For the uplink, the higher-layer parameter *txDirectCurrentLocation* in the *UplinkTxDirectCurrentBWP* IE indicates the location of the transmitter DC subcarrier in the uplink for each of the configured bandwidth parts, including whether the DC subcarrier location is offset by 7.5 kHz relative to the center of the indicated subcarrier or not. Values in the range 0 – 3299 represent the number of the DC subcarrier, the value 3300 indicates that the DC subcarrier is located outside the resource grid, and the value 3301 indicates that the position of the DC subcarrier in the uplink is undetermined.

4.4.3 Resource elements

Each element in the resource grid for antenna port p and subcarrier spacing configuration μ is called a resource element and is uniquely identified by $(k,l)_{p,\mu}$ where k is the index in the frequency domain and l refers to the symbol position in the time domain relative to some reference point. Resource element $(k,l)_{p,\mu}$ corresponds to a physical resource and the complex value $a_{k,l}^{(p,\mu)}$. When there is no risk for confusion, or no particular antenna port or subcarrier spacing is specified, the indices p and μ may be dropped, resulting in $a_{k,l}^{(p)}$ or $a_{k,l}$.

4.4.4 Resource blocks

4.4.4.1 General

A resource block is defined as $N_{\mathrm{sc}}^{\mathrm{RB}} = 12$ consecutive subcarriers in the frequency domain.

4.4.4.2 Point A

Point A serves as a common reference point for resource block grids and is obtained from:

- *offsetToPointA* for a PCell downlink where *offsetToPointA* represents the frequency offset between point A and the lowest subcarrier of the lowest resource block, which overlaps with the SS/PBCH block, or the SS/PBCH block after puncturing if applicable, used by the UE for initial cell selection, expressed in units of resource blocks assuming 15 kHz subcarrier spacing for FR1 and 60 kHz subcarrier spacing for FR2;
  - for operation without shared spectrum channel access in FR1 and FR2-1, the lowest resource block has the subcarrier spacing provided by the higher layer parameter *subCarrierSpacingCommon*;
  - for operation with shared spectrum channel access in FR1 or FR2, and for operation without shared spectrum channel access in FR2-2, the lowest resource block has the subcarrier spacing same as the SS/PBCH block used by the UE for initial cell selection;
- *absoluteFrequencyPointA* for all other cases where *absoluteFrequencyPointA* represents the frequency-location of point A expressed as in ARFCN.

4.4.4.3 Common resource blocks

Common resource blocks are numbered from 0 and upwards in the frequency domain for subcarrier spacing configuration μ. The center of subcarrier 0 of common resource block 0 for subcarrier spacing configuration μ coincides with 'point A'.

The relation between the common resource block number n_{CRB}^{μ} in the frequency domain and resource elements (k,l) for subcarrier spacing configuration μ is given by

$$n_{\mathrm{CRB}}^{\mu} = \left\lfloor \frac{k}{N_{\mathrm{sc}}^{\mathrm{RB}}} \right\rfloor$$

where k is defined relative to point A such that $k = 0$ corresponds to the subcarrier centered around point A.

4.4.4.4 Physical resource blocks

Physical resource blocks for subcarrier spacing configuration μ are defined within a bandwidth part and numbered from 0 to $N_{\mathrm{BWP},i}^{\mathrm{size},\mu} - 1$ where i is the number of the bandwidth part. The relation between the physical resource block n_{PRB}^{μ} in bandwidth part i and the common resource block n_{CRB}^{μ} is given by

$$n_{\mathrm{CRB}}^{\mu} = n_{\mathrm{PRB}}^{\mu} + N_{\mathrm{BWP},i}^{\mathrm{start},\mu}$$

where $N_{\mathrm{BWP},i}^{\mathrm{start},\mu}$ is the common resource block where bandwidth part i starts relative to common resource block 0. When there is no risk for confusion the index μ may be dropped.

4.4.4.5 Virtual resource blocks

Virtual resource blocks are defined within a bandwidth part and numbered from 0 to $N_{\mathrm{BWP},i}^{\mathrm{size}} - 1$ where i is the number of the bandwidth part.

4.4.4.6 Interlaced resource blocks

Multiple interlaces of resource blocks are defined where interlace $m \in \{0,1,\dots,M-1\}$ consists of common resource blocks $\{m, M+m, 2M+m, 3M+m, \dots\}$, with M being the number of interlaces given by Table 4.4.4.6-1. The relation between the interlaced resource block $n_{\mathrm{IRB},m}^{\mu} \in \{0,1,\ldots\}$ in bandwidth part i and interlace m and the common resource block n_{CRB}^{μ} is given by

$$n_{\mathrm{CRB}}^{\mu} = M n_{\mathrm{IRB},m}^{\mu} + N_{\mathrm{BWP},i}^{\mathrm{start},\mu} + \left(\left(m - N_{\mathrm{BWP},i}^{\mathrm{start},\mu}\right) \bmod M\right)$$

where $N_{\mathrm{BWP},i}^{\mathrm{start},\mu}$ is the common resource block where bandwidth part starts relative to common resource block 0. When there is no risk for confusion the index μ may be dropped.

The UE expects that the number of common resource blocks in an interlace contained within bandwidth part i is no less than 10.

Table 4.4.4.6-1: The number of resource block interlaces.

μ	M
0	10
1	5

4.4.5 Bandwidth part

A bandwidth part is a subset of contiguous common resource blocks defined in clause 4.4.4.3 for a given numerology μ_i in bandwidth part i on a given carrier. The starting position $N_{\mathrm{BWP},i}^{\mathrm{start},\mu}$ and the number of resource blocks $N_{\mathrm{BWP},i}^{\mathrm{size},\mu}$ in a bandwidth part shall fulfil $N_{\mathrm{grid},x}^{\mathrm{start},\mu} \le N_{\mathrm{BWP},i}^{\mathrm{start},\mu} < N_{\mathrm{grid},x}^{\mathrm{start},\mu} + N_{\mathrm{grid},x}^{\mathrm{size},\mu}$ and $N_{\mathrm{grid},x}^{\mathrm{start},\mu} < N_{\mathrm{BWP},i}^{\mathrm{start},\mu} + N_{\mathrm{BWP},i}^{\mathrm{size},\mu} \le N_{\mathrm{grid},x}^{\mathrm{start},\mu} + N_{\mathrm{grid},x}^{\mathrm{size},\mu}$, respectively. Configuration of a bandwidth part is described in clause 12 of [5, TS 38.213].

A UE can be configured with up to four bandwidth parts in the downlink with a single downlink bandwidth part being active at a given time. The UE is not expected to receive PDSCH, PDCCH, or CSI-RS (except for RRM) outside an active bandwidth part.

A UE can be configured with up to four bandwidth parts in the uplink with a single uplink bandwidth part being active at a given time. If a UE is configured with a supplementary uplink, the UE can in addition be configured with up to four bandwidth parts in the supplementary uplink with a single supplementary uplink bandwidth part being active at a given time. The UE shall not transmit PUSCH or PUCCH outside an active bandwidth part. For an active cell, the UE shall not transmit SRS outside an active bandwidth part.

Unless otherwise noted, the description in this specification applies to each of the bandwidth parts. When there is no risk of confusion, the index μ may be dropped from $N_{\mathrm{BWP},i}^{\mathrm{start},\mu}$, $N_{\mathrm{BWP},i}^{\mathrm{size},\mu}$, $N_{\mathrm{grid},x}^{\mathrm{start},\mu}$, and $N_{\mathrm{grid},x}^{\mathrm{size},\mu}$.

4.4.6 Common MBS frequency resource

A common MBS frequency resource is a contiguous set of common resource blocks. The starting position $N_{\mathrm{MBS},i}^{\mathrm{start},\mu}$ of the common MBS frequency resource i is defined relative to point A and the size of the common MBS frequency resource is given by $N_{\mathrm{MBS},i}^{\mathrm{size},\mu}$. Resource blocks in a common MBS frequency resource are numbered in the same way as resource blocks in clause 4.4.4.4 with $N_{\mathrm{BWP},i}^{\mathrm{start},\mu}$ and $N_{\mathrm{BWP},i}^{\mathrm{size},\mu}$ replaced by $N_{\mathrm{MBS},i}^{\mathrm{start},\mu}$ and $N_{\mathrm{MBS},i}^{\mathrm{size},\mu}$, respectively.

A UE is not expected to receive PDSCH or PDCCH associated with MBS transmissions scheduled with G-RNTI, G-CS-RNTI, MCCH-RNTI, or multicast-MCCH-RNTI outside the common MBS frequency resource.

4.5 Carrier aggregation

Transmissions in multiple cells can be aggregated. Unless otherwise noted, the description in this specification applies to each of the serving cells.

For carrier aggregation of cells with unaligned frame boundaries, the slot offset $N_{\mathrm{slot,\,offset}}^{\mathrm{CA}}$ between a PCell/PScell and an SCell is determined by higher-layer parameter *ca-SlotOffset* for the SCell. The quantity μ_{offset} is defined as the maximum of the lowest subcarrier spacing configuration among the subcarrier spacings given by the higher-layer parameters *scs-SpecificCarrierList* configured for PCell/PSCell and the SCell, respectively. The slot offset $N_{\mathrm{slot,\,offset}}^{\mathrm{CA}}$ fulfills

- when the lowest subcarrier spacing configuration among the subcarrier spacings configured for the cell is $\mu = 2$ for both cells or $\mu = 3$ for both cells, the start of slot 0 for the cell whose point A has a lower frequency coincides with the start of slot $qN_{\text{slot, offset}}^{\text{CA}} \bmod N_{\text{slot}}^{\text{frame},\mu_{\text{offset}}}$ for the other cell where $q = -1$ if point A of the PCell/PSCell has a frequency lower than the frequency of point A for the SCell, otherwise $q = 1$;
- otherwise, the start of slot 0 for the cell with the lower subcarrier spacing of the lowest subcarrier spacing given by the higher-layer parameters *scs-SpecificCarrierList* configured for the two cells, or the Pcell/PSCell if both cells have the same lowest subcarrier spacing given by the higher-layer parameters *scs-SpecificCarrierList* configured for the two cells, coincides with the start of slot $qN_{\text{slot, offset}}^{\text{CA}} \bmod N_{\text{slot}}^{\text{frame},\mu_{\text{offset}}}$ for the other cell where $q = -1$ if the lowest subcarreier spacing configuration given by *scs-SpecificCarrierList* of the PCell/PSCell is smaller than or equal to the lowest subcarrier spacing given by *scs-SpecificCarrierList* for the SCell, otherwise $q = 1$.

5 Generic functions

5.1 Modulation mapper

The modulation mapper takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols as output.

5.1.1 π/2-BPSK

In case of π/2-BPSK modulation, bit $b(i)$ is mapped to complex-valued modulation symbol $d(i)$ according to

$$d(i) = \frac{e^{j\frac{\pi}{2}(i \bmod 2)}}{\sqrt{2}}\left[(1-2b(i)) + j(1-2b(i))\right]$$

5.1.2 BPSK

In case of BPSK modulation, bit $b(i)$ is mapped to complex-valued modulation symbol $d(i)$ according to

$$d(i) = \frac{1}{\sqrt{2}}\left[(1-2b(i)) + j(1-2b(i))\right]$$

5.1.3 QPSK

In case of QPSK modulation, pairs of bits, $b(2i), b(2i+1)$, are mapped to complex-valued modulation symbols $d(i)$ according to

$$d(i) = \frac{1}{\sqrt{2}}\left[(1-2b(2i)) + j(1-2b(2i+1))\right]$$

5.1.4 16QAM

In case of 16QAM modulation, quadruplets of bits, $b(4i), b(4i+1), b(4i+2), b(4i+3)$, are mapped to complex-valued modulation symbols $d(i)$ according to

$$d(i) = \frac{1}{\sqrt{10}}\left\{(1-2b(4i))\left[2-(1-2b(4i+2))\right] + j(1-2b(4i+1))\left[2-(1-2b(4i+3))\right]\right\}$$

5.1.5 64QAM

In case of 64QAM modulation, hextuplets of bits, $b(6i), b(6i+1), b(6i+2), b(6i+3), b(6i+4), b(6i+5)$, are mapped to complex-valued modulation symbols $d(i)$ according to

$$d(i) = \frac{1}{\sqrt{42}}\Big\{(1-2b(6i))\big[4-(1-2b(6i+2))\big[2-(1-2b(6i+4))\big]\big] + j(1-2b(6i+1))\big[4-(1-2b(6i+3))\big[2-(1-2b(6i+5))\big]\big]\Big\}$$

5.1.6 256QAM

In case of 256QAM modulation, octuplets of bits, $b(8i), b(8i+1), b(8i+2), b(8i+3), b(8i+4), b(8i+5), b(8i+6), b(8i+7)$, are mapped to complex-valued modulation symbols $d(i)$ according to

$$\begin{aligned} d(i) = \frac{1}{\sqrt{170}}\Big\{&(1-2b(8i))\big[8-(1-2b(8i+2))\big[4-(1-2b(8i+4))\big[2-(1-2b(8i+6))\big]\big]\big] \\ &+ j(1-2b(8i+1))\big[8-(1-2b(8i+3))\big[4-(1-2b(8i+5))\big[2-(1-2b(8i+7))\big]\big]\big]\Big\} \end{aligned}$$

5.1.7 1024QAM

In case of 1024QAM modulation, 10-tuplets of bits, $b(10i), b(10i+1), b(10i+2), b(10i+3), b(10i+4), b(10i+5), b(10i+6), b(10i+7), b(10i+8), b(10i+9)$, are mapped to complex-valued modulation symbols $d(i)$ according to

$$\begin{aligned} d(i) = {} & \\ & \frac{1}{\sqrt{682}}\big(1-2b(10i+0)\big)\bigg[16-\big(1-2b(10i+2)\big)\bigg[8-\big(1-2b(10i+4)\big)\bigg[4-\big(1-2b(10i+6)\big)\big[2-\big(1-2b(10i+8)\big)\big] \\ & +j\frac{1}{\sqrt{682}}\big(1-2b(10i+1)\big)\bigg[16-\big(1-2b(10i+3)\big)\bigg[8-\big(1-2b(10i+5)\big)\bigg[4-\big(1-2b(10i+7)\big)\big[2-\big(1-2b(10i+9)\big)\big] \end{aligned}$$

5.2 Sequence generation

5.2.1 Pseudo-random sequence generation

Generic pseudo-random sequences are defined by a length-31 Gold sequence. The output sequence $c(n)$ of length M_{PN}, where $n = 0,1,...,M_{\text{PN}}-1$, is defined by

$$\begin{aligned} c(n) &= \big(x_1(n+N_C) + x_2(n+N_C)\big)\bmod 2 \\ x_1(n+31) &= \big(x_1(n+3) + x_1(n)\big)\bmod 2 \\ x_2(n+31) &= \big(x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)\big)\bmod 2 \end{aligned}$$

where $N_{\text{C}} = 1600$ and the first m-sequence $x_1(n)$ shall be initialized with $x_1(0) = 1, x_1(n) = 0, n = 1,2,...,30$. The initialization of the second m-sequence, $x_2(n)$, is denoted by $c_{\text{init}} = \sum_{i=0}^{30} x_2(i) \cdot 2^i$ with the value depending on the application of the sequence.

5.2.2 Low-PAPR sequence generation type 1

The low-PAPR sequence $r_{u,v}^{(\alpha,\delta)}(n)$ is defined by a cyclic shift α of a base sequence $\bar{r}_{u,v}(n)$ according to

$$r_{u,v}^{(\alpha,\delta)}(n) = e^{j\alpha n}\bar{r}_{u,v}(n), \quad 0 \le n < M_{\text{ZC}}$$

where $M_{\text{ZC}} = mN_{\text{sc}}^{\text{RB}}/2^{\delta}$ is the length of the sequence. Multiple sequences are defined from a single base sequence through different values of α and δ.

Base sequences $\bar{r}_{u,v}(n)$ are divided into groups, where $u \in \{0,1,...,29\}$ is the group number and v is the base sequence number within the group, such that each group contains one base sequence ($v = 0$) of each length $M_{\text{ZC}} = mN_{\text{sc}}^{\text{RB}}/2^{\delta}$, $1/2 \le m/2^{\delta} \le 5$ and two base sequences ($v = 0,1$) of each length $M_{\text{ZC}} = mN_{\text{sc}}^{\text{RB}}/2^{\delta}$, $6 \le m/2^{\delta}$. The definition of the base sequence $\bar{r}_{u,v}(0),...,\bar{r}_{u,v}(M_{\text{ZC}}-1)$ depends on the sequence length M_{ZC}.

5.2.2.1 Base sequences of length 36 or larger

For$M_{\text{ZC}} \ge 3N_{\text{sc}}^{\text{RB}}$, the base sequence $\bar{r}_{u,v}(0),...,\bar{r}_{u,v}(M_{\text{ZC}}-1)$ is given by

$$\begin{aligned} \bar{r}_{u,v}(n) &= x_q\left(n \bmod N_{\text{ZC}}\right) \\ x_q(m) &= e^{-j\frac{\pi q m(m+1)}{N_{\text{ZC}}}} \end{aligned}$$

where

$$\begin{aligned} q &= \lfloor \bar{q} + 1/2 \rfloor + v \cdot (-1)^{\lfloor 2\bar{q} \rfloor} \\ \bar{q} &= N_{\text{ZC}} \cdot (u+1)/31 \end{aligned}$$

The length N_{ZC} is given by the largest prime number such that $N_{\text{ZC}} < M_{\text{ZC}}$.

5.2.2.2 Base sequences of length less than 36

For $M_{\text{ZC}} \in \{6,12,18,24\}$ the base sequence is given by

$$\bar{r}_{u,v}(n) = e^{j\varphi(n)\pi/4}, \quad 0 \le n \le M_{\text{ZC}} - 1$$

where the value of $\varphi(n)$ is given by Tables 5.2.2.2-1 to 5.2.2.2-4.

For $M_{\text{ZC}} = 30$, the base sequence $\bar{r}_{u,v}(0),...,\bar{r}_{u,v}(M_{\text{ZC}}-1)$ is given by

$$\bar{r}_{u,v}(n) = e^{-j\frac{\pi(u+1)(n+1)(n+2)}{31}}, \quad 0 \le n \le M_{\text{ZC}} - 1$$

Table 5.2.2.2-1: Definition of $\varphi(n)$ for $M_{\text{ZC}} = 6$.

u	$\varphi(0),...,\varphi(5)$					
0	-3	-1	3	3	-1	-3
1	-3	3	-1	-1	3	-3
2	-3	-3	-3	3	1	-3
3	1	1	1	3	-1	-3
4	1	1	1	-3	-1	3
5	-3	1	-1	-3	-3	-3
6	-3	1	3	-3	-3	-3
7	-3	-1	1	-3	1	-1
8	-3	-1	-3	1	-3	-3
9	-3	-3	1	-3	3	-3
10	-3	1	3	1	-3	-3
11	-3	-1	-3	1	1	-3
12	1	1	3	-1	-3	3
13	1	1	3	3	-1	3
14	1	1	1	-3	3	-1
15	1	1	1	-1	3	-3
16	-3	-1	-1	-1	3	-1
17	-3	-3	-1	1	-1	-3
18	-3	-3	-3	1	-3	-1
19	-3	1	1	-3	-1	-3
20	-3	3	-3	1	1	-3
21	-3	1	-3	-3	-3	-1
22	1	1	-3	3	1	3
23	1	1	-3	-3	1	-3
24	1	1	3	-1	3	3
25	1	1	-3	1	3	3
26	1	1	-1	-1	3	-1
27	1	1	-1	3	-1	-1
28	1	1	-1	3	-3	-1
29	1	1	-3	1	-1	-1

Table 5.2.2.2-2: Definition of $\varphi(n)$ for $M_{\text{ZC}} = 12$.

u	$\varphi(0), \ldots, \varphi(11)$											
0	-3	1	-3	-3	-3	3	-3	-1	1	1	1	-3
1	-3	3	1	-3	1	3	-1	-1	1	3	3	3
2	-3	3	3	1	-3	3	-1	1	3	-3	3	-3
3	-3	-3	-1	3	3	3	-3	3	-3	1	-1	-3
4	-3	-1	-1	1	3	1	1	-1	1	-1	-3	1
5	-3	-3	3	1	-3	-3	-3	-1	3	-1	1	3
6	1	-1	3	-1	-1	-1	-3	-1	1	1	1	-3
7	-1	-3	3	-1	-3	-3	-3	-1	1	-1	1	-3
8	-3	-1	3	1	-3	-1	-3	3	1	3	3	1
9	-3	-1	-1	-3	-3	-1	-3	3	1	3	-1	-3
10	-3	3	-3	3	3	-3	-1	-1	3	3	1	-3
11	-3	-1	-3	-1	-1	-3	3	3	-1	-1	1	-3
12	-3	-1	3	-3	-3	-1	-3	1	-1	-3	3	3
13	-3	1	-1	-1	3	3	-3	-1	-1	-3	-1	-3
14	1	3	-3	1	3	3	3	1	-1	1	-1	3
15	-3	1	3	-1	-1	-3	-3	-1	-1	3	1	-3
16	-1	-1	-1	-1	1	-3	-1	3	3	-1	-3	1
17	-1	1	1	-1	1	3	3	-1	-1	-3	1	-3
18	-3	1	3	3	-1	-1	-3	3	3	-3	3	-3
19	-3	-3	3	-3	-1	3	3	3	-1	-3	1	-3
20	3	1	3	1	3	-3	-1	1	3	1	-1	-3
21	-3	3	1	3	-3	1	1	1	1	3	-3	3
22	-3	3	3	3	-1	-3	-3	-1	-3	1	3	-3
23	3	-1	-3	3	-3	-1	3	3	3	-3	-1	-3
24	-3	-1	1	-3	1	3	3	3	-1	-3	3	3
25	-3	3	1	-1	3	3	-3	1	-1	1	-1	1
26	-1	1	3	-3	1	-1	1	-1	-1	-3	1	-1
27	-3	-3	3	3	3	-3	-1	1	-3	3	1	-3
28	1	-1	3	1	1	-1	-1	-1	1	3	-3	1
29	-3	3	-3	3	-3	-3	3	-1	-1	1	3	-3

Table 5.2.2.2-3: Definition of $\varphi(n)$ for $M_{\text{ZC}} = 18$

$\boldsymbol{u}$	$\boldsymbol{\varphi(0), \ldots, \varphi(17)}$																	
0	-1	3	-1	-3	3	1	-3	-1	3	-3	-1	-1	1	1	1	-1	-1	-1
1	3	-3	3	-1	1	3	-3	-1	-3	-3	-1	-3	3	1	-1	3	-3	3
2	-3	3	1	-1	-1	3	-3	-1	1	1	1	1	1	-1	3	-1	-3	-1
3	-3	-3	3	3	3	1	-3	1	3	3	1	-3	-3	3	-1	-3	-1	1
4	1	1	-1	-1	-3	-1	1	-3	-3	-3	1	-3	-1	-1	1	-1	3	1
5	3	-3	1	1	3	-1	1	-1	-1	-3	1	1	-1	3	3	-3	3	-1
6	-3	3	-1	1	3	1	-3	-1	1	1	-3	1	3	3	-1	-3	-3	-3
7	1	1	-3	3	3	1	3	-3	3	-1	1	1	-1	1	-3	-3	-1	3
8	-3	1	-3	-3	1	-3	-3	3	1	-3	-1	-3	-3	-3	-1	1	1	3
9	3	-1	3	1	-3	-3	-1	1	-3	-3	3	3	3	1	3	-3	3	-3
10	-3	-3	-3	1	-3	3	1	1	3	-3	-3	1	3	-1	3	-3	-3	3
11	-3	-3	3	3	3	-1	-1	-3	-1	-1	-1	3	1	-3	-3	-1	3	-1
12	-3	-1	-3	-3	1	1	-1	-3	-1	-3	-1	-1	3	3	-1	3	1	3
13	1	1	-3	-3	-3	-3	1	3	-3	3	3	1	-3	-1	3	-1	-3	1
14	-3	3	-1	-3	-1	-3	1	1	-3	-3	-1	-1	3	-3	1	3	1	1
15	3	1	-3	1	-3	3	3	-1	-3	-3	-1	-3	-3	3	-3	-1	1	3
16	-3	-1	-3	-1	-3	1	3	-3	-1	3	3	3	1	-1	-3	3	-1	-3
17	-3	-1	3	3	-1	3	-1	-3	-1	1	-1	-3	-1	-1	-1	3	3	1
18	-3	1	-3	-1	-1	3	1	-3	-3	-3	-1	-3	-3	1	1	1	-1	-1
19	3	3	3	-3	-1	-3	-1	3	-1	1	-1	-3	1	-3	-3	-1	3	3
20	-3	1	1	-3	1	1	3	-3	-1	-3	-1	3	-3	3	-1	-1	-1	-3
21	1	-3	-1	-3	3	3	-1	-3	1	-3	-3	-1	-3	-1	1	3	3	3
22	-3	-3	1	-1	-1	1	1	-3	-1	3	3	3	3	-1	3	1	3	1
23	3	-1	-3	1	-3	-3	-3	3	3	-1	1	-3	-1	3	1	1	3	3
24	3	-1	-1	1	-3	-1	-3	-1	-3	-3	-1	-3	1	1	1	-3	-3	3
25	-3	-3	1	-3	3	3	3	-1	3	1	1	-3	-3	-3	3	-3	-1	-1
26	-3	-1	-1	-3	1	-3	3	-1	-1	-3	3	3	-3	-1	3	-1	-1	-1
27	-3	-3	3	3	-3	1	3	-1	-3	1	-1	-3	3	-3	-1	-1	-1	3
28	-1	-3	1	-3	-3	-3	1	1	3	3	-3	3	3	-3	-1	3	-3	1
29	-3	3	1	-1	-1	-1	-1	1	-1	3	3	-3	-1	1	3	-1	3	-1

Table 5.2.2.2-4: Definition of $\varphi(n)$ for $M_{\mathrm{ZC}} = 24$

u	$\varphi(0),\dots,\varphi(23)$																						
0	-1	-3	3	-1	3	1	3	-1	1	-3	-1	-3	-1	1	3	-3	-1	-3	3	3	3	-3	-3	-3
1	-1	-3	3	1	1	-3	1	-3	-3	1	-3	-1	-1	3	-3	3	3	3	-3	1	3	3	-3	-3
2	-1	-3	-3	1	-1	-1	-3	1	3	-1	-3	-1	-1	-3	1	1	3	1	-3	-1	-1	3	-3	-3
3	1	-3	3	-1	-3	-1	3	3	1	-1	1	1	3	-3	-1	-3	-3	-3	-1	3	-3	-1	-3	-3
4	-1	3	-3	-3	-1	3	-1	-1	1	3	1	3	-1	-1	-3	1	3	1	-1	-3	1	-1	-3	-3
5	-3	-1	1	-3	-3	1	1	-3	3	-1	-1	-3	1	3	1	-1	-3	-1	-3	1	-3	-3	-3	-3
6	-3	3	1	3	-1	1	-3	1	-3	1	-1	-3	-1	-3	-3	-3	-3	-1	-1	-1	1	1	-3	-3
7	-3	1	3	-1	1	-1	3	-3	3	-1	-3	-1	-3	3	-1	-1	-1	-3	-1	-1	-3	3	3	-3
8	-3	1	-3	3	-1	-1	-1	-3	3	1	-1	-3	-1	1	3	-1	1	-1	1	-3	-3	-3	-3	-3
9	1	1	-1	-3	-1	1	1	-3	1	-1	1	-3	3	-3	-3	3	-1	-3	1	3	-3	1	-3	-3
10	-3	-3	-3	-1	3	-3	3	1	3	1	-3	-1	-1	-3	1	1	3	1	-1	-3	3	1	3	-3
11	-3	3	-1	3	1	-1	-1	-1	3	3	1	1	1	3	3	1	-3	-3	-1	1	-3	1	3	-3
12	3	-3	3	-1	-3	1	3	1	-1	-1	-3	-1	3	-3	3	-1	-1	3	3	-3	-3	3	-3	-3
13	-3	3	-1	3	-1	3	3	1	1	-3	1	3	-3	3	-3	-3	-1	1	3	-3	-1	-1	-3	-3
14	-3	1	-3	-1	-1	3	1	3	-3	1	-1	3	3	-1	-3	3	-3	-1	-1	-3	-3	-3	3	-3
15	-3	-1	-1	-3	1	-3	-3	-1	-1	3	-1	1	-1	3	1	-3	-1	3	1	1	-1	-1	-3	-3
16	-3	-3	1	-1	3	3	-3	-1	1	-1	-1	1	1	-1	-1	3	-3	1	-3	1	-1	-1	-1	-3
17	3	-1	3	-1	1	-3	1	1	-3	-3	3	-3	-1	-1	-1	-1	-1	-3	-3	-1	1	1	-3	-3
18	-3	1	-3	1	-3	-3	1	-3	1	-3	-3	-3	-3	-3	1	-3	-3	1	1	-3	1	1	-3	-3
19	-3	-3	3	3	1	-1	-1	-1	1	-3	-1	1	-1	3	-3	-1	-3	-1	-1	1	-3	3	-1	-3
20	-3	-3	-1	-1	-1	-3	1	-1	-3	-1	3	-3	1	-3	3	-3	3	3	1	-1	-1	1	-3	-3
21	3	-1	1	-1	3	-3	1	1	3	-1	-3	3	1	-3	3	-1	-1	-1	-1	1	-3	-3	-3	-3
22	-3	1	-3	3	-3	1	-3	3	1	-1	-3	-1	-3	-3	-3	-3	1	3	-1	1	3	3	3	-3
23	-3	-1	1	-3	-1	-1	1	1	1	3	3	-1	1	-1	1	-1	-1	-3	-3	-3	3	1	-1	-3
24	-3	3	-1	-3	-1	-1	-1	3	-1	-1	3	-3	-1	3	-3	3	-3	-1	3	1	1	-1	-3	-3
25	-3	1	-1	-3	-3	-1	1	-3	-1	-3	1	1	-1	1	1	3	3	3	-1	1	-1	1	-1	-3
26	-1	3	-1	-1	3	3	-1	-1	-1	3	-1	-3	1	3	1	1	-3	-3	-3	-1	-3	-1	-3	-3
27	3	-3	-3	-1	3	3	-3	-1	3	1	1	1	3	-1	3	-3	-1	3	-1	3	1	-1	-3	-3
28	-3	1	-3	1	-3	1	1	3	1	-3	-3	-1	1	3	-1	-3	3	1	-1	-3	-3	-3	-3	-3
29	3	-3	-1	1	3	-1	-1	-3	-1	3	-1	-3	-1	-3	3	-1	3	1	1	-3	3	-3	-3	-3

5.2.3 Low-PAPR sequence generation type 2

The low-PAPR sequence $r_{u,v}^{(\alpha,\delta)}(n)$ is defined by a base sequence $\bar{r}_{u,v}(n)$ according to

$$r_{u,v}^{(\alpha,\delta)}(n) = \bar{r}_{u,v}(n), \qquad 0 \le n < M$$

where $M = mN_{\mathrm{sc}}^{\mathrm{RB}}/2^{\delta}$ is the length of the sequence.

Base sequences $\bar{r}_{u,v}(n)$ are divided into groups, where $u \in \{0,1,\dots,29\}$ is the group number and v is the base sequence number within the group, such that each group contains one base sequence ($v = 0$) of length $M = mN_{\mathrm{sc}}^{\mathrm{RB}}/2^{\delta}$, $1/2 \le m/2^{\delta}$. The sequence $\bar{r}_{u,v}(0),\dots,\bar{r}_{u,v}(M-1)$ is defined by

$$\bar{r}_{u,v}(n) = \frac{1}{\sqrt{M}} \sum_{i=0}^{M-1} \tilde{r}_{u,v}(i) e^{-j\frac{2\pi i n}{M}}$$
$$n = 0,\dots,M-1$$

where the definition of $\tilde{r}_{u,v}(i)$ depends on the sequence length.

5.2.3.1 Sequences of length 30 or larger

For $M \ge 30$, the sequence $\tilde{r}_{u,v}(i)$ is obtained as the complex-valued modulations symbols resulting from $\pi/2$-BPSK modulation as defined in clause 5.1.1 applied to the binary sequence $c(i)$ given by clause 5.2.1, initialized with c_{init}.

5.2.3.2 Sequences of length less than 30

For $M = 6$, the sequence $\tilde{r}_{u,v}(i)$ is given by

$$\tilde{r}_{u,v}(i) = e^{j\varphi(i)\pi/8}, 0 \leq i \leq M-1$$

where the value of $\varphi(i)$ is given by Table 5.2.3.2-1.

For $M \in \{12, 18, 24\}$, the sequence $\tilde{r}_{u,v}(i)$ is obtained as the complex-valued modulations symbols resulting from $\pi/2$-BPSK modulation as defined in clause 5.1.1 applied to the binary sequence $b(i)$ given by Tables 5.2.3.2-2 to 5.2.3.2-4.

Table 5.2.3.2-1: Definition of $\boldsymbol{\varphi(i)}$ for $\boldsymbol{M = 6}$.

$\boldsymbol{u}$	$\boldsymbol{\varphi(0), \ldots, \varphi(5)}$					
0	-1	-7	-3	-5	-1	3
1	-1	3	7	-3	7	3
2	-1	3	1	5	-1	-5
3	-7	-3	-7	5	-7	-3
4	7	5	-1	-7	-3	1
5	3	-3	1	5	-1	-1
6	-7	-3	-7	-3	7	-5
7	-7	-3	1	-5	-1	-5
8	-7	-3	3	-3	-7	-3
9	-7	-7	-1	1	-5	1
10	-7	-3	-7	5	-1	5
11	-7	-7	-3	1	5	-1
12	5	7	-3	-5	5	-5
13	-3	7	-5	-1	-5	-1
14	5	-7	7	1	5	1
15	-7	3	1	5	-1	3
16	-7	-5	-1	-7	-5	5
17	-7	1	-3	3	7	5
18	-7	-7	3	5	1	5
19	-7	-3	3	-1	3	-5
20	-7	-5	5	3	-7	-1
21	1	5	1	5	3	7
22	1	-3	1	-5	-1	3
23	1	7	1	-5	-7	-1
24	1	-1	3	-1	-7	-3
25	1	-1	-5	-1	3	-3
26	1	-1	3	-1	3	7
27	-5	3	7	5	3	7
28	-7	1	-3	1	5	1
29	1	5	3	-7	5	-3

Table 5.2.3.2-2: Definition of $b(i)$ for $M=12$.

u	$b(0),\ldots,b(11)$											
0	0	0	0	0	0	0	1	1	0	1	1	0
1	0	0	0	0	0	1	0	0	0	1	1	1
2	0	0	0	0	0	1	1	1	0	1	1	1
3	1	1	0	1	1	0	1	0	1	0	0	0
4	1	1	0	0	1	0	1	0	1	0	0	1
5	1	0	1	1	0	1	0	0	1	0	1	1
6	0	0	0	1	0	0	1	0	0	0	1	0
7	0	1	0	0	0	1	0	0	1	0	0	0
8	1	0	1	1	1	1	0	1	1	0	1	1
9	1	0	1	1	0	1	1	1	1	0	0	0
10	1	0	1	1	0	1	0	0	0	1	1	0
11	1	0	1	0	0	1	0	0	1	0	1	0
12	1	1	0	0	0	0	0	1	1	1	1	0
13	0	1	0	0	0	1	1	0	1	0	1	1
14	0	0	0	0	0	1	1	0	0	0	1	1
15	0	0	0	0	0	1	0	0	1	0	0	1
16	0	0	1	0	0	1	0	0	0	0	0	1
17	0	0	0	0	0	1	1	0	1	1	1	0
18	0	0	0	1	1	1	1	1	0	0	0	1
19	1	0	0	0	1	0	0	0	0	0	1	1
20	0	1	1	1	1	0	1	0	1	1	1	1
21	0	1	1	1	0	1	0	0	1	1	0	1
22	0	1	1	1	1	1	0	0	1	0	0	0
23	0	1	1	1	0	0	0	0	0	1	0	0
24	0	0	1	1	1	1	1	1	1	1	0	0
25	0	1	1	1	0	0	1	1	0	1	0	0
26	0	1	1	1	0	1	1	1	0	1	1	1
27	0	1	1	1	1	1	1	0	0	0	1	1
28	0	1	1	1	1	0	0	0	0	0	1	1
29	0	1	1	1	0	1	1	1	1	0	1	1

Table 5.2.3.2-3: Definition of $b(i)$ for $M = 18$.

u	$b(0), \ldots, b(17)$																	
0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	0	0	0	1
1	0	0	0	0	0	0	0	1	1	1	1	1	0	0	1	0	0	1
2	0	0	0	0	0	1	1	1	1	0	1	1	1	0	1	1	1	1
3	0	1	0	1	1	0	1	1	0	0	0	1	1	0	1	0	1	1
4	1	1	0	1	0	0	1	0	1	0	1	0	0	1	1	1	1	0
5	0	1	0	1	0	1	1	1	0	0	1	0	1	1	0	1	1	0
6	0	0	0	1	1	1	0	0	0	1	0	0	0	1	1	1	1	1
7	0	1	0	1	0	0	0	1	1	0	1	0	0	0	0	0	1	1
8	0	0	1	0	1	0	0	0	1	0	1	0	0	1	0	0	0	1
9	1	0	1	1	0	0	1	0	1	0	1	0	0	1	0	0	0	1
10	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	1
11	1	1	0	1	1	0	1	1	1	0	1	1	1	1	1	0	0	0
12	1	0	0	0	1	0	1	0	1	0	0	0	1	1	0	1	0	1
13	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
14	0	0	0	0	0	1	1	1	0	1	1	0	1	0	1	1	0	0
15	0	0	1	1	1	0	1	1	0	1	0	0	0	1	1	0	1	0
16	0	1	0	0	1	0	0	0	1	1	1	0	1	0	0	1	1	1
17	0	1	0	0	1	1	0	1	1	0	0	0	0	0	0	0	1	0
18	0	0	1	0	0	1	1	1	1	0	0	0	0	0	1	1	0	0
19	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	1	1
20	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	1	1	1
21	1	1	1	1	0	1	0	1	1	1	1	1	0	0	1	0	0	1
22	1	0	0	1	0	0	0	1	0	0	1	1	1	1	0	1	1	1
23	0	0	1	0	0	0	1	1	1	0	0	0	1	0	0	1	0	1
24	1	1	0	1	1	0	0	0	0	0	0	0	1	1	0	1	1	0
25	1	1	0	1	0	1	0	1	1	0	0	0	0	1	0	0	1	0
26	0	1	1	1	1	1	1	1	0	0	1	0	1	0	0	1	0	0
27	0	1	1	0	1	1	1	0	0	0	0	0	0	0	1	1	0	0
28	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0
29	0	1	1	1	0	1	1	0	1	0	1	1	1	0	1	1	0	0

Table 5.2.3.2-4: Definition of $b(i)$ for $M = 24$

u	$b(0),\ldots,b(23)$																							
0	0	0	0	0	0	0	0	1	0	0	1	1	1	1	1	0	0	1	0	0	1	0	0	1
1	0	0	0	0	0	0	0	1	0	0	1	0	1	1	0	1	1	1	0	0	0	1	1	0
2	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	1	1	1	0	1	1
3	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	0	1	0	1	1	0	1	1
4	1	0	0	1	1	1	1	1	0	1	1	0	1	1	1	0	1	1	0	0	0	1	1	1
5	1	0	1	0	1	1	0	1	1	0	0	1	1	1	1	1	0	0	1	1	0	1	1	1
6	0	1	1	0	0	1	0	0	1	1	1	1	1	1	0	1	1	1	1	0	1	1	0	1
7	1	0	1	1	1	1	1	1	1	1	1	0	1	0	0	1	1	1	0	0	1	1	0	1
8	0	0	1	0	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	1	1	1	0
9	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0	0	1	1	0	0	0	1	0	1
10	1	0	1	0	0	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1	0	0	1	0
11	0	0	1	0	0	1	0	0	0	0	0	1	1	1	0	0	0	1	0	0	1	0	1	0
12	1	0	1	0	0	1	1	1	0	1	0	0	0	1	0	1	1	1	0	0	1	0	1	1
13	1	0	1	0	0	1	1	0	1	1	0	1	0	1	0	1	1	0	1	1	0	0	1	0
14	1	0	1	0	0	0	1	0	0	1	1	1	0	0	0	0	0	1	0	0	1	0	1	1
15	1	0	0	1	0	1	0	0	1	1	0	0	0	0	1	1	1	1	1	1	1	0	0	1
16	0	0	0	1	1	1	1	0	0	1	0	1	0	0	1	1	1	0	1	1	1	0	0	1
17	1	1	0	1	0	1	1	1	0	0	1	1	1	0	0	0	0	0	0	1	1	0	1	0
18	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	0	1	1	0	0	0	1
19	1	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	1
20	0	0	0	0	0	0	1	1	1	0	1	1	0	0	0	1	1	0	0	0	1	0	1	0
21	0	1	1	0	1	0	1	1	1	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1
22	1	0	1	0	0	1	0	0	0	0	0	1	1	1	0	0	1	0	0	0	1	0	1	1
23	1	0	0	1	1	0	1	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	1	1
24	1	0	0	0	1	1	0	1	0	1	0	0	1	0	0	1	1	1	1	1	1	0	0	0
25	1	0	1	0	1	1	0	0	0	1	0	0	0	1	1	1	1	1	1	0	0	1	0	0
26	0	1	0	0	1	0	1	0	1	1	0	0	0	1	1	1	1	1	1	0	0	1	0	0
27	0	1	0	1	1	0	1	0	1	0	1	0	1	1	0	1	1	0	0	1	0	0	1	1
28	0	1	0	0	0	1	1	0	1	0	1	0	1	1	1	0	1	0	0	1	0	0	1	1
29	0	1	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0	1	1

5.3 OFDM baseband signal generation

5.3.1 OFDM baseband signal generation for all channels except PRACH and RIM-RS

The time-continuous signal $s_l^{(p,\mu)}(t)$ on antenna port p and subcarrier spacing configuration μ for OFDM symbol $l \in \left\{0,1,\ldots,N_{\text{slot}}^{\text{subframe},\mu} N_{\text{symb}}^{\text{slot}} - 1\right\}$ in a subframe for any physical channel or signal except PRACH is defined by

$$\begin{aligned}
s_l^{(p,\mu)}(t) &= \begin{cases} \bar{s}_l^{(p,\mu)}(t) & t_{\text{start},l}^{\mu} \le t < t_{\text{start},l}^{\mu} + T_{\text{symb},l}^{\mu} \\ 0 & \text{otherwise} \end{cases} \\
\bar{s}_l^{(p,\mu)}(t) &= \sum_{k=0}^{N_{\text{grid},x}^{\text{size},\mu} N_{\text{sc}}^{\text{RB}} - 1} a_{k,l}^{(p,\mu)} e^{j2\pi\left(k + k_0^{\mu} - N_{\text{grid},x}^{\text{size},\mu} N_{\text{sc}}^{\text{RB}}/2\right)\Delta f\left(t - N_{\text{CP},l}^{\mu} T_{\text{c}} - t_{\text{start},l}^{\mu}\right)} \\
k_0^{\mu} &= \left(N_{\text{grid},x}^{\text{start},\mu} + N_{\text{grid},x}^{\text{size},\mu}/2\right) N_{\text{sc}}^{\text{RB}} - \left(N_{\text{grid},x}^{\text{start},\mu_0} + N_{\text{grid},x}^{\text{size},\mu_0}/2\right) N_{\text{sc}}^{\text{RB}} 2^{\mu_0 - \mu} \\
T_{\text{symb},l}^{\mu} &= \left(N_{\text{u}}^{\mu} + N_{\text{CP},l}^{\mu}\right) T_{\text{c}}
\end{aligned}$$

where $t = 0$ at the start of the subframe,

$$N_{\mathrm{u}}^{\mu} = 2048\kappa \cdot 2^{-\mu}$$

$$N_{\mathrm{CP},l}^{\mu} = \begin{cases} 512\kappa \cdot 2^{-\mu} & \text{extended cyclic prefix} \\ 144\kappa \cdot 2^{-\mu} + 16\kappa & \text{normal cyclic prefix, } l = 0 \text{ or } l = 7 \cdot 2^{\mu} \\ 144\kappa \cdot 2^{-\mu} & \text{normal cyclic prefix, } l \neq 0 \text{ and } l \neq 7 \cdot 2^{\mu} \end{cases}$$

and

- Δf is given by clause 4.2;
- μ is the subcarrier spacing configuration;
- μ_0 is the largest μ value among the subcarrier spacing configurations by *scs-SpecificCarrierList* for each of uplink and downlink and by *sl-SCS-SpecificCarrierList* for sidelink.

The starting position of OFDM symbol l for subcarrier spacing configuration μ in a subframe is given by

$$t_{\mathrm{start},l}^{\mu} = \begin{cases} 0 & l = 0 \\ t_{\mathrm{start},l-1}^{\mu} + T_{\mathrm{symb},l-1}^{\mu} & \text{otherwise} \end{cases}$$

In case of cyclic prefix extension of the first OFDM symbol l allocated for PUSCH, SRS, PUCCH, PSCCH/PSSCH, PSFCH, or S-SS/PSBCH block transmission, the time-continuous signal $s_{\mathrm{ext}}^{(p,\mu)}(t)$ for the interval $t_{\mathrm{start},l}^{\mu} - T_{\mathrm{ext}} \leq t < t_{\mathrm{start},l}^{\mu}$ preceding the first OFDM symbol for PUSCH, SRS, PUCCH, PSCCH/PSSCH, PSFCH, or S-SS/PSBCH block is given by

$$s_{\mathrm{ext}}^{(p,\mu)}(t) = \bar{s}_{l}^{(p,\mu)}(t)$$

where $t < 0$ refers to the signal in the previous subframe and

- for dynamically scheduled PUSCH, SRS, and PUCCH transmissions

$$T_{\mathrm{ext}}=\min\left(\max(T_{\mathrm{ext}}', 0), T_{\mathrm{symb},(l-1)\mathrm{mod}7\cdot 2^{\mu}}^{\mu}\right)$$

$$T_{\mathrm{ext}}' = \sum_{k=1}^{C_i} T_{\mathrm{symb},(l-k)\mathrm{mod}\ 7\cdot 2^{\mu}}^{\mu} - \Delta_i$$

  where Δ_i is given by Table 5.3.1-1 with $C_1 = 1$ for $\mu \in \{0,1\}$, $C_1 = 2$ for $\mu = 2$, and C_2 and C_3 given by the higher-layer parameters *cp-ExtensionC2* and *cp-ExtensionC3*, respectively, and T_{TA} given by clause 4.3.1. For contention-based random access, or in absence of higher-layer configuration of C_2 and C_3, the value of $C_i$shall be set to the largest integer fulfilling $T_{\mathrm{ext}}' < T_{\mathrm{symb},(l-1)\mathrm{mod}7\cdot 2^{\mu}}^{\mu}$ for each of the values of $i \in \{2,3\}$. T_{ext} is applied to the first UL transmission scheduled by the scheduling DCI.

- for a PUSCH transmission using configured grant

$$T_{\mathrm{ext}} = \sum_{k=1}^{2^{\mu}} T_{\mathrm{symb},(l-k)\mathrm{mod}\ 7\cdot 2^{\mu}}^{\mu} - \Delta_i$$

  where Δ_i is given by Table 5.3.1-2 with the index i given by the procedure in [6, TS 38.214].

- for PSCCH/PSSCH, PSFCH, and S-SS/PSBCH block transmission

$$T_{\mathrm{ext}} = \max\left(\sum_{k=1}^{C_i} T_{\mathrm{symb},(l-k)\mathrm{mod}\ 7\cdot 2^{\mu}}^{\mu} - \Delta_i, 0\right)$$

  where Δ_i and C_i are given by Table 5.3.1-3 with the index i given by the procedure in [5, TS 38.213] or [6, TS 38.214].

Table 5.3.1-1: The variables C_i and Δ_i for uplink cyclic prefix extension

T_{ext} index i	C_i	Δ_i
0	-	-
1	C_1	$25 \cdot 10^{-6}$
2	C_2	$16 \cdot 10^{-6} + T_{\text{TA}}$
3	C_3	$25 \cdot 10^{-6} + T_{\text{TA}}$

Table 5.3.1-2: The variable Δ_i for uplink cyclic prefix extension with configured grants.

index i	Δ_i
0	$16 \cdot 10^{-6}$
1	$25 \cdot 10^{-6}$
2	$34 \cdot 10^{-6}$
3	$43 \cdot 10^{-6}$
4	$52 \cdot 10^{-6}$
5	$61 \cdot 10^{-6}$
6	$\sum_{k=1}^{2^\mu} T^{\mu}_{\text{symb},(l-k)\text{mod }7\cdot 2^\mu}$

Table 5.3.1-3: The variables C_i and Δ_i for sidelink cyclic prefix extension

Index i	$\mu = 0$		$\mu = 1$		$\mu = 2$	
	C_i	Δ_i	C_i	Δ_i	C_i	Δ_i
0	-	-	-	-	-	-
1	1	$16 \cdot 10^{-6}$	1	$16 \cdot 10^{-6}$	1	$16 \cdot 10^{-6}$
2	1	$25 \cdot 10^{-6}$	1	$25 \cdot 10^{-6}$	2	$16 \cdot 10^{-6}$
3	1	$34 \cdot 10^{-6}$	2	$16 \cdot 10^{-6}$	2	$25 \cdot 10^{-6}$
4	1	$43 \cdot 10^{-6}$	2	$25 \cdot 10^{-6}$	-	-
5	1	$52 \cdot 10^{-6}$	2	$34 \cdot 10^{-6}$	-	-
6	1	$61 \cdot 10^{-6}$	2	$43 \cdot 10^{-6}$	-	-
7	-	-	2	$52 \cdot 10^{-6}$	-	-
8	-	-	2	$61 \cdot 10^{-6}$	-	-

5.3.2 OFDM baseband signal generation for PRACH

The time-continuous signal $s_l^{(p,\mu)}(t)$ on antenna port p for PRACH is defined by

$$
\begin{aligned}
s_l^{(p,\mu)}(t) &= \sum_{k=0}^{L_{\text{RA}}-1} a_k^{(p,\text{RA})}\, e^{j2\pi\left(k+Kk_1+\bar{k}\right)\Delta f_{\text{RA}}\left(t-N_{\text{CP},l}^{\text{RA}}T_{\text{c}}-t_{\text{start}}^{\text{RA}}\right)} \\
K &= \Delta f / \Delta f_{\text{RA}} \\
k_1 &= k_0^{\mu} + \left(N_{\text{BWP},i}^{\text{start}} - N_{\text{grid}}^{\text{start},\mu}\right)N_{\text{sc}}^{\text{RB}} - N_{\text{grid}}^{\text{size},\mu}\, N_{\text{sc}}^{\text{RB}}/2 + n_{\text{RA}}^{\text{start}}N_{\text{sc}}^{\text{RB}} \\
&\quad + \begin{cases} n_{\text{RA}}N_{\text{RB}}^{\text{RA}}N_{\text{sc}}^{\text{RB}} & \text{if } L_{\text{RA}} \in \{139, 839\} \\ n_{\text{RA}}N_{\text{RB}}^{\text{RA}}N_{\text{sc}}^{\text{RB}} & \text{if } L_{\text{RA}} \in \{571, 1151\} \text{ in FR2-2} \\ \left(N_{\text{RB,UL},n_0+n_{\text{RA}}}^{\text{start},\mu} - N_{\text{RB,UL},n_0}^{\text{start},\mu}\right) N_{\text{sc}}^{\text{RB}} & \text{if } L_{\text{RA}} \in \{571, 1151\} \text{ in FR1} \end{cases} \\
k_0^{\mu} &= \left(N_{\text{grid}}^{\text{start},\mu} + N_{\text{grid}}^{\text{size},\mu}/2\right)N_{\text{sc}}^{\text{RB}} - \left(N_{\text{grid}}^{\text{start},\mu_0} + N_{\text{grid}}^{\text{size},\mu_0}/2\right)N_{\text{sc}}^{\text{RB}}2^{\mu_0-\mu}
\end{aligned}
$$

where $t_{\text{start}}^{\text{RA}} \le t < t_{\text{start}}^{\text{RA}} + \left(N_{\text{u}} + N_{\text{CP},l}^{\text{RA}}\right)T_{\text{c}}$ and

- $\bar{k}$ is given by clause 6.3.3;
- Δf is the subcarrier spacing of the initial uplink bandwidth part during initial access. Otherwise, Δf is the subcarrier spacing of the active uplink bandwidth part;

- μ_0 is the largest μ value among the subcarrier spacing configurations by the higher-layer parameter *scs-SpecificCarrierList*;
- $N_{\mathrm{BWP},i}^{\mathrm{start}}$ is the lowest numbered resource block of the initial uplink bandwidth part and is derived by the higher-layer parameter *initialUplinkBWP* or *initialUplinkBWP-RedCap* during initial access. Otherwise, $N_{\mathrm{BWP},i}^{\mathrm{start}}$ is the lowest numbered resource block of the active uplink bandwidth part and is derived by the higher-layer parameter *BWP-Uplink*;
- $n_{\mathrm{RA}}^{\mathrm{start}}$ is the frequency offset of the lowest PRACH transmission occasion in frequency domain with respect to physical resource block 0 of the active uplink bandwidth part. The quantity $n_{\mathrm{RA}}^{\mathrm{start}}$ is given by the higher-layer parameter *msgA-RO-FrequencyStart* if configured and a type-2 random-access procedure is initiated as described in clause 8.1 of [5, TS 38.213], otherwise by *msg1-FrequencyStart* as described in clause 8.1 of [5 TS 38.213];
- n_{RA} is the PRACH transmission occasion index in frequency domain for a given PRACH transmission occasion in one time instance as given by clause 6.3.3.2;
- $N_{\mathrm{RB}}^{\mathrm{RA}}$ is the number of resource blocks occupied and is given by the parameter allocation expressed in number of RBs for PUSCH in Table 6.3.3.2-1.
- $N_{\mathrm{RB,UL},n}^{\mathrm{start},\mu}$ is the start CRB index of uplink RB set n corresponding to the quantity $RB_{n,\mathrm{UL}}^{\mathrm{start},\mu}$. The UE assumes that the RB set is defined as when the UE is not provided *IntraCellGuardBandsPerSCS* for an UL carrier as described in Clause 7 of [6, TS 38.214]
- n_0 is the index of the RB set which contains the lowest PRACH transmission occasion in frequency domain indicated by $n_{\mathrm{RA}}^{\mathrm{start}}$. The UE may assume that $n_{\mathrm{RA}}^{\mathrm{start}}$ is configured such that each PRACH transmission occasion is fully contained within an RB set.
- L_{RA} and N_{u} are given by clause 6.3.3
- $N_{\mathrm{CP},l}^{\mathrm{RA}} = N_{\mathrm{CP}}^{\mathrm{RA}} + n \cdot 16\kappa$ where
    - for $\Delta f_{\mathrm{RA}} \in \{1.25, 5\}\mathrm{kHz}$, $n = 0$
    - for $\Delta f_{\mathrm{RA}} \in \{15,30,60,120,480,960\}\mathrm{kHz}$, n is the number of times the interval $[t_{\mathrm{start}}^{\mathrm{RA}}, t_{\mathrm{start}}^{\mathrm{RA}} + (N_{\mathrm{u}}^{\mathrm{RA}} + N_{\mathrm{CP}}^{\mathrm{RA}})T_{\mathrm{c}}]$ overlaps with either time instance 0 or time instance $(\Delta f_{\max} N_{\mathrm{f}} / 2000) \cdot T_{\mathrm{c}} = 0.5\ \mathrm{ms}$ in a subframe

The starting position $t_{\mathrm{start}}^{\mathrm{RA}}$ of the PRACH preamble in a subframe (for $\Delta f_{\mathrm{RA}} \in \{1.25, 5, 15, 30\}$ kHz) or in a 60 kHz slot (for $\Delta f_{\mathrm{RA}} \in \{60,120,480,960\}\mathrm{kHz}$) is given by

$$t_{\mathrm{start}}^{\mathrm{RA}} = t_{\mathrm{start},l}^{\mu}$$
$$t_{\mathrm{start},l}^{\mu} = \begin{cases} 0 & l = 0 \\ t_{\mathrm{start},l-1}^{\mu} + \left(N_{\mathrm{u}}^{\mu} + N_{\mathrm{CP},l-1}^{\mu}\right) \cdot T_{\mathrm{c}} & \text{otherwise} \end{cases}$$

where

- the subframe or 60 kHz slot is assumed to start at $t = 0$;
- a timing advance value $N_{\mathrm{TA}} = 0$ shall be assumed;
- N_{u}^{μ} and $N_{\mathrm{CP},l-1}^{\mu}$ are given by clause 5.3.1;
- $\mu = 0$ shall be assumed for $\Delta f_{\mathrm{RA}} \in \{1.25, 5\}$ kHz, otherwise the value of μ corresponds to $\Delta f_{\mathrm{RA}} \in \{15, 30, 60, 120, 480, 960\}$ kHz and the symbol position l is given by

$$l = l_0 + n_t^{\mathrm{RA}} N_{\mathrm{dur}}^{\mathrm{RA}} + 14 n_{\mathrm{slot}}^{\mathrm{RA}}$$

where

- l_0 is given by the parameter "starting symbol" in Tables 6.3.3.2-2 to 6.3.3.2-4;
- n_{t}^{RA} is the PRACH transmission occasion within the PRACH slot, numbered in increasing order from 0 to $N_{\text{t}}^{\text{RA,slot}}-1$ within a RACH slot where $N_{\text{t}}^{\text{RA,slot}}$ is given Tables 6.3.3.2-2 to 6.3.3.2-4 for $L_{\text{RA}} \in \{139,571,1151\}$ and fixed to 1 for $L_{\text{RA}} = 839$;
- $N_{\text{dur}}^{\text{RA}}$ is given by Tables 6.3.3.2-2 to 6.3.3.2-4;
- $n_{\text{slot}}^{\text{RA}}$ is given by
  - if $\Delta f_{\text{RA}} \in \{1.25, 5, 15, 60\}$ kHz, then $n_{\text{slot}}^{\text{RA}} = 0$
  - if $\Delta f_{\text{RA}} \in \{30, 120\}$ kHz and either of "Number of PRACH slots within a subframe" in Tables 6.3.3.2-2 to 6.3.3.2-3 or "Number of PRACH slots within a 60 kHz slot" in Table 6.3.3.2-4 is equal to 1, then $n_{\text{slot}}^{\text{RA}} = 1$, otherwise $n_{\text{slot}}^{\text{RA}} \in \{0,1\}$
  - if $\Delta f_{\text{RA}} \in \{480, 960\}$ kHz and
    - the "Number of PRACH slots within a 60 kHz slot" in Table 6.3.3.2-4 is equal to 1, then $n_{\text{slot}}^{\text{RA}} = 7$ for $\Delta f_{\text{RA}} = 480$ kHz and $n_{\text{slot}}^{\text{RA}} = 15$ for $\Delta f_{\text{RA}} = 960$ kHz, or
    - the "Number of PRACH slots within a 60 kHz slot" in Table 6.3.3.2-4 is equal to 2, then $n_{\text{slot}}^{\text{RA}} \in \{3,7\}$ for $\Delta f_{\text{RA}} = 480$ kHz and $n_{\text{slot}}^{\text{RA}} \in \{7,15\}$ for $\Delta f_{\text{RA}} = 960$ kHz.

If the preamble format given by Tables 6.3.3.2-2 to 6.3.3.2-4 is A1/B1, A2/B2 or A3/B3, then

- if $n_t^{\text{RA}} = N_t^{\text{RA,slot}} - 1$, then the PRACH preamble with the corresponding PRACH preamble format from B1, B2 and B3 is transmitted in the PRACH transmission occasion;
- otherwise the PRACH preamble with the corresponding PRACH preamble format from A1, A2 and A3 is transmitted in the PRACH transmission occasion

5.3.3 OFDM baseband signal generation for RIM-RS

The time-continuous signal $s_l^{(p,\mu)}(t)$ on antenna port p for RIM-RS is defined by

$$s_l^{(p,\mu)}(t) = \sum_{k=0}^{L_{\text{RIM}}-1} a_k^{(p,\text{RIM})}\, e^{j2\pi(k+k_1)\Delta f_{\text{RIM}}\left(t-N_{\text{CP}}^{\text{RIM}}T_{\text{c}}-t_{\text{start},l_0}^{\mu}\right)}$$

where

$$t_{\text{start},l_0}^{\text{RIM}} \leq t < t_{\text{start},l_0}^{\text{RIM}} + \left(N_{\text{u}}^{\text{RIM}} + N_{\text{CP}}^{\text{RIM}}\right)T_{\text{c}}$$

$$N_{\text{u}}^{\text{RIM}} = 2 \cdot 2048\kappa \cdot 2^{-\mu}$$

$$N_{\text{CP}}^{\text{RIM}} = N_{\text{CP},l_0}^{\text{RIM}} + N_{\text{CP},\bar{l}}^{\text{RIM}}$$

$$\bar{l} = \begin{cases} 0 & \text{if } l_0 = N_{\text{symb}}^{\text{slot}} - 1 \\ l_0 + 1 & \text{otherwise} \end{cases}$$

and

- $\Delta f_{\text{RIM}} = 15 \cdot 2^{\mu}$ kHz where $\mu \in \{0,1\}$ is the subcarrier spacing configuration for the RIM-RS;
- k_1 is the starting frequency offset of the RIM-RS as given by clause 7.4.1.6.4.3;
- $L_{\text{RIM}} = 12N_{\text{RB}}^{\text{RIM}}$ is the length of the RIM-RS sequence where $N_{\text{RB}}^{\text{RIM}}$ is the bandwidth of the RIM-RS in resource blocks;
- l_0 is the starting symbol given by clause 7.4.1.6.3;

- $t^{\mathrm{RIM}}_{\mathrm{start},l_0} = t^{\mu}_{\mathrm{start},l}$ is given by clause 5.3.1 with $l = l_0$;
- $N^{\mathrm{RIM}}_{\mathrm{CP},l_0} = N^{\mu}_{\mathrm{CP},l}$ is given by clause 5.3.1 with $l = l_0$.

5.4 Modulation and upconversion

Modulation and upconversion to the carrier frequency f_0 of the complex-valued OFDM baseband signal for antenna port p, subcarrier spacing configuration μ, and OFDM symbol l in a subframe assumed to start at $t=0$ is given by

- for PRACH

$$\mathrm{Re}\left\{s_l^{(p,\mu)}(t)e^{j2\pi f_0 t}\right\}$$

- for RIM-RS

$$\mathrm{Re}\left\{s_l^{(p,\mu)}(t)e^{j2\pi f_0^{\mathrm{RIM}}\left(t-t^{\mu}_{\mathrm{start},l_0}-N_{\mathrm{CP}}^{\mathrm{RIM}}T_{\mathrm{c}}\right)}\right\}$$

  where f_0^{RIM} is the configured reference point for RIM-RS;

- for all other channels and signals

$$\mathrm{Re}\left\{s_l^{(p,\mu)}(t)\cdot e^{j2\pi f_0\left(t-t^{\mu}_{\mathrm{start},l}-N^{\mu}_{\mathrm{CP},l}T_{\mathrm{c}}\right)}\right\}$$

NOTE: For the uplink, the signal $s_l^{(p,\mu)}(t)$ and the baseband signals part thereof should be filtered per UE implementation, as required, to meet the minimum requirements as specified in [38.101-1] and [38.101-2] for the respective frequency range.

6 Uplink

6.1 Overview

6.1.1 Overview of physical channels

An uplink physical channel corresponds to a set of resource elements carrying information originating from higher layers. The following uplink physical channels are defined:

- Physical Uplink Shared Channel, PUSCH
- Physical Uplink Control Channel, PUCCH
- Physical Random Access Channel, PRACH

6.1.2 Overview of physical signals

An uplink physical signal is used by the physical layer but does not carry information originating from higher layers. The following uplink physical signals are defined:

- Demodulation reference signals, DM-RS
- Phase-tracking reference signals, PT-RS
- Sounding reference signal, SRS

6.2 Physical resources

The frame structure and physical resources the UE shall use when transmitting in the uplink transmissions are defined in Clause 4.

The following antenna ports are defined for the uplink:

- Antenna ports starting with 0 for demodulation reference signals for PUSCH
- Antenna ports starting with 1000 for SRS, PUSCH
- Antenna ports starting with 2000 for PUCCH
- Antenna port 4000 for PRACH

If PUSCH repetition Type B as described in clause 6.1 of [6, TS38.214] is applied to a physical channel, the UE transmission shall be such that the channel over which a symbol on the antenna port used for uplink transmission is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed if the two symbols correspond to the same actual repetition of a PUSCH transmission with repetition Type B.

If intra-slot frequency hopping is not enabled for a physical channel and PUSCH repetition Type B is not applied to the physical channel, the UE transmission shall be such that the channel over which a symbol on the antenna port used for uplink transmission is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed if the two symbols correspond to the same slot.

If intra-slot frequency hopping is enabled for a physical channel, the UE transmission shall be such that the channel over which a symbol on the antenna port used for uplink transmission is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed only if the two symbols correspond to the same frequency hop, regardless of whether the frequency hop distance is zero or not.

If DM-RS bundling is applied to PUSCH and/or PUCCH repetitions and/or transport-block processing over multiple slots as described in clause 6.1.7 of [6, 38.214], the UE transmission shall be such that the channel over which a symbol on the antenna port used for uplink transmission is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed if the two symbols are transmitted within the same actual time-domain window.

6.3 Physical channels

6.3.1 Physical uplink shared channel

6.3.1.1 Scrambling

Up to two codewords $q \in \{0,1\}$ can be transmitted. In case of single-codeword transmission, $q = 0$.

For each codeword, the block of bits $b^{(q)}(0),\ldots,b^{(q)}\left(M_{\text{bit}}^{(q)}-1\right)$, where $M_{\text{bit}}^{(q)}$ is the number of bits in codeword q transmitted on the physical channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}^{(q)}(0),\ldots,\tilde{b}^{(q)}\left(M_{\text{bit}}^{(q)}-1\right)$ according to the following pseudo code

```
Set $i = 0$
while $i < M_{\text{bit}}^{(q)}$
    if $b^{(q)}(i) = \text{x}$ // UCI placeholder bits
        $\tilde{b}^{(q)}(i) = 1$
    else
        if $b^{(q)}(i) = \text{y}$ // UCI placeholder bits
```

```
            $\tilde{b}^{(q)}(i) = \tilde{b}^{(q)}(i-1)$
        else
            $\tilde{b}^{(q)}(i) = \left(b^{(q)}(i) + c^{(q)}(i)\right) \bmod 2$
        end if
    end if
    $i = i + 1$
end while
```

where x and y are tags defined in [4, TS 38.212] and where the scrambling sequence $c^{(q)}(i)$ is given by clause 5.2.1. The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = \begin{cases} n_{\text{RNTI}} \cdot 2^{16} + n_{\text{RAPID}} \cdot 2^{10} + n_{\text{ID}} & \text{for msgA on PUSCH} \\ n_{\text{RNTI}} \cdot 2^{15} + q \cdot 2^{14} + n_{\text{ID}} & \text{otherwise} \end{cases}$$

where

- $n_{\text{ID}} \in \{0,1,\ldots,1023\}$ equals the higher-layer parameter *dataScramblingIdentityPUSCH* if configured and the RNTI equals the C-RNTI, MCS-C-RNTI, SP-CSI-RNTI or CS-RNTI, and the transmission is not scheduled using DCI format 0_0 in a common search space;
- $n_{\text{ID}} \in \{0,1,\ldots,1023\}$ equals the higher-layer parameter *msgA-DataScramblingIndex* if configured and the PUSCH transmission is triggered by a Type-2 random access procedure as described in clause 8.1A of [5, TS 38.213];
- $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ otherwise
- n_{RAPID} is the index of the random-access preamble transmitted for msgA as described in clause 5.1.3A of [11, TS 38.321]

and where n_{RNTI} equals the RA-RNTI for msgA and otherwise corresponds to the RNTI associated with the PUSCH transmission as described in clause 6.1 of [6, TS 38.214] and clause 8.3 of [5, TS 38.213].

6.3.1.2 Modulation

For each codeword q, the block of scrambled bits $\tilde{b}^{(q)}(0),\ldots,\tilde{b}^{(q)}\left(M_{\text{bit}}^{(q)}-1\right)$ shall be modulated as described in clause 5.1 using one of the modulation schemes in Table 6.3.1.2-1, resulting in a block of complex-valued modulation symbols $d^{(q)}(0),\ldots,d^{(q)}\left(M_{\text{symb}}^{(q)}-1\right)$.

Table 6.3.1.2-1: Supported modulation schemes.

Transform precoding disabled		**Transform precoding enabled**	
Modulation scheme	**Modulation order Q_{m}**	**Modulation scheme**	**Modulation order Q_{m}**
		π/2-BPSK	1
QPSK	2	QPSK	2
16QAM	4	16QAM	4
64QAM	6	64QAM	6
256QAM	8	256QAM	8

6.3.1.3 Layer mapping

The complex-valued modulation symbols for each of the codewords to be transmitted shall be mapped onto up to four layers according to Table 7.3.1.3-1. Complex-valued modulation symbols $d^{(q)}(0),\ldots,d^{(q)}\left(M_{\text{symb}}^{(q)}-1\right)$ for codeword q

shall be mapped onto the layers $x(i) = [x^{(0)}(i) \quad \ldots \quad x^{(\upsilon-1)}(i)]^{\mathrm{T}}$, $i = 0,1,\ldots,M_{\mathrm{symb}}^{\mathrm{layer}} - 1$ where υ is the number of layers and $M_{\mathrm{symb}}^{\mathrm{layer}}$ is the number of modulation symbols per layer.

6.3.1.4 Transform precoding

If transform precoding is not enabled according to 6.1.3 of [6, TS38.214], $y^{(\lambda)}(i) = x^{(\lambda)}(i)$ for each layer $\lambda = 0,1,\ldots,\upsilon-1$.

If transform precoding is enabled according to 6.1.3 of [6, TS38.214], $\upsilon = 1$ and $\tilde{x}^{(0)}(i)$ depends on the configuration of phase-tracking reference signals.

If the procedure in [6, TS 38.214] indicates that phase-tracking reference signals are not being used, the block of complex-valued symbols $x^{(0)}(0),\ldots,x^{(0)}\left(M_{\mathrm{symb}}^{\mathrm{layer}} - 1\right)$ for the single layer $\lambda = 0$ shall be divided into $M_{\mathrm{symb}}^{\mathrm{layer}}/M_{\mathrm{sc}}^{\mathrm{PUSCH}}$ sets, each corresponding to one OFDM symbol and $\tilde{x}^{(0)}(i) = x^{(0)}(i)$.

If the procedure in [6, TS 38.214] indicates that phase-tracking reference signals are being used, the block of complex-valued symbols $x^{(0)}(0),\ldots,x^{(0)}\left(M_{\mathrm{symb}}^{\mathrm{layer}} - 1\right)$ shall be divided into sets, each set corresponding to one OFDM symbol, and where set l contains $M_{\mathrm{sc}}^{\mathrm{PUSCH}} - \varepsilon_l N_{\mathrm{samp}}^{\mathrm{group}} N_{\mathrm{group}}^{\mathrm{PTRS}}$ symbols and is mapped to the complex-valued symbols $\tilde{x}^{(0)}(lM_{\mathrm{sc}}^{\mathrm{PUSCH}} + i')$ corresponding to OFDM symbol l prior to transform precoding, with $i' \in \{0,1,\ldots,M_{\mathrm{sc}}^{\mathrm{PUSCH}} - 1\}$ and $i' \neq m$. The index m of PT-RS samples in set l, the number of samples per PT-RS group $N_{\mathrm{samp}}^{\mathrm{group}}$, and the number of PT-RS groups $N_{\mathrm{group}}^{\mathrm{PT\text{-}RS}}$ are defined in clause 6.4.1.2.2.2. The quantity $\varepsilon_l = 1$ when OFDM symbol l contains one or more PT-RS samples, otherwise $\varepsilon_l = 0$.

Transform precoding shall be applied according to

$$
\begin{aligned}
y^{(0)}(l \cdot M_{\mathrm{sc}}^{\mathrm{PUSCH}} + k) &= \frac{1}{\sqrt{M_{\mathrm{sc}}^{\mathrm{PUSCH}}}} \sum_{i=0}^{M_{\mathrm{sc}}^{\mathrm{PUSCH}}-1} \tilde{x}^{(0)}(l \cdot M_{\mathrm{sc}}^{\mathrm{PUSCH}} + i) e^{-j\frac{2\pi ik}{M_{\mathrm{sc}}^{\mathrm{PUSCH}}}} \\
k &= 0,\ldots,M_{\mathrm{sc}}^{\mathrm{PUSCH}} - 1 \\
l &= 0,\ldots,M_{\mathrm{symb}}^{\mathrm{layer}}/M_{\mathrm{sc}}^{\mathrm{PUSCH}} - 1
\end{aligned}
$$

resulting in a block of complex-valued symbols $y^{(0)}(0),\ldots,y^{(0)}\left(M_{\mathrm{symb}}^{\mathrm{layer}} - 1\right)$. The variable $M_{\mathrm{sc}}^{\mathrm{PUSCH}} = M_{\mathrm{RB}}^{\mathrm{PUSCH}} \cdot N_{\mathrm{sc}}^{\mathrm{RB}}$, where $M_{\mathrm{RB}}^{\mathrm{PUSCH}}$ represents the bandwidth of the PUSCH in terms of resource blocks, and shall fulfil

$$
M_{\mathrm{RB}}^{\mathrm{PUSCH}} = 2^{\alpha_2} \cdot 3^{\alpha_3} \cdot 5^{\alpha_5}
$$

where $\alpha_2, \alpha_3, \alpha_5$ is a set of non-negative integers.

6.3.1.5 Precoding

The block of vectors $[y^{(0)}(i) \quad \ldots \quad y^{(\upsilon-1)}(i)]^{\mathrm{T}}$ shall be precoded according to

$$
\begin{bmatrix} z^{(p_0)}(i) \\ \vdots \\ z^{(p_{\rho-1})}(i) \end{bmatrix} = W \begin{bmatrix} y^{(0)}(i) \\ \vdots \\ y^{(\upsilon-1)}(i) \end{bmatrix}
$$

where $i = 0,1,\ldots,M_{\mathrm{symb}}^{\mathrm{ap}} - 1$, $M_{\mathrm{symb}}^{\mathrm{ap}} = M_{\mathrm{symb}}^{\mathrm{layer}}$. The set of antenna ports $\{p_0,\ldots,p_{\rho-1}\}$ shall be determined according to the procedure in [6, TS 38.214].

For non-codebook-based transmission, the precoding matrix W equals the identity matrix.

For codebook-based transmission, the precoding matrix W depends on the number of antenna ports used for the transmission:

- for single-layer transmission on a single antenna port, $W = 1$;

- for transmissions using 2, or 4 antenna ports, W is given by Tables 6.3.1.5-1 to 6.3.1.5-7;
- for transmissions using 8 antenna ports, W is given by

$$W_{f(i)} = W'_i$$

  where

  - the subscripts i and $f(i)$ denote the row of the respective matrix;
  - $f(i)$ is given by Table 6.3.1.5-8;
  - the intermediate precoding matrix W' is given by Tables 6.3.1.5-9 to 6.3.1.5-24, 6.3.1.5-29 to 6.3.1.5-36, and 6.3.1.5-39 to 6.3.1.5-47 with $0_{m\times n}$ representing the all-zero matrix with m rows and n columns;
  - the submatrices $\bar{W}_{m,n}$ are given by Tables 6.3.1.5-25 to 6.3.1.5-28 and 6.3.1.5-37 to 6.3.1.5-38.

The TPMI index used in the tables above is obtained from the DCI scheduling the uplink transmission or the higher layer parameters according to the procedure in [6, TS 38.214].

When the higher-layer parameter *txConfig* is not configured, the precoding matrix $W = 1$.

Table 6.3.1.5-1: Precoding matrix W for single-layer transmission using two antenna ports.

TPMI index	W **(ordered from left to right in increasing order of TPMI index)**							
0 – 5	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\0\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}0\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-	-

Table 6.3.1.5-2: Precoding matrix W for single-layer transmission using four antenna ports with transform precoding enabled.

TPMI index	W **(ordered from left to right in increasing order of TPMI index)**							
0 – 7	$\frac{1}{2}\begin{bmatrix}1\\0\\0\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\0\\1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\0\\0\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\-1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\j\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\-j\\0\end{bmatrix}$
8 – 15	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\j\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\-1\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\-j\\-j\end{bmatrix}$
16 – 23	$\frac{1}{2}\begin{bmatrix}1\\j\\1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\j\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\-1\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\-j\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\1\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\j\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\-1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\-j\\j\end{bmatrix}$
24 – 27	$\frac{1}{2}\begin{bmatrix}1\\-j\\1\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\j\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\-1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\-j\\1\end{bmatrix}$	-	-	-	-

Table 6.3.1.5-3: Precoding matrix W for single-layer transmission using four antenna ports with transform precoding disabled.

TPMI index	W (ordered from left to right in increasing order of TPMI index)							
0 – 7	$\frac{1}{2}\begin{bmatrix}1\\0\\0\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\0\\1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\0\\0\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\-1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\j\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\-j\\0\end{bmatrix}$
8 – 15	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\1\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\j\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\-1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\-j\\-j\end{bmatrix}$
16 – 23	$\frac{1}{2}\begin{bmatrix}1\\j\\1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\j\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\-1\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\-j\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\j\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\-1\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\-j\\j\end{bmatrix}$
24 – 27	$\frac{1}{2}\begin{bmatrix}1\\-j\\1\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\j\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\-1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\-j\\-1\end{bmatrix}$	-	-	-	-

Table 6.3.1.5-4: Precoding matrix W for two-layer transmission using two antenna ports with transform precoding disabled.

TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$	-

Table 6.3.1.5-5: Precoding matrix W for two-layer transmission using four antenna ports with transform precoding disabled.

TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\0 & 0\\0 & 0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 0\\0 & 1\\0 & 0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 0\\0 & 0\\0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0 & 0\\1 & 0\\0 & 1\\0 & 0\end{bmatrix}$
4 – 7	$\frac{1}{2}\begin{bmatrix}0 & 0\\1 & 0\\0 & 0\\0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0 & 0\\0 & 0\\1 & 0\\0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\1 & 0\\0 & -j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\1 & 0\\0 & j\end{bmatrix}$
8 – 11	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\-j & 0\\0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\-j & 0\\0 & -1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\-1 & 0\\0 & -j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\-1 & 0\\0 & j\end{bmatrix}$
12 – 15	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\j & 0\\0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0\\0 & 1\\j & 0\\0 & -1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1\\1 & 1\\1 & -1\\1 & -1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1\\1 & 1\\j & -j\\j & -j\end{bmatrix}$
16 – 19	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1\\j & j\\1 & -1\\j & -j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1\\j & j\\j & -j\\-1 & 1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1\\-1 & -1\\1 & -1\\-1 & 1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1\\-1 & -1\\j & -j\\-j & j\end{bmatrix}$
20 – 21	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1\\-j & -j\\1 & -1\\-j & j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1\\-j & -j\\j & -j\\1 & -1\end{bmatrix}$	-	-

Table 6.3.1.5-6: Precoding matrix W for three-layer transmission using four antenna ports with transform precoding disabled.

TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{2}\begin{bmatrix}1 & 0 & 0\\0 & 1 & 0\\0 & 0 & 1\\0 & 0 & 0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0 & 0\\0 & 1 & 0\\1 & 0 & 0\\0 & 0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 0 & 0\\0 & 1 & 0\\-1 & 0 & 0\\0 & 0 & 1\end{bmatrix}$	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1 & 1 & 1\\1 & -1 & 1\\1 & 1 & -1\\1 & -1 & -1\end{bmatrix}$
4 – 6	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1 & 1 & 1\\1 & -1 & 1\\j & j & -j\\j & -j & -j\end{bmatrix}$	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1 & 1 & 1\\-1 & 1 & -1\\1 & 1 & -1\\-1 & 1 & 1\end{bmatrix}$	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1 & 1 & 1\\-1 & 1 & -1\\j & j & -j\\-j & j & j\end{bmatrix}$	-

Table 6.3.1.5-7: Precoding matrix W for four-layer transmission using four antenna ports with transform precoding disabled.

TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{2}\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1&1&0&0\\0&0&1&1\\1&-1&0&0\\0&0&1&-1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1&1&0&0\\0&0&1&1\\j&-j&0&0\\0&0&j&-j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&1&-1&-1\\1&-1&-1&1\end{bmatrix}$
4	$\frac{1}{4}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\j&j&-j&-j\\j&-j&-j&j\end{bmatrix}$	-	-	-

Table 6.3.1.5-8: The port mapping function $f(i)$ for transmission using 8 antenna ports.

i	Higher-layer parameter *CodebookTypeUL*							
	codebook1		codebook2		codebook3		codebook4	
	antenna port group	$f(i)$	antenna port group	$f(i)$	antenna port group	$f(i)$	antenna port group	$f(i)$
0	0	0	0	0	0	0	0	0
1		1		1		4	1	1
2		2		4	1	1	2	2
3		3		5		5	3	3
4		4	1	2	2	2	4	4
5		5		3		6	5	5
6		6		6	3	3	6	6
7		7		7		7	7	7

Table 6.3.1.5-9: Intermediate precoding matrix W' for *codebook1=ng1n4n1* and single-layer transmission using eight antenna ports.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)							
0 – 7	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\1\\1\\1\\1\\1\\1\\1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\1\\1\\1\\j\\j\\j\\j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\1\\1\\1\\-1\\-1\\-1\\-1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\1\\1\\1\\-j\\-j\\-j\\-j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\j\\-1\\-j\\1\\j\\-1\\-j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\j\\-1\\-j\\j\\-1\\-j\\1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\j\\-1\\-j\\-1\\-j\\1\\j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\j\\-1\\-j\\-j\\1\\j\\-1\end{bmatrix}$
8 – 15	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\-1\\1\\-1\\1\\-1\\1\\-1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\-1\\1\\-1\\j\\-j\\j\\-j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\-1\\1\\-1\\-1\\1\\-1\\1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\-1\\1\\-1\\-j\\j\\-j\\j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\-j\\-1\\j\\1\\-j\\-1\\j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\-j\\-1\\j\\j\\1\\-j\\-1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\-j\\-1\\j\\-1\\j\\1\\-j\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\-j\\-1\\j\\-j\\-1\\j\\1\end{bmatrix}$

Table 6.3.1.5-10: Intermediate precoding matrix W' for *codebook1=ng1n4n1* and two-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)							
0 – 7	$\frac{1}{4}\begin{bmatrix}1 & 1\\ 1 & 1\\ 1 & 1\\ 1 & 1\\ 1 & -1\\ 1 & -1\\ 1 & -1\\ 1 & -1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ 1 & 1\\ 1 & 1\\ 1 & 1\\ j & -j\\ j & -j\\ j & -j\\ j & -j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ 1 & j\\ 1 & -1\\ 1 & -j\\ 1 & -1\\ 1 & -j\\ 1 & 1\\ 1 & j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ 1 & j\\ 1 & -1\\ 1 & -j\\ j & -j\\ j & 1\\ j & j\\ j & -1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ 1 & -1\\ 1 & 1\\ 1 & -1\\ 1 & -1\\ 1 & 1\\ 1 & -1\\ 1 & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ 1 & -1\\ 1 & 1\\ 1 & -1\\ j & -j\\ j & j\\ j & -j\\ j & j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ 1 & -j\\ 1 & -1\\ 1 & j\\ 1 & -1\\ 1 & j\\ 1 & 1\\ 1 & -j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ 1 & -j\\ 1 & -1\\ 1 & j\\ j & -j\\ j & -1\\ j & j\\ j & 1\end{bmatrix}$
8 – 15	$\frac{1}{4}\begin{bmatrix}1 & 1\\ j & j\\ -1 & -1\\ -j & -j\\ 1 & -1\\ j & -j\\ -1 & 1\\ -j & j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ j & j\\ -1 & -1\\ -j & -j\\ j & -j\\ -1 & 1\\ -j & j\\ 1 & -1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ j & -1\\ -1 & 1\\ -j & -1\\ 1 & -1\\ j & 1\\ -1 & -1\\ -j & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ j & -1\\ -1 & 1\\ -j & -1\\ j & -j\\ -1 & j\\ -j & -j\\ 1 & j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ j & -j\\ -1 & -1\\ -j & j\\ 1 & -1\\ j & j\\ -1 & 1\\ -j & -j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ j & -j\\ -1 & -1\\ -j & j\\ j & -j\\ -1 & -1\\ -j & j\\ 1 & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ j & 1\\ -1 & 1\\ -j & 1\\ 1 & -1\\ j & -1\\ -1 & -1\\ -j & -1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ j & 1\\ -1 & 1\\ -j & 1\\ j & -j\\ -1 & -j\\ -j & -j\\ 1 & -j\end{bmatrix}$
16 – 23	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -1 & -1\\ 1 & 1\\ -1 & -1\\ 1 & -1\\ -1 & 1\\ 1 & -1\\ -1 & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -1 & -1\\ 1 & 1\\ -1 & -1\\ j & -j\\ -j & j\\ j & -j\\ -j & j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -1 & -j\\ 1 & -1\\ -1 & j\\ 1 & -1\\ -1 & j\\ 1 & 1\\ -1 & -j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -1 & -j\\ 1 & -1\\ -1 & j\\ j & -j\\ -j & -1\\ j & j\\ -j & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -1 & 1\\ 1 & 1\\ -1 & 1\\ 1 & -1\\ -1 & -1\\ 1 & -1\\ -1 & -1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -1 & 1\\ 1 & 1\\ -1 & 1\\ j & -j\\ -j & -j\\ j & -j\\ -j & -j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -1 & j\\ 1 & -1\\ -1 & -j\\ 1 & -1\\ -1 & -j\\ 1 & 1\\ -1 & j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -1 & j\\ 1 & -1\\ -1 & -j\\ j & -j\\ -j & 1\\ j & j\\ -j & -1\end{bmatrix}$
24 – 31	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -j & -j\\ -1 & -1\\ j & j\\ 1 & -1\\ -j & j\\ -1 & 1\\ j & -j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -j & -j\\ -1 & -1\\ j & j\\ j & -j\\ 1 & -1\\ -j & j\\ -1 & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -j & 1\\ -1 & 1\\ j & 1\\ 1 & -1\\ -j & -1\\ -1 & -1\\ j & -1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -j & 1\\ -1 & 1\\ j & 1\\ j & -j\\ 1 & -j\\ -j & -j\\ -1 & -j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -j & j\\ -1 & -1\\ j & -j\\ 1 & -1\\ -j & -j\\ -1 & 1\\ j & j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -j & j\\ -1 & -1\\ j & -j\\ j & -j\\ 1 & 1\\ -j & j\\ -1 & -1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -j & -1\\ -1 & 1\\ j & -1\\ 1 & -1\\ -j & 1\\ -1 & -1\\ j & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1\\ -j & -1\\ -1 & 1\\ j & -1\\ j & -j\\ 1 & j\\ -j & -j\\ -1 & j\end{bmatrix}$

Table 6.3.1.5-11: Intermediate precoding matrix W' for *codebook1=ng1n4n1* and three-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ 1 & j & 1 \\ 1 & -1 & 1 \\ 1 & -j & 1 \\ 1 & 1 & -1 \\ 1 & j & -1 \\ 1 & -1 & -1 \\ 1 & -j & -1\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ 1 & j & 1 \\ 1 & -1 & 1 \\ 1 & -j & 1 \\ j & j & -j \\ j & -1 & -j \\ j & -j & -j \\ j & 1 & -j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & -1 \\ 1 & -1 & -1 \\ 1 & 1 & -1 \\ 1 & -1 & -1\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & 1 \\ 1 & -1 & 1 \\ j & j & -j \\ j & -j & -j \\ j & j & -j \\ j & -j & -j\end{bmatrix}$
4 – 7	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ 1 & -j & 1 \\ 1 & -1 & 1 \\ 1 & j & 1 \\ 1 & 1 & -1 \\ 1 & -j & -1 \\ 1 & -1 & -1 \\ 1 & j & -1\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ 1 & -j & 1 \\ 1 & -1 & 1 \\ 1 & j & 1 \\ j & j & -j \\ j & 1 & -j \\ j & -j & -j \\ j & -1 & -j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ j & -1 & j \\ -1 & 1 & -1 \\ -j & -1 & -j \\ 1 & 1 & -1 \\ j & -1 & -j \\ -1 & 1 & 1 \\ -j & -1 & j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ j & -1 & j \\ -1 & 1 & -1 \\ -j & -1 & -j \\ j & j & -j \\ -1 & -j & 1 \\ -j & j & j \\ 1 & -j & -1\end{bmatrix}$
8 – 11	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ j & -j & j \\ -1 & -1 & -1 \\ -j & j & -j \\ 1 & 1 & -1 \\ j & -j & -j \\ -1 & -1 & 1 \\ -j & j & j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ j & -j & j \\ -1 & -1 & -1 \\ -j & j & -j \\ j & j & -j \\ -1 & 1 & 1 \\ -j & -j & j \\ 1 & -1 & -1\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ j & 1 & j \\ -1 & 1 & -1 \\ -j & 1 & -j \\ 1 & 1 & -1 \\ j & 1 & -j \\ -1 & 1 & 1 \\ -j & 1 & j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ j & 1 & j \\ -1 & 1 & -1 \\ -j & 1 & -j \\ j & j & -j \\ -1 & j & 1 \\ -j & j & j \\ 1 & j & -1\end{bmatrix}$
12 – 15	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -1 & -j & -1 \\ 1 & -1 & 1 \\ -1 & j & -1 \\ 1 & 1 & -1 \\ -1 & -j & 1 \\ 1 & -1 & -1 \\ -1 & j & 1\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -1 & -j & -1 \\ 1 & -1 & 1 \\ -1 & j & -1 \\ j & j & -j \\ -j & 1 & j \\ j & -j & -j \\ -j & -1 & j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -1 & 1 & -1 \\ 1 & 1 & 1 \\ -1 & 1 & -1 \\ 1 & 1 & -1 \\ -1 & 1 & 1 \\ 1 & 1 & -1 \\ -1 & 1 & 1\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -1 & 1 & -1 \\ 1 & 1 & 1 \\ -1 & 1 & -1 \\ j & j & -j \\ -j & j & j \\ j & j & -j \\ -j & j & j\end{bmatrix}$
16 – 19	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -1 & j & -1 \\ 1 & -1 & 1 \\ -1 & -j & -1 \\ 1 & 1 & -1 \\ -1 & j & 1 \\ 1 & -1 & -1 \\ -1 & -j & 1\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -1 & j & -1 \\ 1 & -1 & 1 \\ -1 & -j & -1 \\ j & j & -j \\ -j & -1 & j \\ j & -j & -j \\ -j & 1 & j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -j & 1 & -j \\ -1 & 1 & -1 \\ j & 1 & j \\ 1 & 1 & -1 \\ -j & 1 & j \\ -1 & 1 & 1 \\ j & 1 & -j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -j & 1 & -j \\ -1 & 1 & -1 \\ j & 1 & j \\ j & j & -j \\ 1 & j & -1 \\ -j & j & j \\ -1 & j & 1\end{bmatrix}$
20 – 23	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -j & j & -j \\ -1 & -1 & -1 \\ j & -j & j \\ 1 & 1 & -1 \\ -j & j & j \\ -1 & -1 & 1 \\ j & -j & -j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -j & j & -j \\ -1 & -1 & -1 \\ j & -j & j \\ j & j & -j \\ 1 & -1 & -1 \\ -j & -j & j \\ -1 & 1 & 1\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -j & -1 & -j \\ -1 & 1 & -1 \\ j & -1 & j \\ 1 & 1 & -1 \\ -j & -1 & j \\ -1 & 1 & 1 \\ j & -1 & -j\end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix}1 & 1 & 1 \\ -j & -1 & -j \\ -1 & 1 & -1 \\ j & -1 & j \\ j & j & -j \\ 1 & -j & -1 \\ -j & j & j \\ -1 & -j & 1\end{bmatrix}$

Table 6.3.1.5-12: Intermediate precoding matrix W' for *codebook1=ng1n4n1* and four-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&j&1&j\\1&-1&1&-1\\1&-j&1&-j\\1&1&-1&-1\\1&j&-1&-j\\1&-1&-1&1\\1&-j&-1&j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&j&1&j\\1&-1&1&-1\\1&-j&1&-j\\j&j&-j&-j\\j&-1&-j&1\\j&-j&-j&j\\j&1&-j&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&1&1&1\\1&-1&1&-1\\1&1&-1&-1\\1&-1&-1&1\\1&1&-1&-1\\1&-1&-1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&1&1&1\\1&-1&1&-1\\j&j&-j&-j\\j&-j&-j&j\\j&j&-j&-j\\j&-j&-j&j\end{bmatrix}$
4 – 7	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-j&1&-j\\1&-1&1&-1\\1&j&1&j\\1&1&-1&-1\\1&-j&-1&j\\1&-1&-1&1\\1&j&-1&-j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-j&1&-j\\1&-1&1&-1\\1&j&1&j\\j&j&-j&-j\\j&1&-j&-1\\j&-j&-j&j\\j&-1&-j&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\j&-1&j&-1\\-1&1&-1&1\\-j&-1&-j&-1\\1&1&-1&-1\\j&-1&-j&1\\-1&1&1&-1\\-j&-1&j&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\j&-1&j&-1\\-1&1&-1&1\\-j&-1&-j&-1\\j&j&-j&-j\\-1&-j&1&j\\-j&j&j&-j\\1&-j&-1&j\end{bmatrix}$
8 – 11	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\j&-j&j&-j\\-1&-1&-1&-1\\-j&j&-j&j\\1&1&-1&-1\\j&-j&-j&j\\-1&-1&1&1\\-j&j&j&-j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\j&-j&j&-j\\-1&-1&-1&-1\\-j&j&-j&j\\j&j&-j&-j\\-1&1&1&-1\\-j&-j&j&j\\1&-1&-1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\j&1&j&1\\-1&1&-1&1\\-j&1&-j&1\\1&1&-1&-1\\j&1&-j&-1\\-1&1&1&-1\\-j&1&j&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\j&1&j&1\\-1&1&-1&1\\-j&1&-j&1\\j&j&-j&-j\\-1&j&1&-j\\-j&j&j&-j\\1&j&-1&-j\end{bmatrix}$
12 – 15	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&-j&-1&-j\\1&-1&1&-1\\-1&j&-1&j\\1&1&-1&-1\\-1&-j&1&j\\1&-1&-1&1\\-1&j&1&-j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&-j&-1&-j\\1&-1&1&-1\\-1&j&-1&j\\j&j&-j&-j\\-j&1&j&-1\\j&-j&-j&j\\-j&-1&j&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\1&1&1&1\\-1&1&-1&1\\1&1&-1&1\\-1&1&1&1\\1&1&-1&1\\-1&1&1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\1&1&1&1\\-1&1&-1&1\\j&j&-j&-j\\-j&j&j&-j\\j&j&-j&-j\\-j&j&j&-j\end{bmatrix}$
16 – 19	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&j&-1&j\\1&-1&1&-1\\-1&-j&-1&-j\\1&1&-1&-1\\-1&j&1&-j\\1&-1&-1&1\\-1&-j&1&j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&j&-1&j\\1&-1&1&-1\\-1&-j&-1&-j\\j&j&-j&-j\\-j&-1&j&1\\j&-j&-j&j\\-j&1&j&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-j&1&-j&1\\-1&1&-1&1\\j&1&j&1\\1&1&-1&-1\\-j&1&j&-1\\-1&1&1&-1\\j&1&-j&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-j&1&-j&1\\-1&1&-1&1\\j&1&j&1\\j&j&-j&-j\\1&j&-1&-j\\-j&j&j&-j\\-1&j&1&-j\end{bmatrix}$
20 – 23	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-j&j&-j&j\\-1&-1&-1&-1\\j&-j&j&-j\\1&1&-1&-1\\-j&j&j&-j\\-1&-1&1&1\\j&-j&-j&j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-j&j&-j&j\\-1&-1&-1&-1\\j&-j&j&-j\\j&j&-j&-j\\1&-1&-1&1\\-j&-j&j&j\\-1&1&1&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-j&-1&-j&-1\\-1&1&-1&1\\j&-1&j&-1\\1&1&-1&-1\\-j&-1&j&1\\-1&1&1&-1\\j&-1&-j&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-j&-1&-j&-1\\-1&1&-1&1\\j&-1&j&-1\\j&j&-j&-j\\1&-j&-1&j\\-j&j&j&-j\\-1&-j&1&j\end{bmatrix}$

Table 6.3.1.5-13: Intermediate precoding matrix W' for *codebook1=ng1n4n1* and five-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	**Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)**	
0 – 1	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & j & -1 \\ 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & -j & -j & -1 \\ 1 & -1 & 1 & -1 & 1 \\ 1 & -1 & j & -j & -1 \\ 1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -j & j & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & j & -1 \\ 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & -j & -j & -1 \\ j & -j & 1 & -1 & 1 \\ j & -j & j & -j & -1 \\ j & -j & -1 & 1 & 1 \\ j & -j & -j & j & -1 \end{bmatrix}$
2 – 3	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ j & j & -1 & -1 & -j \\ -1 & -1 & 1 & 1 & -1 \\ -j & -j & -1 & -1 & j \\ 1 & -1 & 1 & -1 & 1 \\ j & -j & -1 & 1 & -j \\ -1 & 1 & 1 & -1 & -1 \\ -j & j & -1 & 1 & j \end{bmatrix}$	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ j & j & -1 & -1 & -j \\ -1 & -1 & 1 & 1 & -1 \\ -j & -j & -1 & -1 & j \\ j & -j & 1 & -1 & 1 \\ -1 & 1 & -1 & 1 & -j \\ -j & j & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & j \end{bmatrix}$
4 – 5	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -j & -j & 1 \\ 1 & 1 & -1 & -1 & 1 \\ -1 & -1 & j & j & 1 \\ 1 & -1 & 1 & -1 & 1 \\ -1 & 1 & -j & j & 1 \\ 1 & -1 & -1 & 1 & 1 \\ -1 & 1 & j & -j & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -j & -j & 1 \\ 1 & 1 & -1 & -1 & 1 \\ -1 & -1 & j & j & 1 \\ j & -j & 1 & -1 & 1 \\ -j & j & -j & j & 1 \\ j & -j & -1 & 1 & 1 \\ -j & j & j & -j & 1 \end{bmatrix}$
6 – 7	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -j & -j & 1 & 1 & j \\ -1 & -1 & 1 & 1 & -1 \\ j & j & 1 & 1 & -j \\ 1 & -1 & 1 & -1 & 1 \\ -j & j & 1 & -1 & j \\ -1 & 1 & 1 & -1 & -1 \\ j & -j & 1 & -1 & -j \end{bmatrix}$	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -j & -j & 1 & 1 & j \\ -1 & -1 & 1 & 1 & -1 \\ j & j & 1 & 1 & -j \\ j & -j & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 & j \\ -j & j & 1 & -1 & -1 \\ -1 & 1 & 1 & -1 & -j \end{bmatrix}$

Table 6.3.1.5-14: Intermediate precoding matrix W' for *codebook1=ng1n4n1* and six-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)	
0 – 1	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & j & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -j & -j & -1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & j & -j & -1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 \\ 1 & -1 & -j & j & -1 & 1 \end{bmatrix}$	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & j & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -j & -j & -1 & -1 \\ j & -j & j & -j & 1 & -1 \\ j & -j & -1 & 1 & -1 & 1 \\ j & -j & -j & j & 1 & -1 \\ j & -j & 1 & -1 & -1 & 1 \end{bmatrix}$
2 – 3	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ j & j & -1 & -1 & -j & -j \\ -1 & -1 & 1 & 1 & -1 & -1 \\ -j & -j & -1 & -1 & j & j \\ 1 & -1 & 1 & -1 & 1 & -1 \\ j & -j & -1 & 1 & -j & j \\ -1 & 1 & 1 & -1 & -1 & 1 \\ -j & j & -1 & 1 & j & -j \end{bmatrix}$	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ j & j & -1 & -1 & -j & -j \\ -1 & -1 & 1 & 1 & -1 & -1 \\ -j & -j & -1 & -1 & j & j \\ j & -j & j & -j & 1 & -1 \\ -1 & 1 & -j & j & -j & j \\ -j & j & j & -j & -1 & 1 \\ 1 & -1 & -j & j & j & -j \end{bmatrix}$
4 – 5	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -j & -j & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 \\ -1 & -1 & j & j & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 1 & -j & j & 1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 \\ -1 & 1 & j & -j & 1 & -1 \end{bmatrix}$	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -j & -j & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 \\ -1 & -1 & j & j & 1 & 1 \\ j & -j & j & -j & 1 & -1 \\ -j & j & 1 & -1 & 1 & -1 \\ j & -j & -j & j & 1 & -1 \\ -j & j & -1 & 1 & 1 & -1 \end{bmatrix}$
6 – 7	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -j & -j & 1 & 1 & j & j \\ -1 & -1 & 1 & 1 & -1 & -1 \\ j & j & 1 & 1 & -j & -j \\ 1 & -1 & 1 & -1 & 1 & -1 \\ -j & j & 1 & -1 & j & -j \\ -1 & 1 & 1 & -1 & -1 & 1 \\ j & -j & 1 & -1 & -j & j \end{bmatrix}$	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -j & -j & 1 & 1 & j & j \\ -1 & -1 & 1 & 1 & -1 & -1 \\ j & j & 1 & 1 & -j & -j \\ j & -j & j & -j & 1 & -1 \\ 1 & -1 & j & -j & j & -j \\ -j & j & j & -j & -1 & 1 \\ -1 & 1 & j & -j & -j & j \end{bmatrix}$

Table 6.3.1.5-15: Intermediate precoding matrix W' for *codebook1=ng1n4n1* and seven-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)	
0 – 1	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & -1 & -1 & -j & -j \\ 1 & 1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -j & -1 & -1 & j & j \\ 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ 1 & -1 & j & -1 & 1 & -j & j \\ 1 & -1 & -1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -j & -1 & 1 & j & -j \end{bmatrix}$	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & -1 & -1 & -j & -j \\ 1 & 1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -j & -1 & -1 & j & j \\ j & -j & j & 1 & -1 & 1 & -1 \\ j & -j & -1 & -1 & 1 & -j & j \\ j & -j & -j & 1 & -1 & -1 & 1 \\ j & -j & 1 & -1 & 1 & j & -j \end{bmatrix}$
2 – 3	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ j & j & -1 & -j & -j & 1 & 1 \\ -1 & -1 & 1 & -1 & -1 & 1 & 1 \\ -j & -j & -1 & j & j & 1 & 1 \\ 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ j & -j & -1 & -j & j & 1 & -1 \\ -1 & 1 & 1 & -1 & 1 & 1 & -1 \\ -j & j & -1 & j & -j & 1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ j & j & -1 & -j & -j & 1 & 1 \\ -1 & -1 & 1 & -1 & -1 & 1 & 1 \\ -j & -j & -1 & j & j & 1 & 1 \\ j & -j & j & 1 & -1 & 1 & -1 \\ -1 & 1 & -j & -j & j & 1 & -1 \\ -j & j & j & -1 & 1 & 1 & -1 \\ 1 & -1 & -j & j & -j & 1 & -1 \end{bmatrix}$

Table 6.3.1.5-16: Intermediate precoding matrix W' for *codebook1=ng1n4n1* and eight-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)	
0 – 1	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & j & -1 & -1 & -j & -j \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -j & -j & -1 & -1 & j & j \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & j & -j & -1 & 1 & -j & j \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -j & j & -1 & 1 & j & -j \end{bmatrix}$	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & j & -1 & -1 & -j & -j \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -j & -j & -1 & -1 & j & j \\ j & -j & j & -j & 1 & -1 & 1 & -1 \\ j & -j & -1 & 1 & -1 & 1 & -j & j \\ j & -j & -j & j & 1 & -1 & -1 & 1 \\ j & -j & 1 & -1 & -1 & 1 & j & -j \end{bmatrix}$
2 – 3	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ j & j & -1 & -1 & -j & -j & 1 & 1 \\ -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 \\ -j & -j & -1 & -1 & j & j & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ j & -j & -1 & 1 & -j & j & 1 & -1 \\ -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 \\ -j & j & -1 & 1 & j & -j & 1 & -1 \end{bmatrix}$	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ j & j & -1 & -1 & -j & -j & 1 & 1 \\ -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 \\ -j & -j & -1 & -1 & j & j & 1 & 1 \\ j & -j & j & -j & 1 & -1 & 1 & -1 \\ -1 & 1 & -j & j & -j & j & 1 & -1 \\ -j & j & j & -j & -1 & 1 & 1 & -1 \\ 1 & -1 & -j & j & j & -j & 1 & -1 \end{bmatrix}$

Table 6.3.1.5-17: Intermediate precoding matrix W' for *codebook1=ng1n2n2* and single-layer transmission using eight antenna ports.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)							
0 – 7	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ j \\ j \\ j \\ j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ -1 \\ -1 \\ -1 \\ -1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ -j \\ -j \\ -j \\ -j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ -1 \\ 1 \\ -1 \\ 1 \\ -1 \\ 1 \\ -1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ -1 \\ 1 \\ -1 \\ j \\ -j \\ j \\ -j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ -1 \\ 1 \\ -1 \\ -1 \\ 1 \\ -1 \\ 1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ -1 \\ 1 \\ -1 \\ -j \\ j \\ -j \\ j \end{bmatrix}$
8 – 15	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ -1 \\ -1 \\ 1 \\ 1 \\ -1 \\ -1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ -1 \\ -1 \\ j \\ j \\ -j \\ -j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ -1 \\ -1 \\ -1 \\ -1 \\ 1 \\ 1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ -1 \\ -1 \\ -j \\ -j \\ j \\ j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ -1 \\ -1 \\ 1 \\ 1 \\ -1 \\ -1 \\ 1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ -1 \\ -1 \\ 1 \\ j \\ -j \\ -j \\ j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ -1 \\ -1 \\ 1 \\ -1 \\ 1 \\ 1 \\ -1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ -1 \\ -1 \\ 1 \\ -j \\ j \\ j \\ -j \end{bmatrix}$

Table 6.3.1.5-18: Intermediate precoding matrix W' for *codebook1=ng1n2n2* and two-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)							
0 – 7	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 1 \\ 1 & 1 \\ 1 & -1 \\ 1 & -1 \\ 1 & -1 \\ 1 & -1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 1 \\ 1 & 1 \\ j & -j \\ j & -j \\ j & -j \\ j & -j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & -1 \\ 1 & -1 \\ 1 & -1 \\ 1 & -1 \\ 1 & 1 \\ 1 & 1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & -1 \\ 1 & -1 \\ j & -j \\ j & -j \\ j & j \\ j & j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & -1 \\ 1 & 1 \\ 1 & -1 \\ 1 & -1 \\ 1 & 1 \\ 1 & -1 \\ 1 & 1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & -1 \\ 1 & 1 \\ 1 & -1 \\ j & -j \\ j & j \\ j & -j \\ j & j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & -1 \\ 1 & -1 \\ 1 & 1 \\ 1 & -1 \\ 1 & 1 \\ 1 & 1 \\ 1 & -1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & -1 \\ 1 & -1 \\ 1 & 1 \\ j & -j \\ j & j \\ j & j \\ j & -j \end{bmatrix}$
8 – 15	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ 1 & 1 \\ -1 & -1 \\ 1 & -1 \\ -1 & 1 \\ 1 & -1 \\ -1 & 1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ 1 & 1 \\ -1 & -1 \\ j & -j \\ -j & j \\ j & -j \\ -j & j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ 1 & -1 \\ -1 & 1 \\ 1 & -1 \\ -1 & 1 \\ 1 & 1 \\ -1 & -1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ 1 & -1 \\ -1 & 1 \\ j & -j \\ -j & j \\ j & j \\ -j & -j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & 1 \\ 1 & 1 \\ -1 & 1 \\ 1 & -1 \\ -1 & -1 \\ 1 & -1 \\ -1 & -1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & 1 \\ 1 & 1 \\ -1 & 1 \\ j & -j \\ -j & -j \\ j & -j \\ -j & -j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & 1 \\ 1 & -1 \\ -1 & -1 \\ 1 & -1 \\ -1 & -1 \\ 1 & 1 \\ -1 & 1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & 1 \\ 1 & -1 \\ -1 & -1 \\ j & -j \\ -j & -j \\ j & j \\ -j & j \end{bmatrix}$
16 – 23	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ -1 & -1 \\ -1 & -1 \\ 1 & -1 \\ 1 & -1 \\ -1 & 1 \\ -1 & 1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ -1 & -1 \\ -1 & -1 \\ j & -j \\ j & -j \\ -j & j \\ -j & j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ -1 & 1 \\ -1 & 1 \\ 1 & -1 \\ 1 & -1 \\ -1 & -1 \\ -1 & -1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ -1 & 1 \\ -1 & 1 \\ j & -j \\ j & -j \\ -j & -j \\ -j & -j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & -1 \\ -1 & -1 \\ -1 & 1 \\ 1 & -1 \\ 1 & 1 \\ -1 & 1 \\ -1 & -1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & -1 \\ -1 & -1 \\ -1 & 1 \\ j & -j \\ j & j \\ -j & j \\ -j & -j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & -1 \\ -1 & 1 \\ -1 & -1 \\ 1 & -1 \\ 1 & 1 \\ -1 & -1 \\ -1 & 1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ 1 & -1 \\ -1 & 1 \\ -1 & -1 \\ j & -j \\ j & j \\ -j & -j \\ -j & j \end{bmatrix}$
24 – 31	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ -1 & -1 \\ 1 & 1 \\ 1 & -1 \\ -1 & 1 \\ -1 & 1 \\ 1 & -1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ -1 & -1 \\ 1 & 1 \\ j & -j \\ -j & j \\ -j & j \\ j & -j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ -1 & 1 \\ 1 & -1 \\ 1 & -1 \\ -1 & 1 \\ -1 & -1 \\ 1 & 1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ -1 & 1 \\ 1 & -1 \\ j & -j \\ -j & j \\ -j & -j \\ j & j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & 1 \\ -1 & -1 \\ 1 & -1 \\ 1 & -1 \\ -1 & -1 \\ -1 & 1 \\ 1 & 1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & 1 \\ -1 & -1 \\ 1 & -1 \\ j & -j \\ -j & -j \\ -j & j \\ j & j \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & 1 \\ -1 & 1 \\ 1 & 1 \\ 1 & -1 \\ -1 & -1 \\ -1 & -1 \\ 1 & -1 \end{bmatrix}$	$\frac{1}{4}\begin{bmatrix} 1 & 1 \\ -1 & 1 \\ -1 & 1 \\ 1 & 1 \\ j & -j \\ -j & -j \\ -j & -j \\ j & -j \end{bmatrix}$

Table 6.3.1.5-19: Intermediate precoding matrix W' for *codebook1=ng1n2n2* and three-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & -1 \\ 1 & 1 & -1 \\ 1 & -1 & -1 \\ 1 & -1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & -1 & 1 \\ j & j & -j \\ j & j & -j \\ j & -j & -j \\ j & -j & -j \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & -1 \\ 1 & -1 & -1 \\ 1 & 1 & -1 \\ 1 & -1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & 1 \\ 1 & -1 & 1 \\ j & j & -j \\ j & -j & -j \\ j & j & -j \\ j & -j & -j \end{bmatrix}$
4 – 7	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & -1 \\ 1 & -1 & -1 \\ 1 & -1 & -1 \\ 1 & 1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ 1 & -1 & 1 \\ 1 & 1 & 1 \\ j & j & -j \\ j & -j & -j \\ j & -j & -j \\ j & j & -j \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & -1 & -1 \\ 1 & -1 & 1 \\ -1 & 1 & -1 \\ 1 & 1 & -1 \\ -1 & -1 & 1 \\ 1 & -1 & -1 \\ -1 & 1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & -1 & -1 \\ 1 & -1 & 1 \\ -1 & 1 & -1 \\ j & j & -j \\ -j & -j & j \\ j & -j & -j \\ -j & j & j \end{bmatrix}$
8 – 11	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & 1 & -1 \\ 1 & 1 & 1 \\ -1 & 1 & -1 \\ 1 & 1 & -1 \\ -1 & 1 & 1 \\ 1 & 1 & -1 \\ -1 & 1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & 1 & -1 \\ 1 & 1 & 1 \\ -1 & 1 & -1 \\ j & j & -j \\ -j & j & j \\ j & j & -j \\ -j & j & j \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & 1 & -1 \\ 1 & -1 & 1 \\ -1 & -1 & -1 \\ 1 & 1 & -1 \\ -1 & 1 & 1 \\ 1 & -1 & -1 \\ -1 & -1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & 1 & -1 \\ 1 & -1 & 1 \\ -1 & -1 & -1 \\ j & j & -j \\ -j & j & j \\ j & -j & -j \\ -j & -j & j \end{bmatrix}$
12 – 15	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ -1 & 1 & -1 \\ -1 & 1 & -1 \\ 1 & 1 & -1 \\ 1 & 1 & -1 \\ -1 & 1 & 1 \\ -1 & 1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ -1 & 1 & -1 \\ -1 & 1 & -1 \\ j & j & -j \\ j & j & -j \\ -j & j & j \\ -j & j & j \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ -1 & -1 & -1 \\ -1 & 1 & -1 \\ 1 & 1 & -1 \\ 1 & -1 & -1 \\ -1 & -1 & 1 \\ -1 & 1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ -1 & -1 & -1 \\ -1 & 1 & -1 \\ j & j & -j \\ j & -j & -j \\ -j & -j & j \\ -j & j & j \end{bmatrix}$
16 – 19	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ -1 & 1 & -1 \\ -1 & -1 & -1 \\ 1 & 1 & -1 \\ 1 & -1 & -1 \\ -1 & 1 & 1 \\ -1 & -1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 1 \\ -1 & 1 & -1 \\ -1 & -1 & -1 \\ j & j & -j \\ j & -j & -j \\ -j & j & -j \\ -j & -j & j \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & -1 & -1 \\ -1 & 1 & -1 \\ 1 & -1 & 1 \\ 1 & 1 & -1 \\ -1 & -1 & 1 \\ -1 & 1 & 1 \\ 1 & -1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & -1 & -1 \\ -1 & 1 & -1 \\ 1 & -1 & 1 \\ j & j & -j \\ -j & -j & j \\ -j & j & j \\ j & -j & -j \end{bmatrix}$
20 – 23	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & 1 & -1 \\ -1 & -1 & -1 \\ 1 & -1 & 1 \\ 1 & 1 & -1 \\ -1 & 1 & 1 \\ -1 & -1 & 1 \\ 1 & -1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & 1 & -1 \\ -1 & -1 & -1 \\ 1 & -1 & 1 \\ j & j & -j \\ -j & j & j \\ -j & -j & j \\ j & -j & -j \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & 1 & -1 \\ -1 & 1 & -1 \\ 1 & 1 & 1 \\ 1 & 1 & -1 \\ -1 & 1 & 1 \\ -1 & 1 & 1 \\ 1 & 1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{6}}\begin{bmatrix} 1 & 1 & 1 \\ -1 & 1 & -1 \\ -1 & 1 & -1 \\ 1 & 1 & 1 \\ j & j & -j \\ -j & j & j \\ -j & j & j \\ j & j & -j \end{bmatrix}$

Table 6.3.1.5-20: Intermediate precoding matrix W' for *codebook1=ng1n2n2* and four-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&1&1&1\\1&-1&1&-1\\1&-1&1&-1\\1&1&-1&-1\\1&1&-1&-1\\1&-1&-1&1\\1&-1&-1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&1&1&1\\1&-1&1&-1\\1&-1&1&-1\\j&j&-j&-j\\j&j&-j&-j\\j&-j&-j&j\\j&-j&-j&j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&1&1&1\\1&-1&1&-1\\1&1&-1&-1\\1&-1&-1&1\\1&1&-1&-1\\1&-1&-1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&1&1&1\\1&-1&1&-1\\j&j&-j&-j\\j&-j&-j&j\\j&j&-j&-j\\j&-j&-j&j\end{bmatrix}$
4 – 7	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&-1&1&-1\\1&1&1&1\\1&1&-1&-1\\1&-1&-1&1\\1&-1&-1&1\\1&1&-1&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&-1&1&-1\\1&1&1&1\\j&j&-j&-j\\j&-j&-j&j\\j&-j&-j&j\\j&j&-j&-j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&-1&-1&-1\\1&-1&1&-1\\-1&1&-1&1\\1&1&-1&-1\\-1&-1&1&1\\1&-1&-1&1\\-1&1&1&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&-1&-1&-1\\1&-1&1&-1\\-1&1&-1&1\\j&j&-j&-j\\-j&-j&j&j\\j&-j&-j&j\\-j&j&j&-j\end{bmatrix}$
8 – 11	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\1&1&1&1\\-1&1&-1&1\\1&1&-1&-1\\-1&1&1&-1\\1&1&-1&-1\\-1&1&1&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\1&1&1&1\\-1&1&-1&1\\j&j&-j&-j\\-j&j&j&-j\\j&j&-j&-j\\-j&j&j&-j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\1&-1&1&-1\\-1&-1&-1&-1\\1&1&-1&-1\\-1&1&1&-1\\1&-1&-1&1\\-1&-1&1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\1&-1&1&-1\\-1&-1&-1&-1\\j&j&-j&-j\\-j&j&j&-j\\j&-j&-j&j\\-j&-j&j&j\end{bmatrix}$
12 – 15	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&1&1&1\\-1&1&-1&1\\-1&1&-1&1\\1&1&-1&-1\\1&1&-1&-1\\-1&1&1&-1\\-1&1&1&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&1&1&1\\-1&1&-1&1\\-1&1&-1&1\\j&j&-j&-j\\j&j&-j&-j\\-j&j&j&-j\\-j&j&j&-j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\-1&-1&-1&-1\\-1&1&-1&1\\1&1&-1&-1\\1&-1&-1&1\\-1&-1&1&1\\-1&1&1&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\-1&-1&-1&-1\\-1&1&-1&1\\j&j&-j&-j\\j&-j&-j&j\\-j&-j&j&j\\-j&j&j&-j\end{bmatrix}$
16 – 19	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\-1&1&-1&1\\-1&-1&-1&-1\\1&1&-1&-1\\1&-1&-1&1\\-1&1&1&-1\\-1&-1&1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\-1&1&-1&1\\-1&-1&-1&-1\\j&j&-j&-j\\j&-j&-j&j\\-j&j&-j&-j\\-j&-j&j&j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&-1&-1&-1\\-1&1&-1&1\\1&-1&1&-1\\1&1&-1&-1\\-1&-1&1&1\\-1&1&1&-1\\1&-1&-1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&-1&-1&-1\\-1&1&-1&1\\1&-1&1&-1\\j&j&-j&-j\\-j&-j&j&j\\-j&j&j&-j\\j&-j&-j&j\end{bmatrix}$
20 – 23	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\-1&-1&-1&-1\\1&-1&1&-1\\1&1&-1&-1\\-1&1&1&-1\\-1&-1&1&1\\1&-1&-1&1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\-1&-1&-1&-1\\1&-1&1&-1\\j&j&-j&-j\\-j&j&j&-j\\-j&-j&j&j\\j&-j&-j&j\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\-1&1&-1&1\\1&1&1&1\\1&1&-1&-1\\-1&1&1&-1\\-1&1&1&-1\\1&1&-1&-1\end{bmatrix}$	$\frac{1}{4\sqrt{2}}\begin{bmatrix}1&1&1&1\\-1&1&-1&1\\-1&1&-1&1\\1&1&1&1\\j&j&-j&-j\\-j&j&j&-j\\-j&j&j&-j\\j&j&-j&-j\end{bmatrix}$

Table 6.3.1.5-21: Intermediate precoding matrix W' for *codebook1=ng1n2n2* and five-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)	
0 – 1	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 \\ 1 & 1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & -1 \\ 1 & -1 & -1 & 1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 \\ 1 & 1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 \\ j & -j & 1 & -1 & 1 \\ j & -j & 1 & -1 & -1 \\ j & -j & -1 & 1 & -1 \\ j & -j & -1 & 1 & 1 \end{bmatrix}$
2 – 3	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & -1 \\ 1 & -1 & 1 & -1 & 1 \\ -1 & 1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 \\ -1 & 1 & 1 & -1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & -1 \\ j & -j & 1 & -1 & 1 \\ -j & j & -1 & 1 & 1 \\ j & -j & -1 & 1 & -1 \\ -j & j & 1 & -1 & -1 \end{bmatrix}$
4 – 5	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 \\ -1 & -1 & 1 & 1 & 1 \\ -1 & -1 & 1 & 1 & -1 \\ 1 & -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 & -1 \\ -1 & 1 & 1 & -1 & 1 \\ -1 & 1 & 1 & -1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 \\ -1 & -1 & 1 & 1 & 1 \\ -1 & -1 & 1 & 1 & -1 \\ j & -j & 1 & -1 & 1 \\ j & -j & 1 & -1 & -1 \\ -j & j & 1 & -1 & 1 \\ -j & j & 1 & -1 & -1 \end{bmatrix}$
6 – 7	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 \\ -1 & -1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 \\ -1 & 1 & -1 & 1 & 1 \\ -1 & 1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{10}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 \\ -1 & -1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 \\ j & -j & 1 & -1 & 1 \\ -j & j & -1 & 1 & 1 \\ -j & j & 1 & -1 & 1 \\ j & -j & -1 & 1 & 1 \end{bmatrix}$

Table 6.3.1.5-22: Intermediate precoding matrix W' for *codebook1=ng1n2n2* and six-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)	
0 – 1	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 \end{bmatrix}$	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 \\ j & -j & j & -j & 1 & -1 \\ j & -j & j & -j & -1 & 1 \\ j & -j & -j & j & -1 & 1 \\ j & -j & -j & j & 1 & -1 \end{bmatrix}$
2 – 3	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 \\ -1 & 1 & 1 & -1 & -1 & 1 \end{bmatrix}$	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & -1 & -1 \\ j & -j & j & -j & 1 & -1 \\ -j & j & -j & j & 1 & -1 \\ j & -j & -j & j & -1 & 1 \\ -j & j & j & -j & -1 & 1 \end{bmatrix}$
4 – 5	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 \\ -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 & 1 & -1 \\ -1 & 1 & 1 & -1 & -1 & 1 \end{bmatrix}$	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 \\ -1 & -1 & 1 & 1 & -1 & -1 \\ j & -j & j & -j & 1 & -1 \\ j & -j & j & -j & -1 & 1 \\ -j & j & j & -j & 1 & -1 \\ -j & j & j & -j & -1 & 1 \end{bmatrix}$
6 – 7	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 & 1 & -1 \\ -1 & 1 & 1 & -1 & 1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 \end{bmatrix}$	$\frac{1}{4\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 \\ j & -j & j & -j & 1 & -1 \\ -j & j & -j & j & 1 & -1 \\ -j & j & j & -j & 1 & -1 \\ j & -j & -j & j & 1 & -1 \end{bmatrix}$

Table 6.3.1.5-23: Intermediate precoding matrix W' for *codebook1=ng1n2n2* and seven-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)	
0 – 1	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & -1 & 1 & 1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & 1 & 1 \\ j & -j & j & 1 & -1 & 1 & -1 \\ j & -j & j & -1 & 1 & -1 & 1 \\ j & -j & -j & 1 & -1 & -1 & 1 \\ j & -j & -j & -1 & 1 & 1 & -1 \end{bmatrix}$
2 – 3	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & -1 & 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & 1 & -1 & -1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & -1 & -1 \\ j & -j & j & 1 & -1 & 1 & -1 \\ -j & j & -j & 1 & -1 & 1 & -1 \\ j & -j & -j & 1 & -1 & -1 & 1 \\ -j & j & j & 1 & -1 & -1 & 1 \end{bmatrix}$
4 – 5	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & 1 & -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 \\ -1 & 1 & 1 & -1 & 1 & 1 & -1 \\ -1 & 1 & 1 & 1 & -1 & -1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & 1 & -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 & 1 & -1 & -1 \\ j & -j & j & 1 & -1 & 1 & -1 \\ j & -j & j & -1 & 1 & 1 & 1 \\ -j & j & j & -1 & 1 & -1 & -1 \\ -j & j & j & 1 & -1 & -1 & 1 \end{bmatrix}$
6 – 7	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ -1 & -1 & 1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -1 & -1 & -1 & 1 & 1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{14}}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ -1 & -1 & 1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & 1 & 1 \\ j & -j & j & 1 & -1 & 1 & -1 \\ -j & j & -j & 1 & -1 & 1 & -1 \\ -j & j & j & -1 & 1 & 1 & -1 \\ j & -j & -j & -1 & 1 & 1 & -1 \end{bmatrix}$

Table 6.3.1.5-24: Intermediate precoding matrix W' for *codebook1=ng1n2n2* and eight-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index	Intermediate precoder matrix W' (ordered from left to right in increasing order of TPMI index)	
0 – 1	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ j & -j & j & -j & 1 & -1 & 1 & -1 \\ j & -j & j & -j & -1 & 1 & -1 & 1 \\ j & -j & -j & j & 1 & -1 & -1 & 1 \\ j & -j & -j & j & -1 & 1 & 1 & -1 \end{bmatrix}$
2 – 3	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 \end{bmatrix}$	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\ j & -j & j & -j & 1 & -1 & 1 & -1 \\ -j & j & -j & j & 1 & -1 & 1 & -1 \\ j & -j & -j & j & 1 & -1 & -1 & 1 \\ -j & j & j & -j & 1 & -1 & -1 & 1 \end{bmatrix}$
4 – 5	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 \\ -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 \end{bmatrix}$	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 \\ -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\ j & -j & j & -j & 1 & -1 & 1 & -1 \\ j & -j & j & -j & -1 & 1 & 1 & 1 \\ -j & j & j & -j & -1 & 1 & -1 & -1 \\ -j & j & j & -j & 1 & -1 & -1 & 1 \end{bmatrix}$
6 – 7	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 \\ -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$	$\frac{1}{8}\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 \\ -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ j & -j & j & -j & 1 & -1 & 1 & -1 \\ -j & j & -j & j & 1 & -1 & 1 & -1 \\ -j & j & j & -j & -1 & 1 & 1 & -1 \\ j & -j & -j & j & -1 & 1 & 1 & -1 \end{bmatrix}$

Table 6.3.1.5-25: Submatrices $\overline{W}_{1,i}$ for *codebook2* and used in Tables 6.3.1.5-29 to 6.3.1.5-31.

i	$\overline{\boldsymbol{W}}_{\mathbf{1},i}$ (ordered from left to right in increasing order of i)							
0 – 7	$\frac{1}{2}\begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ 1 \\ j \\ j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ 1 \\ -1 \\ -1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ 1 \\ -j \\ -j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ j \\ 1 \\ j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ j \\ j \\ -1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ j \\ -1 \\ -j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ j \\ -j \\ 1 \end{bmatrix}$
8 – 15	$\frac{1}{2}\begin{bmatrix} 1 \\ -1 \\ 1 \\ -1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ -1 \\ j \\ -j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ -1 \\ -1 \\ 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ -1 \\ -j \\ j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ -j \\ 1 \\ -j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ -j \\ j \\ 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ -j \\ -1 \\ j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 \\ -j \\ -j \\ -1 \end{bmatrix}$

Table 6.3.1.5-26: Submatrices $\overline{W}_{2,i}$ for *codebook2* and used in Tables 6.3.1.5-30 to 6.3.1.5-33.

i	$\overline{\boldsymbol{W}}_{2,i}$ (ordered from left to right in increasing order of i)			
0 – 3	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & -1 \\ 1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & 1 \\ j & -j \\ j & -j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 1 \\ j & j \\ 1 & -1 \\ j & -j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 1 \\ j & j \\ j & -j \\ -1 & 1 \end{bmatrix}$
4 – 7	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ 1 & -1 \\ -1 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 1 \\ -1 & -1 \\ j & -j \\ -j & j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 1 \\ -j & -j \\ 1 & -1 \\ -j & -j \end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 1 \\ -j & -j \\ j & -j \\ 1 & -1 \end{bmatrix}$

Table 6.3.1.5-27: Submatrices $\overline{W}_{3,i}$ for *codebook2* and used in Tables 6.3.1.5-31, 6.3.1.5-33, 6.3.1.5-34, and 6.3.1.5-35.

$\boldsymbol{i}$	$\overline{\boldsymbol{W}}_{3,i}$ (ordered from left to right in increasing order of $\boldsymbol{i}$)			
0 – 3	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1 & 1 & 1\\ 1 & -1 & 1\\ 1 & 1 & -1\\ 1 & -1 & -1\end{bmatrix}$	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1 & 1 & 1\\ 1 & -1 & 1\\ j & j & -j\\ j & -j & -j\end{bmatrix}$	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1 & 1 & 1\\ -1 & 1 & -1\\ 1 & 1 & -1\\ -1 & 1 & 1\end{bmatrix}$	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1 & 1 & 1\\ -1 & 1 & -1\\ j & j & -j\\ -j & j & j\end{bmatrix}$

Table 6.3.1.5-28: Submatrices $\overline{W}_{4,i}$ for *codebook2* and used in Tables 6.3.1.5-32, 6.3.1.5-35, and 6.3.1.5-36.

$\boldsymbol{i}$	$\overline{\boldsymbol{W}}_{4,i}$ **(ordered from left to right in increasing order of $\boldsymbol{i}$)**	
0 – 1	$\frac{1}{4}\begin{bmatrix}1 & 1 & 1 & 1\\ 1 & -1 & 1 & -1\\ 1 & 1 & -1 & -1\\ 1 & -1 & -1 & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1 & 1 & 1\\ 1 & -1 & 1 & -1\\ j & j & -j & -j\\ j & -j & -j & j\end{bmatrix}$

Table 6.3.1.5-29: Intermediate precoding matrix W' for *codebook2* and single-layer transmission using eight antenna ports.

TPMI index $\boldsymbol{i}$	Intermediate precoder matrix $\boldsymbol{W'}$
0 – 15	$\frac{1}{\sqrt{2}}\begin{bmatrix}\overline{W}_{1,i}\\ 0_{4\times 1}\end{bmatrix}$
16 – 31	$\frac{1}{\sqrt{2}}\begin{bmatrix}0_{4\times 1}\\ \overline{W}_{1,(i-16)}\end{bmatrix}$
32	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\end{bmatrix}$

Table 6.3.1.5-30: Intermediate precoding matrix W' for *codebook2* and two-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index $\boldsymbol{i}$	Intermediate precoder matrix $\boldsymbol{W'}$
0 – 7	$\frac{1}{\sqrt{2}}\begin{bmatrix}\overline{W}_{2,i}\\ 0_{4\times 2}\end{bmatrix}$
8 – 15	$\frac{1}{\sqrt{2}}\begin{bmatrix}0_{4\times 2}\\ \overline{W}_{2,(i-8)}\end{bmatrix}$
16 – 271	$\frac{1}{\sqrt{2}}\begin{bmatrix}\overline{W}_{1,\lfloor (i-16)/16\rfloor} & 0_{4\times 1}\\ 0_{4\times 1} & \overline{W}_{1,(i \bmod 16)}\end{bmatrix}$

Table 6.3.1.5-31: Intermediate precoding matrix W' for *codebook2* and three-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 3	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{3,i}\\0_{4\times3}\end{bmatrix}$
4 – 7	$\frac{1}{\sqrt{2}}\begin{bmatrix}0_{4\times3}\\\bar{W}_{3,(i-4)}\end{bmatrix}$
8 – 135	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{1,\lfloor(i-8)/8\rfloor} & 0_{4\times2}\\0_{4\times1} & \bar{W}_{2,(i \bmod 8)}\end{bmatrix}$
136 – 263	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{2,\lfloor(i-136)/16\rfloor} & 0_{4\times1}\\0_{4\times2} & \bar{W}_{1,((i-136) \bmod 16)}\end{bmatrix}$

Table 6.3.1.5-32: Intermediate precoding matrix W' for *codebook2* and four-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 1	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{4,i}\\0_{4\times4}\end{bmatrix}$
2 – 3	$\frac{1}{\sqrt{2}}\begin{bmatrix}0_{4\times4}\\\bar{W}_{4,(i-2)}\end{bmatrix}$
4 – 67	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{2,\lfloor(i-4)/8\rfloor} & 0_{4\times2}\\0_{4\times2} & \bar{W}_{2,((i-4) \bmod 8)}\end{bmatrix}$

Table 6.3.1.5-33: Intermediate precoding matrix W' for *codebook2* and five-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 31	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{2,\lfloor i/4\rfloor} & 0_{4\times3}\\0_{4\times2} & \bar{W}_{3,(i \bmod 4)}\end{bmatrix}$

Table 6.3.1.5-34: Intermediate precoding matrix W' for *codebook2* and six-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 15	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{3,\lfloor i/4\rfloor} & 0_{4\times3}\\0_{4\times3} & \bar{W}_{3,(i \bmod 4)}\end{bmatrix}$

Table 6.3.1.5-35: Intermediate precoding matrix W' for *codebook2* and seven-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 7	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{3,\lfloor i/2\rfloor} & \mathbf{0}_{4\times4}\\\mathbf{0}_{4\times3} & \bar{W}_{4,(i \bmod 2)}\end{bmatrix}$

Table 6.3.1.5-36: Intermediate precoding matrix W' for *codebook2* and eight-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 3	$\frac{1}{\sqrt{2}}\begin{bmatrix}\bar{W}_{4,\lfloor i/2\rfloor} & 0_{4\times4}\\0_{4\times4} & \bar{W}_{4,(i \bmod 2)}\end{bmatrix}$

Table 6.3.1.5-37: Submatrices $\overline{W}_{1,i}$ for *codebook3* and used in Tables 6.3.1.5-39 to 6.3.1.5-45.

i	$\boldsymbol{\overline{W}_{1,i}}$ **(ordered from left to right in increasing order of i)**			
0 – 3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$

Table 6.3.1.5-38: Submatrices $\overline{W}_{2,i}$ for *codebook3* and used in Tables 6.3.1.5-40 to 6.3.1.5-46.

i	$\boldsymbol{\overline{W}_{2,i}}$ **(ordered from left to right in increasing order of i)**	
0 – 1	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$

Table 6.3.1.5-39: Intermediate precoding matrix W' for *codebook3* and single-layer transmission using eight antenna ports.

TPMI index i	Intermediate precoder matrix W'
0 – 3	$\frac{1}{2}\begin{bmatrix}\overline{W}_{1,i}\\0_{2\times 1}\\0_{2\times 1}\\0_{2\times 1}\end{bmatrix}$
4 – 7	$\frac{1}{2}\begin{bmatrix}0_{2\times 1}\\\overline{W}_{1,(i-4)}\\0_{2\times 1}\\0_{2\times 1}\end{bmatrix}$
8 – 11	$\frac{1}{2}\begin{bmatrix}0_{2\times 1}\\0_{2\times 1}\\\overline{W}_{1,(i-8)}\\0_{2\times 1}\end{bmatrix}$
12 – 15	$\frac{1}{2}\begin{bmatrix}0_{2\times 1}\\0_{2\times 1}\\0_{2\times 1}\\\overline{W}_{1,(i-12)}\end{bmatrix}$
16	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1\\1\\1\\1\\1\\1\\1\\1\end{bmatrix}$

Table 6.3.1.5-40: Intermediate precoding matrix W' for *codebook3* and two-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	**Intermediate precoder matrix W'**
0 – 1	$\frac{1}{2}\begin{bmatrix} \overline{W}_{2,i} \\ 0_{2\times 2} \\ 0_{2\times 2} \\ 0_{2\times 2} \end{bmatrix}$
2 – 3	$\frac{1}{2}\begin{bmatrix} 0_{2\times 2} \\ \overline{W}_{2,(i-2)} \\ 0_{2\times 2} \\ 0_{2\times 2} \end{bmatrix}$
4 – 5	$\frac{1}{2}\begin{bmatrix} 0_{2\times 2} \\ 0_{2\times 2} \\ \overline{W}_{2,(i-4)} \\ 0_{2\times 2} \end{bmatrix}$
6 – 7	$\frac{1}{2}\begin{bmatrix} 0_{2\times 2} \\ 0_{2\times 2} \\ 0_{2\times 2} \\ \overline{W}_{2,(i-6)} \end{bmatrix}$
8 – 23	$\frac{1}{2}\begin{bmatrix} \overline{W}_{1,\lfloor (i-8)/4 \rfloor} & 0_{2\times 1} \\ 0_{2\times 1} & \overline{W}_{1,(i \bmod 4)} \\ 0_{2\times 1} & 0_{2\times 1} \\ 0_{2\times 1} & 0_{2\times 1} \end{bmatrix}$
24 – 39	$\frac{1}{2}\begin{bmatrix} \overline{W}_{1,\lfloor (i-24)/4 \rfloor} & 0_{2\times 1} \\ 0_{2\times 1} & 0_{2\times 1} \\ 0_{2\times 1} & \overline{W}_{1,(i \bmod 4)} \\ 0_{2\times 1} & 0_{2\times 1} \end{bmatrix}$
40 – 55	$\frac{1}{2}\begin{bmatrix} \overline{W}_{1,\lfloor (i-40)/4 \rfloor} & 0_{2\times 1} \\ 0_{2\times 1} & 0_{2\times 1} \\ 0_{2\times 1} & 0_{2\times 1} \\ 0_{2\times 1} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
56 – 71	$\frac{1}{2}\begin{bmatrix} 0_{2\times 1} & 0_{2\times 1} \\ \overline{W}_{1,\lfloor (i-56)/4 \rfloor} & 0_{2\times 1} \\ 0_{2\times 1} & \overline{W}_{1,(i \bmod 4)} \\ 0_{2\times 1} & 0_{2\times 1} \end{bmatrix}$
72 – 87	$\frac{1}{2}\begin{bmatrix} 0_{2\times 1} & 0_{2\times 1} \\ \overline{W}_{1,\lfloor (i-72)/4 \rfloor} & 0_{2\times 1} \\ 0_{2\times 1} & 0_{2\times 1} \\ 0_{2\times 1} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
88 – 103	$\frac{1}{2}\begin{bmatrix} 0_{2\times 1} & 0_{2\times 1} \\ 0_{2\times 1} & 0_{2\times 1} \\ \overline{W}_{1,\lfloor (i-88)/4 \rfloor} & 0_{2\times 1} \\ 0_{2\times 1} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
104	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}$

Table 6.3.1.5-41: Intermediate precoding matrix W' for *codebook3* and three-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 7	$\frac{1}{2}\begin{bmatrix} \overline{W}_{2,\lfloor i/4\rfloor} & 0_{2\times1} \\ 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \\ 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times1} \end{bmatrix}$
8 – 15	$\frac{1}{2}\begin{bmatrix} \overline{W}_{2,\lfloor (i-8)/4\rfloor} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \\ 0_{2\times2} & 0_{2\times1} \end{bmatrix}$
16 – 23	$\frac{1}{2}\begin{bmatrix} \overline{W}_{2,\lfloor (i-16)/4\rfloor} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
24 – 31	$\frac{1}{2}\begin{bmatrix} 0_{2\times2} & 0_{2\times1} \\ \overline{W}_{2,\lfloor (i-24)/4\rfloor} & 0_{2\times1} \\ 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \\ 0_{2\times2} & 0_{2\times1} \end{bmatrix}$
32 – 39	$\frac{1}{2}\begin{bmatrix} 0_{2\times2} & 0_{2\times1} \\ \overline{W}_{2,\lfloor (i-32)/4\rfloor} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
40 – 47	$\frac{1}{2}\begin{bmatrix} 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times1} \\ \overline{W}_{2,\lfloor (i-40)/4\rfloor} & 0_{2\times1} \\ 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
48 – 111	$\frac{1}{2}\begin{bmatrix} \overline{W}_{1,\lfloor (i-48)/16\rfloor} & 0_{2\times1} & 0_{2\times1} \\ 0_{2\times1} & \overline{W}_{1,\lfloor (i \bmod 16)/4\rfloor} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & \overline{W}_{1,(i \bmod 4)} \\ 0_{2\times1} & 0_{2\times1} & 0_{2\times1} \end{bmatrix}$
112 – 175	$\frac{1}{2}\begin{bmatrix} \overline{W}_{1,\lfloor (i-112)/16\rfloor} & 0_{2\times1} & 0_{2\times1} \\ 0_{2\times1} & \overline{W}_{1,\lfloor (i \bmod 16)/4\rfloor} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
176 – 239	$\frac{1}{2}\begin{bmatrix} \overline{W}_{1,\lfloor (i-176)/16\rfloor} & 0_{2\times1} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & 0_{2\times1} \\ 0_{2\times1} & \overline{W}_{1,\lfloor (i \bmod 16)/4\rfloor} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
240 – 303	$\frac{1}{2}\begin{bmatrix} 0_{2\times1} & 0_{2\times1} & 0_{2\times1} \\ \overline{W}_{1,\lfloor (i-240)/16\rfloor} & 0_{2\times1} & 0_{2\times1} \\ 0_{2\times1} & \overline{W}_{1,\lfloor (i \bmod 16)/4\rfloor} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
304	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$

Table 6.3.1.5-42: Intermediate precoding matrix W' for *codebook3* and four-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	**Intermediate precoder matrix W'**
0 – 255	$\frac{1}{2}\begin{bmatrix} \overline{W}_{1,\lfloor i/64 \rfloor} & 0_{2\times1} & 0_{2\times1} & 0_{2\times1} \\ 0_{2\times1} & \overline{W}_{1,\lfloor (i \bmod 64)/16 \rfloor} & 0_{2\times1} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & \overline{W}_{1,\lfloor (i \bmod 16)/4 \rfloor} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & 0_{2\times1} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
256 – 259	$\frac{1}{2}\begin{bmatrix} \overline{W}_{2,\lfloor (i-256)/2 \rfloor} & 0_{2\times2} \\ 0_{2\times2} & \overline{W}_{2,(i \bmod 2)} \\ 0_{2\times2} & 0_{2\times2} \\ 0_{2\times2} & 0_{2\times2} \end{bmatrix}$
260 – 263	$\frac{1}{2}\begin{bmatrix} \overline{W}_{2,\lfloor (i-260)/2 \rfloor} & 0_{2\times2} \\ 0_{2\times2} & 0_{2\times2} \\ 0_{2\times2} & \overline{W}_{2,(i \bmod 2)} \\ 0_{2\times2} & 0_{2\times2} \end{bmatrix}$
264 – 267	$\frac{1}{2}\begin{bmatrix} \overline{W}_{2,\lfloor (i-264)/2 \rfloor} & 0_{2\times2} \\ 0_{2\times2} & 0_{2\times2} \\ 0_{2\times2} & 0_{2\times2} \\ 0_{2\times2} & \overline{W}_{2,(i \bmod 2)} \end{bmatrix}$
268 – 271	$\frac{1}{2}\begin{bmatrix} 0_{2\times2} & 0_{2\times2} \\ \overline{W}_{2,\lfloor (i-268)/2 \rfloor} & 0_{2\times2} \\ 0_{2\times2} & \overline{W}_{2,(i \bmod 2)} \\ 0_{2\times2} & 0_{2\times2} \end{bmatrix}$
272 – 275	$\frac{1}{2}\begin{bmatrix} 0_{2\times2} & 0_{2\times2} \\ \overline{W}_{2,\lfloor (i-272)/2 \rfloor} & 0_{2\times2} \\ 0_{2\times2} & 0_{2\times2} \\ 0_{2\times2} & \overline{W}_{2,(i \bmod 2)} \end{bmatrix}$
276 – 279	$\frac{1}{2}\begin{bmatrix} 0_{2\times2} & 0_{2\times2} \\ 0_{2\times2} & 0_{2\times2} \\ \overline{W}_{2,\lfloor (i-276)/2 \rfloor} & 0_{2\times2} \\ 0_{2\times2} & \overline{W}_{2,(i \bmod 2)} \end{bmatrix}$

Table 6.3.1.5-43: Intermediate precoding matrix W' for *codebook3* and five-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	**Intermediate precoder matrix W'**
0 – 15	$\frac{1}{2}\begin{bmatrix} \overline{W}_{2,\lfloor i/8 \rfloor} & 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & \overline{W}_{2,\lfloor (i \bmod 8)/4 \rfloor} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
16 – 31	$\frac{1}{2}\begin{bmatrix} 0_{2\times2} & 0_{2\times2} & 0_{2\times1} \\ \overline{W}_{2,\lfloor (i-16)/8 \rfloor} & 0_{2\times2} & 0_{2\times1} \\ 0_{2\times2} & \overline{W}_{2,\lfloor (i \bmod 8)/4 \rfloor} & 0_{2\times1} \\ 0_{2\times2} & 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$
32 – 159	$\frac{1}{2}\begin{bmatrix} \overline{W}_{1,\lfloor (i-32)/32 \rfloor} & 0_{2\times1} & 0_{2\times2} & 0_{2\times1} \\ 0_{2\times1} & \overline{W}_{1,\lfloor (i \bmod 32)/8 \rfloor} & 0_{2\times2} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & \overline{W}_{2,\lfloor (i \bmod 8)/4 \rfloor} & 0_{2\times1} \\ 0_{2\times1} & 0_{2\times1} & 0_{2\times2} & \overline{W}_{1,(i \bmod 4)} \end{bmatrix}$

Table 6.3.1.5-44: Intermediate precoding matrix W' for *codebook3* and six-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 7	$\frac{1}{2}\begin{bmatrix} \bar{W}_{2,\lfloor i/4 \rfloor} & 0_{2\times 2} & 0_{2\times 2} \\ 0_{2\times 2} & \bar{W}_{2,\lfloor (i \bmod 4)/2 \rfloor} & 0_{2\times 2} \\ 0_{2\times 2} & 0_{2\times 2} & \bar{W}_{2,(i \bmod 2)} \\ 0_{2\times 2} & 0_{2\times 2} & 0_{2\times 2} \end{bmatrix}$
8 – 15	$\frac{1}{2}\begin{bmatrix} \bar{W}_{2,\lfloor (i-8)/4 \rfloor} & 0_{2\times 2} & 0_{2\times 2} \\ 0_{2\times 2} & 0_{2\times 2} & 0_{2\times 2} \\ 0_{2\times 2} & \bar{W}_{2,\lfloor (i \bmod 4)/2 \rfloor} & 0_{2\times 2} \\ 0_{2\times 2} & 0_{2\times 2} & \bar{W}_{2,(i \bmod 2)} \end{bmatrix}$
16 – 79	$\frac{1}{2}\begin{bmatrix} \bar{W}_{2,\lfloor (i-16)/32 \rfloor} & 0_{2\times 1} & 0_{2\times 2} & 0_{2\times 1} \\ 0_{2\times 2} & \bar{W}_{1,\lfloor ((i-16) \bmod 32)/8 \rfloor} & 0_{2\times 2} & 0_{2\times 1} \\ 0_{2\times 2} & 0_{2\times 1} & \bar{W}_{2,\lfloor (i \bmod 8)/4 \rfloor} & 0_{2\times 1} \\ 0_{2\times 2} & 0_{2\times 1} & 0_{2\times 2} & \bar{W}_{1,(i \bmod 4)} \end{bmatrix}$

Table 6.3.1.5-45: Intermediate precoding matrix W' for *codebook3* and seven-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 31	$\frac{1}{2}\begin{bmatrix} \bar{W}_{2,\lfloor i/16 \rfloor} & 0_{2\times 1} & 0_{2\times 2} & 0_{2\times 2} \\ 0_{2\times 2} & \bar{W}_{1,\lfloor (i \bmod 16)/4 \rfloor} & 0_{2\times 2} & 0_{2\times 2} \\ 0_{2\times 2} & 0_{2\times 1} & \bar{W}_{2,\lfloor (i \bmod 4)/2 \rfloor} & 0_{2\times 2} \\ 0_{2\times 2} & 0_{2\times 1} & 0_{2\times 2} & \bar{W}_{2,(i \bmod 2)} \end{bmatrix}$

Table 6.3.1.5-46: Intermediate precoding matrix W' for *codebook3* and eight-layer transmission using eight antenna ports with transform precoding disabled.

TPMI index i	Intermediate precoder matrix W'
0 – 15	$\frac{1}{2}\begin{bmatrix} \bar{W}_{2,\lfloor i/8 \rfloor} & 0_{2\times 2} & 0_{2\times 2} & 0_{2\times 2} \\ 0_{2\times 2} & \bar{W}_{2,\lfloor (i \bmod 8)/4 \rfloor} & 0_{2\times 2} & 0_{2\times 2} \\ 0_{2\times 2} & 0_{2\times 2} & \bar{W}_{2,\lfloor (i \bmod 4)/2 \rfloor} & 0_{2\times 2} \\ 0_{2\times 2} & 0_{2\times 2} & 0_{2\times 2} & \bar{W}_{2,(i \bmod 2)} \end{bmatrix}$

Table 6.3.1.5-47: Intermediate precoding matrix W' for *codebook4* and transmission using eight antenna ports. Up to 8 layers are supported with transform precoding disabled and up to one layer with transform precoding enabled.

TPMI index	Intermediate precoder matrix W'
$0 - \Delta(v) - 1$	$W' = \frac{1}{2\sqrt{2}}[e_{p_0} \dots e_{p_{v-1}}]$ where column i of W', denoted e_i, has an element 1 on the row corresponding to the port p_i on which layer i is to be transmitted, and element 0 in all other rows, $p_i < p_{i+1}$, $L = \sum_{p=0}^{7} \delta(p) 2^p$, where $\delta(p) = 1$ if a layer is to be transmitted on port p and $\delta(p) = 0$ otherwise, and $\Delta(z) = \sum_{k=1}^{z} C(8, k)$ for $z \geq 1$, where $C(x, y)$ is defined by Table 5.2.2.2.5-4 of [6, TS 38.214]. TPMI indices 0 to $\Delta(v) - 1$ are mapped to values of L, first by increasing values of the number of transmitted layers, and then by increasing values of L for a given number of layers.
255	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$
256	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}$
257	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$
258	$\frac{1}{2\sqrt{2}}\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

6.3.1.6 Mapping to virtual resource blocks

For each of the antenna ports used for transmission of the PUSCH, the block of complex-valued symbols $z^{(p)}(0),...,z^{(p)}(M_{\text{symb}}^{\text{ap}}-1)$ shall be multiplied with the amplitude scaling factor β_{PUSCH} in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $z^{(p)}(0)$ to resource elements $(k', l)_{p,\mu}$ in the virtual resource blocks assigned for transmission which meet all of the following criteria:

- they are in the virtual resource blocks assigned for transmission, and
- the corresponding resource elements in the corresponding physical resource blocks are not used for transmission of the associated DM-RS, PT-RS, or DM-RS intended for other co-scheduled UEs as described in clause 6.4.1.1.3

The mapping to resource elements $(k', l)_{p,\mu}$ allocated for PUSCH according to [6, TS 38.214] shall be in increasing order of first the index k' over the assigned virtual resource blocks, where $k' = 0$ is the first subcarrier in the lowest-numbered virtual resource block assigned for transmission, and then the index l, with the starting position given by [6, TS 38.214].

6.3.1.7 Mapping from virtual to physical resource blocks

Virtual resource blocks shall be mapped to physical resource blocks according to non-interleaved mapping.

For non-interleaved VRB-to-PRB mapping for uplink resource allocation types 0 and 1 [6, TS 38.214], virtual resource block n is mapped to physical resource block n except for PUSCH scheduled by RAR UL grant or PUSCH scheduled by DCI format 0_0 with CRC scrambled by TC-RNTI in active uplink bandwidth part i starting at $N_{\text{BWP},i}^{\text{start}}$, including all resource blocks of the initial uplink bandwidth part starting at $N_{\text{BWP},0}^{\text{start}}$, and having the same subcarrier spacing and cyclic prefix as the initial uplink bandwidth part, in which case virtual resource block n is mapped to physical resource block $n+N_{\text{BWP},0}^{\text{start}}-N_{\text{BWP},i}^{\text{start}}$.

For non-interleaved VRB-to-PRB mapping for uplink resource allocation type 2 [6, TS 38.214], virtual resource block n is mapped to physical resource block n.

6.3.2 Physical uplink control channel

6.3.2.1 General

The physical uplink control channel supports multiple formats as shown in Table 6.3.2.1-1. In case intra-slot frequency hopping is configured for PUCCH formats 1, 3, or 4 according to clause 9.2.1 of [5, TS38.213], the number of symbols in the first hop is given by $\left\lfloor N_{\text{symb}}^{\text{PUCCH}}/2\right\rfloor$ where $N_{\text{symb}}^{\text{PUCCH}}$ is the length of the PUCCH transmission in OFDM symbols.

Table 6.3.2.1-1: PUCCH formats.

PUCCH format	Length in OFDM symbols $N_{\text{symb}}^{\text{PUCCH}}$	Number of bits
0	1 – 2	≤2
1	4 – 14	≤2
2	1 – 2	>2
3	4 – 14	>2
4	4 – 14	>2

6.3.2.2 Sequence and cyclic shift hopping

PUCCH formats 0, 1, 3, and 4 use sequences $r_{u,v}^{(\alpha,\delta)}(n)$ given by clause 5.2.2 with $\delta=0$ where the sequence group u and the sequence number v depend on the sequence hopping in clause 6.3.2.2.1 and the cyclic shift α depends on the cyclic shift hopping in clause 6.3.2.2.2.

6.3.2.2.1 Group and sequence hopping

The sequence group $u=\left(f_{\text{gh}}+f_{\text{ss}}\right)\bmod 30$ and the sequence number v within the group depends on the higher-layer parameter *pucch-GroupHopping*:

- if *pucch-GroupHopping* equals 'neither'

$$f_{\text{gh}}=0$$

$$f_{\text{ss}}=n_{\text{ID}}\bmod 30$$

$$v=0$$

where n_{ID} is given by the higher-layer parameter *hoppingId* if configured, otherwise $n_{\text{ID}}=N_{\text{ID}}^{\text{cell}}$.

- if *pucch-GroupHopping* equals 'enable'

$$f_{\mathrm{gh}} = \left(\sum_{m=0}^{7} 2^m c\left(8\left(2n_{\mathrm{s,f}}^{\mu} + n_{\mathrm{hop}}\right) + m\right)\right) \bmod 30$$
$$f_{\mathrm{ss}} = n_{\mathrm{ID}} \bmod 30$$
$$v = 0$$

where the pseudo-random sequence $c(i)$ is defined by clause 5.2.1 and shall be initialized at the beginning of each radio frame with $c_{\mathrm{init}} = \lfloor n_{\mathrm{ID}}/30 \rfloor$ where n_{ID} is given by the higher-layer parameter *hoppingId* if configured, otherwise $n_{\mathrm{ID}} = N_{\mathrm{ID}}^{\mathrm{cell}}$.

- if *pucch-GroupHopping* equals 'disable'

$$f_{\mathrm{gh}} = 0$$
$$f_{\mathrm{ss}} = n_{\mathrm{ID}} \bmod 30$$
$$v = c\left(2n_{\mathrm{s,f}}^{\mu} + n_{\mathrm{hop}}\right)$$

where the pseudo-random sequence $c(i)$ is defined by clause 5.2.1 and shall be initialized at the beginning of each radio frame with $c_{\mathrm{init}} = 2^5 \lfloor n_{\mathrm{ID}}/30 \rfloor + (n_{\mathrm{ID}} \bmod 30)$ where n_{ID} is given by the higher-layer parameter *hoppingId* if configured, otherwise $n_{\mathrm{ID}} = N_{\mathrm{ID}}^{\mathrm{cell}}$.

The frequency hopping index $n_{\mathrm{hop}} = 0$ if intra-slot frequency hopping is disabled by the higher-layer parameter *intraSlotFrequencyHopping*. If frequency hopping is enabled by the higher-layer parameter *intraSlotFrequencyHopping*, $n_{\mathrm{hop}} = 0$ for the first hop and $n_{\mathrm{hop}} = 1$ for the second hop.

6.3.2.2.2 Cyclic shift hopping

The cyclic shift α varies as a function of the symbol and slot number according to

$$\alpha_l = \frac{2\pi}{N_{\mathrm{sc}}^{\mathrm{RB}}}\left(\left(m_0 + m_{\mathrm{cs}} + m_{\mathrm{int}} + n_{\mathrm{cs}}\left(n_{\mathrm{s,f}}^{\mu}, l + l'\right)\right) \bmod N_{\mathrm{sc}}^{\mathrm{RB}}\right)$$

where

- $n_{\mathrm{s,f}}^{\mu}$ is the slot number in the radio frame
- l is the OFDM symbol number in the PUCCH transmission where $l = 0$ corresponds to the first OFDM symbol of the PUCCH transmission,
- l' is the index of the OFDM symbol in the slot that corresponds to the first OFDM symbol of the PUCCH transmission in the slot given by [5, TS 38.213]
- m_0 is given by [5, TS 38.213] for PUCCH format 0 and 1 while for PUCCH format 3 and 4 is defined in clause 6.4.1.3.3.1
- $m_{\mathrm{cs}} = 0$ except for PUCCH format 0 when it depends on the information to be transmitted according to clause 9.2 of [5, TS 38.213].
- m_{int} is given by
  - $m_{\mathrm{int}} = 5n_{\mathrm{IRB}}^{\mu}$ for PUCCH formats 0 and 1 if PUCCH shall use interlaced mapping according to any of the higher-layer parameters *useInterlacePUCCH-PUSCH* in *BWP-UplinkCommon* or *useInterlacePUCCH-PUSCH* in *BWP-UplinkDedicated*, where n_{IRB}^{μ} is the resource block number within the interlace;
  - $m_{\mathrm{int}} = 0$ otherwise

The function $n_{\mathrm{cs}}(n_{\mathrm{c}}, l)$ is given by

$$n_{\mathrm{cs}}\left(n_{\mathrm{s,f}}^{\mu}, l\right) = \sum_{m=0}^{7} 2^m c\left(8N_{\mathrm{symb}}^{\mathrm{slot}} n_{\mathrm{s,f}}^{\mu} + 8l + m\right)$$

where the pseudo-random sequence $c(i)$ is defined by clause 5.2.1. The pseudo-random sequence generator shall be initialized with $c_{\text{init}} = n_{\text{ID}}$, where n_{ID} is given by the higher-layer parameter *hoppingId* if configured, otherwise $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$.

6.3.2.3 PUCCH format 0

6.3.2.3.1 Sequence generation

The sequence $x(n)$ shall be generated according to

$$\begin{aligned} x\left(lM_{\text{RB}}^{\text{PUCCH,0}}N_{\text{sc}}^{\text{RB}} + n\right) &= r_{u,v}^{(\alpha,\delta)}(n) \\ n &= 0,1,\dots,M_{\text{RB}}^{\text{PUCCH,0}}N_{\text{sc}}^{\text{RB}} - 1 \\ l &= \begin{cases} 0 & \text{for single-symbol PUCCH transmission} \\ 0,1 & \text{for double-symbol PUCCH transmission} \end{cases} \end{aligned}$$

where $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 6.3.2.2 with m_{cs} depending on the information to be transmitted according to clause 9.2 of [5, TS 38.213]. The quantity $M_{\text{RB}}^{\text{PUCCH,0}}$ is given by clause 9.2.1 of [5, TS 38.213].

6.3.2.3.2 Mapping to physical resources

The sequence $x(n)$ shall be multiplied with the amplitude scaling factor $\beta_{\text{PUCCH,0}}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $x(0)$ to resource elements $(k,l)_{p,\mu}$ assigned for transmission according to clause 9.2.1 of [5, TS 38.213] in increasing order of first the index k over the assigned physical resources spanning $M_{\text{RB}}^{\text{PUCCH,0}}$ resource blocks, and then the index l on antenna port $p = 2000$.

For interlaced transmission, the mapping operation shall be repeated for each resource block in the interlace and in the active bandwidth part over the assigned physical resource blocks according to clause 9.2.1 of [5, TS 38.213], with the resource-block dependent sequence generated according to clause 6.3.2.2.

6.3.2.4 PUCCH format 1

6.3.2.4.1 Sequence modulation

The block of bits $b(0),\dots,b(M_{\text{bit}}-1)$ shall be modulated as described in clause 5.1 using BPSK if $M_{\text{bit}} = 1$ and QPSK if $M_{\text{bit}} = 2$, resulting in a complex-valued symbol $d(0)$.

The complex-valued symbol $d(0)$ shall be multiplied with a sequence $r_{u,v}^{(\alpha,\delta)}(n)$ according to

$$\begin{aligned} y(n) &= d(0)r_{u,v}^{(\alpha,\delta)}(n) \\ n &= 0,1,\dots,M_{\text{RB}}^{\text{PUCCH,1}}N_{\text{sc}}^{\text{RB}} - 1 \end{aligned}$$

where $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 6.3.2.2. The quantity $M_{\text{RB}}^{\text{PUCCH,1}}$ is given by clause 9.2.1 of [5, TS 38.213].

The block of complex-valued symbols $y(0),\dots,y\left(M_{\text{RB}}^{\text{PUCCH,1}}N_{\text{sc}}^{\text{RB}} - 1\right)$ shall be block-wise spread with the orthogonal sequence $w_i(m)$ according to

$$\begin{aligned} z\left(m'M_{\text{RB}}^{\text{PUCCH,1}}N_{\text{sc}}^{\text{RB}}N_{\text{SF,0}}^{\text{PUCCH,1}} + mM_{\text{RB}}^{\text{PUCCH,1}}N_{\text{sc}}^{\text{RB}} + n\right) &= w_i(m)y(n) \\ n &= 0,1,\dots,M_{\text{RB}}^{\text{PUCCH,1}}N_{\text{sc}}^{\text{RB}} - 1 \\ m &= 0,1,\dots,N_{\text{SF},m'}^{\text{PUCCH,1}} - 1 \\ m' &= \begin{cases} 0 & \text{no intra-slot frequency hopping} \\ 0,1 & \text{intra-slot frequency hopping} \end{cases} \end{aligned}$$

where $N_{\text{SF},m'}^{\text{PUCCH,1}}$ is given by Table 6.3.2.4.1-1. Intra-slot frequency hopping shall be assumed when the higher-layer parameter *intraSlotFrequencyHopping* is provided, regardless of whether the frequency-hop distance is zero or not, and interlaced mapping is not enabled, otherwise no intra-slot frequency hopping shall be assumed.

The orthogonal sequence $w_i(m)$ is given by Table 6.3.2.4.1-2 where i is the index of the orthogonal sequence to use according to clause 9.2.1 of [5, TS 38.213]. In case of a PUCCH transmission spanning multiple slots according to clause 9.2.6 of [5, TS38.213], the complex-valued symbol $d(0)$ is repeated for the subsequent slots.

Table 6.3.2.4.1-1: Number of PUCCH symbols and the corresponding $N^{\text{PUCCH},1}_{\text{SF},m'}$.

PUCCH length, $N^{\text{PUCCH},1}_{\text{symb}}$	$N^{\text{PUCCH},1}_{\text{SF},m'}$		
	No intra-slot hopping	**Intra-slot hopping**	
	$m'=0$	$m'=0$	$m'=1$
4	2	1	1
5	2	1	1
6	3	1	2
7	3	1	2
8	4	2	2
9	4	2	2
10	5	2	3
11	5	2	3
12	6	3	3
13	6	3	3
14	7	3	4

Table 6.3.2.4.1-2: Orthogonal sequences $w_i(m) = e^{j2\pi\phi(m)/N^{\text{PUCCH},1}_{\text{SF},m'}}$ for PUCCH format 1.

$N^{\text{PUCCH},1}_{\text{SF},m'}$	φ						
	$i=0$	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$	$i=6$
1	[0]	-	-	-	-	-	-
2	[0 0]	[0 1]	-	-	-	-	-
3	[0 0 0]	[0 1 2]	[0 2 1]	-	-	-	-
4	[0 0 0 0]	[0 2 0 2]	[0 0 2 2]	[0 2 2 0]	-	-	-
5	[0 0 0 0 0]	[0 1 2 3 4]	[0 2 4 1 3]	[0 3 1 4 2]	[0 4 3 2 1]	-	-
6	[0 0 0 0 0 0]	[0 1 2 3 4 5]	[0 2 4 0 2 4]	[0 3 0 3 0 3]	[0 4 2 0 4 2]	[0 5 4 3 2 1]	-
7	[0 0 0 0 0 0 0]	[0 1 2 3 4 5 6]	[0 2 4 6 1 3 5]	[0 3 6 2 5 1 4]	[0 4 1 5 2 6 3]	[0 5 3 1 6 4 2]	[0 6 5 4 3 2 1]

6.3.2.4.2 Mapping to physical resources

The sequence $z(n)$ shall be multiplied with the amplitude scaling factor $\beta_{\text{PUCCH},1}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $z(n)$ to resource elements $(k,l)_{p,\mu}$ which meet all of the following criteria:

- they are in the resource blocks assigned for transmission,
- they are not used by the associated DM-RS

The mapping to resource elements $(k,l)_{p,\mu}$ not reserved for other purposes shall be in increasing order of first the index k over the assigned physical resource blocks according to clause 9.2.1 of [5, TS 38.213], and then the index l on antenna port $p = 2000$.

For interlaced transmission, the mapping operation shall be repeated for each resource block in the interlace and in the active bandwidth part over the assigned physical resource blocks according to clause 9.2.1 of [5, TS 38.213], with the resource-block dependent sequence generated according to clause 6.3.2.2.

6.3.2.5 PUCCH format 2

6.3.2.5.1 Scrambling

The block of bits $b(0),\ldots,b(M_{\text{bit}}-1)$, where M_{bit} is the number of bits transmitted on the physical channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0),\ldots,\tilde{b}(M_{\text{bit}}-1)$ according to the following pseudo code

```
Set $i = 0$
while $i < M_{\text{bit}}$
    if $b(i) = y$    // UCI placeholder bits
        $\tilde{b}(i) = \tilde{b}(i-1)$
    else
        $\tilde{b}(i) = (b(i) + c(i)) \bmod 2$
    end if
    $i = i + 1$
end while
```

where y is the tag defined in [4, TS38.212] and the scrambling sequence $c(i)$ is given by clause 5.2.1. The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{15} + n_{\text{ID}}$$

where

- $n_{\text{ID}} \in \{0,1,\ldots,1023\}$ equals the higher-layer parameter *dataScramblingIdentityPUSCH* if configured,
- $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ otherwise

and n_{RNTI} is given by the C-RNTI.

6.3.2.5.2 Modulation

The block of scrambled bits $\tilde{b}(0),\ldots,\tilde{b}(M_{\text{bit}}-1)$ shall be modulated as described in clause 5.1 using QPSK, resulting in a block of complex-valued modulation symbols $d(0),\ldots,d(M_{\text{symb}}-1)$ where $M_{\text{symb}} = M_{\text{bit}}/2$.

6.3.2.5.2A Spreading

Spreading shall be applied according to

$$\begin{aligned} z\left(mN_{\text{SF}}^{\text{PUCCH,2}} + i\right) &= w_n(i)d(m) \\ i &= 0,1,\ldots,N_{\text{SF}}^{\text{PUCCH,2}} - 1 \\ m &= 0,1,\ldots,M_{\text{symb}} - 1 \end{aligned}$$

resulting in a block of complex-valued symbols $z(0),\ldots,z(N_{\text{SF}}^{\text{PUCCH,2}} M_{\text{symb}} - 1)$.

If the higher layer parameter *interlace1* is not configured, and the higher-layer parameter *occ-Length* is configured,

- $N_{\text{SF}}^{\text{PUCCH,2}} \in \{2,4\}$ is given by the higher-layer parameter *occ-Length*;
- $w_n(i)$ is given by Tables 6.3.2.5A-1 and 6.3.2.5A-2 where $n = (n_0 + n_{\text{IRB}}) \bmod N_{\text{SF}}^{\text{PUCCH,2}}$, the quantity n_0 is the index of the orthogonal sequence to use given by the higher-layer parameter *occ-Index*, and n_{IRB} is the interlaced resource block number as defined in clause 4.4.4.6 within the interlace given by the higher-layer parameter *Interlace0*.

otherwise $N_{\text{SF}}^{\text{PUCCH,2}} = 1$ and $w_n(i) = 1$.

Table 6.3.2.5A-1: Orthogonal sequences $w_n(i)$ for PUCCH format 2 when $N_{\text{SF}}^{\text{PUCCH,2}} = 2$.

n	$w_n(i)$
0	$[+1 \quad +1]$
1	$[+1 \quad -1]$

Table 6.3.2.5A-2: Orthogonal sequences $w_n(i)$ for PUCCH format 2 when $N_{\text{SF}}^{\text{PUCCH,2}} = 4$.

n	$w_n(i)$
0	$[+1 \quad +1 \quad +1 \quad +1]$
1	$[+1 \quad -1 \quad +1 \quad -1]$
2	$[+1 \quad +1 \quad -1 \quad -1]$
3	$[+1 \quad -1 \quad -1 \quad +1]$

6.3.2.5.3 Mapping to physical resources

The block of complex-valued symbols $z(0), \ldots, z(N_{\text{SF}}^{\text{PUCCH,2}} M_{\text{symb}} - 1)$ shall be multiplied with the amplitude scaling factor $\beta_{\text{PUCCH,2}}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $z(0)$ to resource elements $(k,l)_{p,\mu}$ which meet all of the following criteria:

- they are in the resource blocks assigned for transmission,
- they are not used by the associated DM-RS.

The mapping to resource elements $(k,l)_{p,\mu}$ not reserved for other purposes shall be in increasing order of first the index k over the assigned physical resource blocks according to clause 9.2.1 of [5, TS 38.213], and then the index l on antenna port $p = 2000$.

6.3.2.6 PUCCH formats 3 and 4

6.3.2.6.1 Scrambling

The block of bits $b(0), \ldots, b(M_{\text{bit}} - 1)$, where M_{bit} is the number of bits transmitted on the physical channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0), \ldots, \tilde{b}(M_{\text{bit}} - 1)$ according to the following pseudo code

```
Set $i = 0$
while $i < M_{\text{bit}}$
    if $b(i) = y$    // UCI placeholder bits
        $\tilde{b}(i) = \tilde{b}(i-1)$
    else
        $\tilde{b}(i) = (b(i) + c(i)) \bmod 2$
    end if
    $i = i + 1$
end while
```

where y is the tag defined in [4, TS38.212] and the scrambling sequence $c(i)$ is given by clause 5.2.1. The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{15} + n_{\text{ID}}$$

where

- $n_{\mathrm{ID}} \in \{0,1,\dots,1023\}$ equals the higher-layer parameter *dataScramblingIdentityPUSCH* if configured,
- $n_{\mathrm{ID}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ otherwise

and n_{RNTI} is given by the C-RNTI.

6.3.2.6.2 Modulation

The block of scrambled bits $\tilde{b}(0),\dots,\tilde{b}(M_{\mathrm{bit}}-1)$ shall be modulated as described in clause 5.1 using QPSK unless π/2-BPSK is configured, resulting in a block of complex-valued modulation symbols $d(0),\dots,d(M_{\mathrm{symb}}-1)$ where $M_{\mathrm{symb}} = M_{\mathrm{bit}}/2$ for QPSK and $M_{\mathrm{symb}} = M_{\mathrm{bit}}$ for π/2-BPSK.

6.3.2.6.3 Block-wise spreading

For both PUCCH format 3 and 4, $M_{\mathrm{sc}}^{\mathrm{PUCCH},s} = M_{\mathrm{RB}}^{\mathrm{PUCCH},s} N_{\mathrm{sc}}^{\mathrm{RB}}$ with $M_{\mathrm{RB}}^{\mathrm{PUCCH},s}$ representing the bandwidth of the PUCCH in terms of resource blocks according to clauses 9.2.3, 9.2.5.1 and 9.2.5.2 of [5, TS 38.213] and shall for non-interlaced mapping fulfil

$$M_{\mathrm{RB}}^{\mathrm{PUCCH},s} = 2^{\alpha_2} \cdot 3^{\alpha_3} \cdot 5^{\alpha_5}$$

where $\alpha_2, \alpha_3, \alpha_5$ is a set of non-negative integers and $s \in \{3,4\}$. For interlaced mapping, $M_{\mathrm{RB}}^{\mathrm{PUCCH},3} = 10$ if a single interlace is configured and $M_{\mathrm{RB}}^{\mathrm{PUCCH},3} = 20$ if two interlaces are configured.

For PUCCH format 3, if interlaced mapping is not configured, no block-wise spreading is applied and

$$\begin{aligned} y\left(lM_{\mathrm{sc}}^{\mathrm{PUCCH},3}+k\right) &= d\left(lM_{\mathrm{sc}}^{\mathrm{PUCCH},3}+k\right) \\ k &= 0,1,\dots,M_{\mathrm{sc}}^{\mathrm{PUCCH},3}-1 \\ l &= 0,1,\dots,\left(M_{\mathrm{symb}}/M_{\mathrm{sc}}^{\mathrm{PUCCH},3}\right)-1 \end{aligned}$$

where $M_{\mathrm{RB}}^{\mathrm{PUCCH},3} \geq 1$ is given by clauses 9.2.3, 9.2.5.1 and 9.2.5.2 of [5, TS 38.213] and $N_{\mathrm{SF}}^{\mathrm{PUCCH},3} = 1$.

For PUCCH format 3 with interlaced mapping and PUCCH format 4, block-wise spreading shall be applied according to

$$\begin{aligned} y\left(lM_{\mathrm{sc}}^{\mathrm{PUCCH},s}+k\right) &= w_n\left(\left\lfloor k\frac{N_{\mathrm{SF}}^{\mathrm{PUCCH},s}}{M_{\mathrm{sc}}^{\mathrm{PUCCH},s}}\right\rfloor\right) d\left(l\frac{M_{\mathrm{sc}}^{\mathrm{PUCCH},s}}{N_{\mathrm{SF}}^{\mathrm{PUCCH},s}} + k \bmod \frac{M_{\mathrm{sc}}^{\mathrm{PUCCH},s}}{N_{\mathrm{SF}}^{\mathrm{PUCCH},s}}\right) \\ k &= 0,1,\dots,M_{\mathrm{sc}}^{\mathrm{PUCCH},s}-1 \\ l &= 0,1,\dots,\left(N_{\mathrm{SF}}^{\mathrm{PUCCH},s} M_{\mathrm{symb}}/M_{\mathrm{sc}}^{\mathrm{PUCCH},s}\right)-1 \end{aligned}$$

where

- for PUCCH format 3 with interlaced mapping, $N_{\mathrm{SF}}^{\mathrm{PUCCH},3} \in \{1,2,4\}$ if a single interlace is configured and $N_{\mathrm{SF}}^{\mathrm{PUCCH},3} = 1$, $w_n = 1$ if two interlaces are configured;
- for PUCCH format 4, $M_{\mathrm{RB}}^{\mathrm{PUCCH},4}$ is given by clause 9.2.1 of [5, TS 38.213] and $N_{\mathrm{SF}}^{\mathrm{PUCCH},4} \in \{2,4\}$ is given by the higher-layer parameter *occ-Length*;

and w_n is given by Tables 6.3.2.6.3-1 and 6.3.2.6.3-2 for $N_{\mathrm{SF}}^{\mathrm{PUCCH},s} > 1$ where n is the index of the orthogonal sequence to use according to clause 9.2.1 of [5, TS 38.213]. The quantity $N_{\mathrm{SF}}^{\mathrm{PUCCH},3} \in \{2,4\}$ is given by the higher-layer parameter *occ-Length* if provided, otherwise $N_{\mathrm{SF}}^{\mathrm{PUCCH},3} = 1$.

Table 6.3.2.6.3-1: Orthogonal sequences $w_n(m)$ for PUCCH format 3 with interlaced mapping and PUCCH format 4 when $N_{\mathrm{SF}}^{\mathrm{PUCCH},s} = 2$.

n	w_n
0	$[+1 \quad +1]$
1	$[+1 \quad -1]$

Table 6.3.2.6.3-2: Orthogonal sequences $w_n(m)$ for PUCCH format 3 with interlaced mapping and PUCCH format 4 when $N_{\mathrm{SF}}^{\mathrm{PUCCH},s} = 4$.

n	w_n
0	$[+1 \quad +1 \quad +1 \quad +1]$
1	$[+1 \quad -j \quad -1 \quad +j]$
2	$[+1 \quad -1 \quad +1 \quad -1]$
3	$[+1 \quad +j \quad -1 \quad -j]$

6.3.2.6.4 Transform precoding

The block of complex-valued symbols $y(0), \ldots, y(N_{\mathrm{SF}}^{\mathrm{PUCCH},s} M_{\mathrm{symb}} - 1)$ shall be transform precoded according to

$$z(l \cdot M_{\mathrm{sc}}^{\mathrm{PUCCH},s} + k) = \frac{1}{\sqrt{M_{\mathrm{sc}}^{\mathrm{PUCCH},s}}} \sum_{m=0}^{M_{\mathrm{sc}}^{\mathrm{PUCCH},s}-1} y(l \cdot M_{\mathrm{sc}}^{\mathrm{PUCCH},s} + m) e^{-j\frac{2\pi mk}{M_{\mathrm{sc}}^{\mathrm{PUCCH},s}}}$$

$$k = 0, \ldots, M_{\mathrm{sc}}^{\mathrm{PUCCH},s} - 1$$

$$l = 0, \ldots, \left(N_{\mathrm{SF}}^{\mathrm{PUCCH},s} M_{\mathrm{symb}} \big/ M_{\mathrm{sc}}^{\mathrm{PUCCH},s}\right) - 1$$

resulting in a block of complex-valued symbols $z(0), \ldots, z(N_{\mathrm{SF}}^{\mathrm{PUCCH},s} M_{\mathrm{symb}} - 1)$.

6.3.2.6.5 Mapping to physical resources

The block of modulation symbols $z(0), \ldots, z(N_{\mathrm{SF}}^{\mathrm{PUCCH},s} M_{\mathrm{symb}} - 1)$ shall be multiplied with the amplitude scaling factor $\beta_{\mathrm{PUCCH},s}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $z(0)$ to resource elements $(k, l)_{p,\mu}$ which meet all of the following criteria:

- they are in the resource blocks assigned for transmission,
- they are not used by the associated DM-RS

The mapping to resource elements $(k, l)_{p,\mu}$ not reserved for other purposes shall be in increasing order of first the index k over the assigned physical resource blocks according to clause 9.2.1 of [5, TS 38.213], and then the index l on antenna port $p = 2000$.

In case of intra-slot frequency hopping according to clause 9.2.1 of [5, TS 38.213], $\left\lfloor N_{\mathrm{symb}}^{\mathrm{PUCCH},s} / 2 \right\rfloor$ OFDM symbols shall be transmitted in the first hop and $N_{\mathrm{symb}}^{\mathrm{PUCCH},s} - \left\lfloor N_{\mathrm{symb}}^{\mathrm{PUCCH},s} / 2 \right\rfloor$ symbols in the second hop where $N_{\mathrm{symb}}^{\mathrm{PUCCH},s}$ is the total number of OFDM symbols used in one slot for PUCCH transmission.

6.3.3 Physical random-access channel

6.3.3.1 Sequence generation

The set of random-access preambles $x_{u,v}(n)$ shall be generated according to

$$x_{u,v}(n) = x_u((n + C_v) \bmod L_{\text{RA}})$$
$$x_u(i) = e^{-j\frac{\pi u i(i+1)}{L_{\text{RA}}}}, i = 0,1,\ldots,L_{\text{RA}} - 1$$

from which the frequency-domain representation shall be generated according to

$$y_{u,v}(n) = \sum_{m=0}^{L_{\text{RA}}-1} x_{u,v}(m) \cdot e^{-j\frac{2\pi mn}{L_{\text{RA}}}}$$

where $L_{\text{RA}} = 839$, $L_{\text{RA}} = 139$, $L_{\text{RA}} = 1151$, or $L_{\text{RA}} = 571$ depending on the PRACH preamble format as given by Tables 6.3.3.1-1 and 6.3.3.1-2.

There are 64 preambles defined in each time-frequency PRACH occasion, enumerated in increasing order of first increasing cyclic shift C_v of a logical root sequence, and then in increasing order of the logical root sequence index, starting with the index obtained from the higher-layer parameter *prach-RootSequenceIndex* or *rootSequenceIndex-BFR* or by *msgA-PRACH-RootSequenceIndex* if configured and a type-2 random-access procedure is initiated as described in clause 8.1 of [5, TS 38.213]. Additional preamble sequences, in case 64 preambles cannot be generated from a single root Zadoff-Chu sequence, are obtained from the root sequences with the consecutive logical indexes until all the 64 sequences are found. The logical root sequence order is cyclic; the logical index 0 is consecutive to $L_{\text{RA}} - 2$. The sequence number u is obtained from the logical root sequence index according to Tables 6.3.3.1-3 to 6.3.3.1-4B.

The cyclic shift C_v is given by

$$C_v = \begin{cases} vN_{\text{CS}} & v = 0,1,\ldots,\lfloor L_{\text{RA}}/N_{\text{CS}} \rfloor - 1, N_{\text{CS}} \neq 0 & \text{for unrestricted sets} \\ 0 & N_{\text{CS}} = 0 & \text{for unrestricted sets} \\ d_{\text{start}} \lfloor v/n_{\text{shift}}^{\text{RA}} \rfloor + (v \bmod n_{\text{shift}}^{\text{RA}}) N_{\text{CS}} & v = 0,1,\ldots,w-1 & \text{for restricted sets type A and B} \\ \bar{\bar{d}}_{\text{start}} + (v - w) N_{\text{CS}} & v = w,\ldots,w + \bar{\bar{n}}_{\text{shift}}^{\text{RA}} - 1 & \text{for restricted sets type B} \\ \bar{\bar{\bar{d}}}_{\text{start}} + (v - w - \bar{\bar{n}}_{\text{shift}}^{\text{RA}}) N_{\text{CS}} & v = w + \bar{\bar{n}}_{\text{shift}}^{\text{RA}},\ldots,w + \bar{\bar{n}}_{\text{shift}}^{\text{RA}} + \bar{\bar{\bar{n}}}_{\text{shift}}^{\text{RA}} - 1 & \text{for restricted sets type B} \end{cases}$$
$$w = n_{\text{shift}}^{\text{RA}} n_{\text{group}}^{\text{RA}} + \bar{n}_{\text{shift}}^{\text{RA}}$$

where N_{CS} is given by Tables 6.3.3.1-5 to 6.3.3.1-7, the higher-layer parameter *msgA-RestrictedSetConfig*, if provided, determines the type of restricted sets (unrestricted, restricted type A, restricted type B); otherwise, the higher-layer parameter *restrictedSetConfig* determines the type of restricted sets (unrestricted, restricted type A, restricted type B), and Tables 6.3.3.1-1 and 6.3.3.1-2 indicate the type of restricted sets supported for the different preamble formats.

The variable d_u is given by

$$d_u = \begin{cases} q & 0 \le q < L_{\text{RA}}/2 \\ L_{\text{RA}} - q & \text{otherwise} \end{cases}$$

where q is the smallest non-negative integer that fulfils $(qu) \bmod L_{\text{RA}} = 1$. The parameters for restricted sets of cyclic shifts depend on d_u.

For restricted set type A, the parameters are given by:

- for $N_{\text{CS}} \le d_u < L_{\text{RA}}/3$

$$\begin{aligned} n_{\text{shift}}^{\text{RA}} &= \lfloor d_u / N_{\text{CS}} \rfloor \\ d_{\text{start}} &= 2d_u + n_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\ n_{\text{group}}^{\text{RA}} &= \lfloor L_{\text{RA}} / d_{\text{start}} \rfloor \\ \bar{n}_{\text{shift}}^{\text{RA}} &= \max\left(\left\lfloor (L_{\text{RA}} - 2d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}}) / N_{\text{CS}} \right\rfloor, 0 \right) \end{aligned}$$

- for $L_{\text{RA}}/3 \le d_u \le (L_{\text{RA}} - N_{\text{CS}})/2$

$$\begin{aligned} n_{\text{shift}}^{\text{RA}} &= \lfloor (L_{\text{RA}} - 2d_u) / N_{\text{CS}} \rfloor \\ d_{\text{start}} &= L_{\text{RA}} - 2d_u + n_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\ n_{\text{group}}^{\text{RA}} &= \lfloor d_u / d_{\text{start}} \rfloor \\ \bar{n}_{\text{shift}}^{\text{RA}} &= \min\left(\max\left(\left\lfloor (d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}}) / N_{\text{CS}} \right\rfloor, 0 \right), n_{\text{shift}}^{\text{RA}} \right) \end{aligned}$$

For restricted set type B, the parameters are given by:

- for $N_{\text{CS}} \le d_u < L_{\text{RA}}/5$

$$\begin{aligned} n_{\text{shift}}^{\text{RA}} &= \lfloor d_u / N_{\text{CS}} \rfloor \\ d_{\text{start}} &= 4d_u + n_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\ n_{\text{group}}^{\text{RA}} &= \lfloor L_{\text{RA}} / d_{\text{start}} \rfloor \\ \bar{n}_{\text{shift}}^{\text{RA}} &= \max\left(\left\lfloor (L_{\text{RA}} - 4d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}}) / N_{\text{CS}} \right\rfloor, 0 \right) \end{aligned}$$

- for $L_{\text{RA}}/5 \le d_u \le \left(L_{\text{RA}} - N_{\text{CS}}\right)/4$

$$\begin{aligned} n_{\text{shift}}^{\text{RA}} &= \left\lfloor \left(L_{\text{RA}} - 4d_u\right) / N_{\text{CS}} \right\rfloor \\ d_{\text{start}} &= L_{\text{RA}} - 4d_u + n_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\ n_{\text{group}}^{\text{RA}} &= \lfloor d_u / d_{\text{start}} \rfloor \\ \bar{n}_{\text{shift}}^{\text{RA}} &= \min\left(\max\left(\left\lfloor (d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}}) / N_{\text{CS}} \right\rfloor, 0 \right), n_{\text{shift}}^{\text{RA}} \right) \end{aligned}$$

- for $(L_{\text{RA}} + N_{\text{CS}})/4 \le d_u < 2L_{\text{RA}}/7$

$$\begin{aligned} n_{\text{shift}}^{\text{RA}} &= \lfloor (4d_u - L_{\text{RA}}) / N_{\text{CS}} \rfloor \\ d_{\text{start}} &= 4d_u - L_{\text{RA}} + n_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\ \bar{\bar{d}}_{\text{start}} &= L_{\text{RA}} - 3d_u + n_{\text{group}}^{\text{RA}} d_{\text{start}} + \bar{n}_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\ \bar{\bar{\bar{d}}}_{\text{start}} &= L_{\text{RA}} - 2d_u + n_{\text{group}}^{\text{RA}} d_{\text{start}} + \bar{\bar{n}}_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\ n_{\text{group}}^{\text{RA}} &= \lfloor d_u / d_{\text{start}} \rfloor \\ \bar{n}_{\text{shift}}^{\text{RA}} &= \max\left(\left\lfloor \left(L_{\text{RA}} - 3d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}} \right) / N_{\text{CS}} \right\rfloor, 0 \right) \\ \bar{\bar{n}}_{\text{shift}}^{\text{RA}} &= \left\lfloor \min\left(d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}}, 4d_u - L_{\text{RA}} - \bar{n}_{\text{shift}}^{\text{RA}} N_{\text{CS}} \right) / N_{\text{CS}} \right\rfloor \\ \bar{\bar{\bar{n}}}_{\text{shift}}^{\text{RA}} &= \left\lfloor \left(\left(1 - \min\left(1, \bar{n}_{\text{shift}}^{\text{RA}}\right) \right) \left(d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}} \right) + \min\left(1, \bar{n}_{\text{shift}}^{\text{RA}}\right) \left(4d_u - L_{\text{RA}} - \bar{n}_{\text{shift}}^{\text{RA}} N_{\text{CS}} \right) \right) / N_{\text{CS}} \right\rfloor - \bar{\bar{n}}_{\text{shift}}^{\text{RA}} \end{aligned}$$

- for $2L_{\text{RA}}/7 \le d_u \le (L_{\text{RA}} - N_{\text{CS}})/3$

$$\begin{aligned}
n_{\text{shift}}^{\text{RA}} &= \lfloor (L_{\text{RA}} - 3d_u)/N_{\text{CS}} \rfloor \\
d_{\text{start}} &= L_{\text{RA}} - 3d_u + n_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\
\bar{\bar{d}}_{\text{start}} &= d_u + n_{\text{group}}^{\text{RA}} d_{\text{start}} + \bar{n}_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\
\bar{\bar{\bar{d}}}_{\text{start}} &= 0 \\
n_{\text{group}}^{\text{RA}} &= \lfloor d_u / d_{\text{start}} \rfloor \\
\bar{n}_{\text{shift}}^{\text{RA}} &= \max\left(\left\lfloor \left(4d_u - L_{\text{RA}} - n_{\text{group}}^{\text{RA}} d_{\text{start}}\right) \middle/ N_{\text{CS}} \right\rfloor, 0\right) \\
\bar{\bar{n}}_{\text{shift}}^{\text{RA}} &= \left\lfloor \min\left(d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}}, L_{\text{RA}} - 3d_u - \bar{n}_{\text{shift}}^{\text{RA}} N_{\text{CS}}\right) \middle/ N_{\text{CS}} \right\rfloor \\
\bar{\bar{\bar{n}}}_{\text{shift}}^{\text{RA}} &= 0
\end{aligned}$$

- for $(L_{\text{RA}} + N_{\text{CS}})/3 \le d_u < 2L_{\text{RA}}/5$

$$\begin{aligned}
n_{\text{shift}}^{\text{RA}} &= \lfloor (3d_u - L_{\text{RA}})/N_{\text{CS}} \rfloor \\
d_{\text{start}} &= 3d_u - L_{\text{RA}} + n_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\
\bar{\bar{d}}_{\text{start}} &= 0 \\
\bar{\bar{\bar{d}}}_{\text{start}} &= 0 \\
n_{\text{group}}^{\text{RA}} &= \lfloor d_u / d_{\text{start}} \rfloor \\
\bar{n}_{\text{shift}}^{\text{RA}} &= \max\left(\left\lfloor \left(L_{\text{RA}} - 2d_u - n_{\text{group}}^{\text{RA}} d_{\text{start}}\right) \middle/ N_{\text{CS}} \right\rfloor, 0\right) \\
\bar{\bar{n}}_{\text{shift}}^{\text{RA}} &= 0 \\
\bar{\bar{\bar{n}}}_{\text{shift}}^{\text{RA}} &= 0
\end{aligned}$$

- for $2L_{\text{RA}}/5 \le d_u \le (L_{\text{RA}} - N_{\text{CS}})/2$

$$\begin{aligned}
n_{\text{shift}}^{\text{RA}} &= \lfloor (L_{\text{RA}} - 2d_u)/N_{\text{CS}} \rfloor \\
d_{\text{start}} &= 2(L_{\text{RA}} - 2d_u) + n_{\text{shift}}^{\text{RA}} N_{\text{CS}} \\
\bar{\bar{d}}_{\text{start}} &= 0 \\
\bar{\bar{\bar{d}}}_{\text{start}} &= 0 \\
n_{\text{group}}^{\text{RA}} &= \lfloor (L_{\text{RA}} - d_u)/d_{\text{start}} \rfloor \\
\bar{n}_{\text{shift}}^{\text{RA}} &= \max\left(\left\lfloor \left(3d_u - L_{\text{RA}} - n_{\text{group}}^{\text{RA}} d_{\text{start}}\right) \middle/ N_{\text{CS}} \right\rfloor, 0\right) \\
\bar{\bar{n}}_{\text{shift}}^{\text{RA}} &= 0 \\
\bar{\bar{\bar{n}}}_{\text{shift}}^{\text{RA}} &= 0
\end{aligned}$$

For all other values of d_u, there are no cyclic shifts in the restricted set.

Table 6.3.3.1-1: PRACH preamble formats for $L_{\text{RA}} = 839$ and $\Delta f_{\text{RA}} \in \{1.25, 5\}$ kHz.

Format	L_{RA}	Δf_{RA}	N_{u}	$N_{\text{CP}}^{\text{RA}}$	Support for restricted sets
0	839	1.25 kHz	24576κ	3168κ	Type A, Type B
1	839	1.25 kHz	$2 \cdot 24576\kappa$	21024κ	Type A, Type B
2	839	1.25 kHz	$4 \cdot 24576\kappa$	4688κ	Type A, Type B
3	839	5 kHz	$4 \cdot 6144\kappa$	3168κ	Type A, Type B

Table 6.3.3.1-2: Preamble formats for $L_{\mathrm{RA}} \in \{139, 571, 1151\}$ and $\Delta f_{\mathrm{RA}} = 15 \cdot 2^{\mu}$ kHz where $\mu \in \{0, 1, 2, 3, 5, 6\}$.

Format	L_{RA}			Δf_{RA}	N_{u}	$N_{\mathrm{CP}}^{\mathrm{RA}}$	Support for restricted sets
	$\mu \in \{0,1,2,3,5,6\}$	$\mu \in \{0,3\}$	$\mu \in \{1,3,5\}$				
A1	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$288\kappa \cdot 2^{-\mu}$	-
A2	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$576\kappa \cdot 2^{-\mu}$	-
A3	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$864\kappa \cdot 2^{-\mu}$	-
B1	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$216\kappa \cdot 2^{-\mu}$	-
B2	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$360\kappa \cdot 2^{-\mu}$	-
B3	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$504\kappa \cdot 2^{-\mu}$	-
B4	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$12 \cdot 2048\kappa \cdot 2^{-\mu}$	$936\kappa \cdot 2^{-\mu}$	-
C0	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$2048\kappa \cdot 2^{-\mu}$	$1240\kappa \cdot 2^{-\mu}$	-
C2	139	1151	571	$15 \cdot 2^{\mu}$ kHz	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$	

Table 6.3.3.1-3: Mapping from *logical index* i to sequence number u for preamble formats with $L_{\mathrm{RA}} = 839$.

i	Sequence number u in increasing order of i																			
0 – 19	129	710	140	699	120	719	210	629	168	671	84	755	105	734	93	746	70	769	60	779
20 – 39	2	837	1	838	56	783	112	727	148	691	80	759	42	797	40	799	35	804	73	766
40 – 59	146	693	31	808	28	811	30	809	27	812	29	810	24	815	48	791	68	771	74	765
60 – 79	178	661	136	703	86	753	78	761	43	796	39	800	20	819	21	818	95	744	202	637
80 – 99	190	649	181	658	137	702	125	714	151	688	217	622	128	711	142	697	122	717	203	636
100 – 119	118	721	110	729	89	750	103	736	61	778	55	784	15	824	14	825	12	827	23	816
120 – 139	34	805	37	802	46	793	207	632	179	660	145	694	130	709	223	616	228	611	227	612
140 – 159	132	707	133	706	143	696	135	704	161	678	201	638	173	666	106	733	83	756	91	748
160 – 179	66	773	53	786	10	829	9	830	7	832	8	831	16	823	47	792	64	775	57	782
180 – 199	104	735	101	738	108	731	208	631	184	655	197	642	191	648	121	718	141	698	149	690
200 – 219	216	623	218	621	152	687	144	695	134	705	138	701	199	640	162	677	176	663	119	720
220 – 239	158	681	164	675	174	665	171	668	170	669	87	752	169	670	88	751	107	732	81	758
240 – 259	82	757	100	739	98	741	71	768	59	780	65	774	50	789	49	790	26	813	17	822
260 – 279	13	826	6	833	5	834	33	806	51	788	75	764	99	740	96	743	97	742	166	673
280 – 299	172	667	175	664	187	652	163	676	185	654	200	639	114	725	189	650	115	724	194	645
300 – 319	195	644	192	647	182	657	157	682	156	683	211	628	154	685	123	716	139	700	212	627
320 – 339	153	686	213	626	215	624	150	689	225	614	224	615	221	618	220	619	127	712	147	692
340 – 359	124	715	193	646	205	634	206	633	116	723	160	679	186	653	167	672	79	760	85	754
360 – 379	77	762	92	747	58	781	62	777	69	770	54	785	36	803	32	807	25	814	18	821
380 – 399	11	828	4	835	3	836	19	820	22	817	41	798	38	801	44	795	52	787	45	794
400 – 419	63	776	67	772	72	767	76	763	94	745	102	737	90	749	109	730	165	674	111	728
420 – 439	209	630	204	635	117	722	188	651	159	680	198	641	113	726	183	656	180	659	177	662
440 – 459	196	643	155	684	214	625	126	713	131	708	219	620	222	617	226	613	230	609	232	607
460 – 479	262	577	252	587	418	421	416	423	413	426	411	428	376	463	395	444	283	556	285	554
480 – 499	379	460	390	449	363	476	384	455	388	451	386	453	361	478	387	452	360	479	310	529
500 – 519	354	485	328	511	315	524	337	502	349	490	335	504	324	515	323	516	320	519	334	505
520 – 539	359	480	295	544	385	454	292	547	291	548	381	458	399	440	380	459	397	442	369	470
540 – 559	377	462	410	429	407	432	281	558	414	425	247	592	277	562	271	568	272	567	264	575
560 – 579	259	580	237	602	239	600	244	595	243	596	275	564	278	561	250	589	246	593	417	422
580 – 599	248	591	394	445	393	446	370	469	365	474	300	539	299	540	364	475	362	477	298	541
600 – 619	312	527	313	526	314	525	353	486	352	487	343	496	327	512	350	489	326	513	319	520
620 – 639	332	507	333	506	348	491	347	492	322	517	330	509	338	501	341	498	340	499	342	497
640 – 659	301	538	366	473	401	438	371	468	408	431	375	464	249	590	269	570	238	601	234	605
660 – 679	257	582	273	566	255	584	254	585	245	594	251	588	412	427	372	467	282	557	403	436
680 – 699	396	443	392	447	391	448	382	457	389	450	294	545	297	542	311	528	344	495	345	494
700 – 719	318	521	331	508	325	514	321	518	346	493	339	500	351	488	306	533	289	550	400	439
720 – 739	378	461	374	465	415	424	270	569	241	598	231	608	260	579	268	571	276	563	409	430
740 – 759	398	441	290	549	304	535	308	531	358	481	316	523	293	546	288	551	284	555	368	471
760 – 779	253	586	256	583	263	576	242	597	274	565	402	437	383	456	357	482	329	510	317	522
780 – 799	307	532	286	553	287	552	266	573	261	578	236	603	303	536	356	483	355	484	405	434
800 – 819	404	435	406	433	235	604	267	572	302	537	309	530	265	574	233	606	367	472	296	543
820 – 837	336	503	305	534	373	466	280	559	279	560	419	420	240	599	258	581	229	610	-	-

Table 6.3.3.1-4: Mapping from *logical index* i to sequence number u for preamble formats with $L_{\text{RA}} = 139$.

i	Sequence number u in increasing order of i																			
0 – 19	1	138	2	137	3	136	4	135	5	134	6	133	7	132	8	131	9	130	10	129
20 – 39	11	128	12	127	13	126	14	125	15	124	16	123	17	122	18	121	19	120	20	119
40 – 59	21	118	22	117	23	116	24	115	25	114	26	113	27	112	28	111	29	110	30	109
60 – 79	31	108	32	107	33	106	34	105	35	104	36	103	37	102	38	101	39	100	40	99
80 – 99	41	98	42	97	43	96	44	95	45	94	46	93	47	92	48	91	49	90	50	89
100 – 119	51	88	52	87	53	86	54	85	55	84	56	83	57	82	58	81	59	80	60	79
120 – 137	61	78	62	77	63	76	64	75	65	74	66	73	67	72	68	71	69	70	-	-
138 – 837	N/A																			

Table 6.3.3.1-4A: Mapping from *logical index* i to sequence number u for preamble formats with $L_{\text{RA}} = 1151$.

i	Sequence number u in increasing order of i																			
0-19	1	1150	2	1149	3	1148	4	1147	5	1146	6	1145	7	1144	8	1143	9	1142	10	1141
20-39	11	1140	12	1139	13	1138	14	1137	15	1136	16	1135	17	1134	18	1133	19	1132	20	1131
40-59	21	1130	22	1129	23	1128	24	1127	25	1126	26	1125	27	1124	28	1123	29	1122	30	1121
60-79	31	1120	32	1119	33	1118	34	1117	35	1116	36	1115	37	1114	38	1113	39	1112	40	1111
80-99	41	1110	42	1109	43	1108	44	1107	45	1106	46	1105	47	1104	48	1103	49	1102	50	1101
100-119	51	1100	52	1099	53	1098	54	1097	55	1096	56	1095	57	1094	58	1093	59	1092	60	1091
120-139	61	1090	62	1089	63	1088	64	1087	65	1086	66	1085	67	1084	68	1083	69	1082	70	1081
140-159	71	1080	72	1079	73	1078	74	1077	75	1076	76	1075	77	1074	78	1073	79	1072	80	1071
160-179	81	1070	82	1069	83	1068	84	1067	85	1066	86	1065	87	1064	88	1063	89	1062	90	1061
180-199	91	1060	92	1059	93	1058	94	1057	95	1056	96	1055	97	1054	98	1053	99	1052	100	1051
200-219	101	1050	102	1049	103	1048	104	1047	105	1046	106	1045	107	1044	108	1043	109	1042	110	1041
220-239	111	1040	112	1039	113	1038	114	1037	115	1036	116	1035	117	1034	118	1033	119	1032	120	1031
240-259	121	1030	122	1029	123	1028	124	1027	125	1026	126	1025	127	1024	128	1023	129	1022	130	1021
260-279	131	1020	132	1019	133	1018	134	1017	135	1016	136	1015	137	1014	138	1013	139	1012	140	1011
280-299	141	1010	142	1009	143	1008	144	1007	145	1006	146	1005	147	1004	148	1003	149	1002	150	1001
300-319	151	1000	152	999	153	998	154	997	155	996	156	995	157	994	158	993	159	992	160	991
320-339	161	990	162	989	163	988	164	987	165	986	166	985	167	984	168	983	169	982	170	981
340-359	171	980	172	979	173	978	174	977	175	976	176	975	177	974	178	973	179	972	180	971
360-379	181	970	182	969	183	968	184	967	185	966	186	965	187	964	188	963	189	962	190	961
380-399	191	960	192	959	193	958	194	957	195	956	196	955	197	954	198	953	199	952	200	951
400-419	201	950	202	949	203	948	204	947	205	946	206	945	207	944	208	943	209	942	210	941
420-439	211	940	212	939	213	938	214	937	215	936	216	935	217	934	218	933	219	932	220	931
440-459	221	930	222	929	223	928	224	927	225	926	226	925	227	924	228	923	229	922	230	921
460-479	231	920	232	919	233	918	234	917	235	916	236	915	237	914	238	913	239	912	240	911
480-499	241	910	242	909	243	908	244	907	245	906	246	905	247	904	248	903	249	902	250	901
500-519	251	900	252	899	253	898	254	897	255	896	256	895	257	894	258	893	259	892	260	891
520-539	261	890	262	889	263	888	264	887	265	886	266	885	267	884	268	883	269	882	270	881
540-559	271	880	272	879	273	878	274	877	275	876	276	875	277	874	278	873	279	872	280	871
560-579	281	870	282	869	283	868	284	867	285	866	286	865	287	864	288	863	289	862	290	861
580-599	291	860	292	859	293	858	294	857	295	856	296	855	297	854	298	853	299	852	300	851
600-619	301	850	302	849	303	848	304	847	305	846	306	845	307	844	308	843	309	842	310	841
620-639	311	840	312	839	313	838	314	837	315	836	316	835	317	834	318	833	319	832	320	831
640-659	321	830	322	829	323	828	324	827	325	826	326	825	327	824	328	823	329	822	330	821
660-679	331	820	332	819	333	818	334	817	335	816	336	815	337	814	338	813	339	812	340	811
680-699	341	810	342	809	343	808	344	807	345	806	346	805	347	804	348	803	349	802	350	801
700-719	351	800	352	799	353	798	354	797	355	796	356	795	357	794	358	793	359	792	360	791
720-739	361	790	362	789	363	788	364	787	365	786	366	785	367	784	368	783	369	782	370	781
740-759	371	780	372	779	373	778	374	777	375	776	376	775	377	774	378	773	379	772	380	771
760-779	381	770	382	769	383	768	384	767	385	766	386	765	387	764	388	763	389	762	390	761
780-799	391	760	392	759	393	758	394	757	395	756	396	755	397	754	398	753	399	752	400	751
800-819	401	750	402	749	403	748	404	747	405	746	406	745	407	744	408	743	409	742	410	741
820-839	411	740	412	739	413	738	414	737	415	736	416	735	417	734	418	733	419	732	420	731
840-859	421	730	422	729	423	728	424	727	425	726	426	725	427	724	428	723	429	722	430	721
860-879	431	720	432	719	433	718	434	717	435	716	436	715	437	714	438	713	439	712	440	711
880-899	441	710	442	709	443	708	444	707	445	706	446	705	447	704	448	703	449	702	450	701
900-919	451	700	452	699	453	698	454	697	455	696	456	695	457	694	458	693	459	692	460	691
920-939	461	690	462	689	463	688	464	687	465	686	466	685	467	684	468	683	469	682	470	681
940-959	471	680	472	679	473	678	474	677	475	676	476	675	477	674	478	673	479	672	480	671
960-979	481	670	482	669	483	668	484	667	485	666	486	665	487	664	488	663	489	662	490	661
980-999	491	660	492	659	493	658	494	657	495	656	496	655	497	654	498	653	499	652	500	651
1000-1019	501	650	502	649	503	648	504	647	505	646	506	645	507	644	508	643	509	642	510	641
1020-1039	511	640	512	639	513	638	514	637	515	636	516	635	517	634	518	633	519	632	520	631
1040-1059	521	630	522	629	523	628	524	627	525	626	526	625	527	624	528	623	529	622	530	621
1060-1079	531	620	532	619	533	618	534	617	535	616	536	615	537	614	538	613	539	612	540	611
1080-1099	541	610	542	609	543	608	544	607	545	606	546	605	547	604	548	603	549	602	550	601
1100-1119	551	600	552	599	553	598	554	597	555	596	556	595	557	594	558	593	559	592	560	591
1120-1139	561	590	562	589	563	588	564	587	565	586	566	585	567	584	568	583	569	582	570	581
1140-1149	571	580	572	579	573	578	574	577	575	576	-	-	-	-	-	-	-	-	-	-

Table 6.3.3.1-4B: Mapping from *logical index* i to sequence number u for preamble formats with $L_{\text{RA}} = 571$.

i	Sequence number u in increasing order of i																			
0-19	1	570	2	569	3	568	4	567	5	566	6	565	7	564	8	563	9	562	10	561
20-39	11	560	12	559	13	558	14	557	15	556	16	555	17	554	18	553	19	552	20	551
40-59	21	550	22	549	23	548	24	547	25	546	26	545	27	544	28	543	29	542	30	541
60-79	31	540	32	539	33	538	34	537	35	536	36	535	37	534	38	533	39	532	40	531
80-99	41	530	42	529	43	528	44	527	45	526	46	525	47	524	48	523	49	522	50	521
100-119	51	520	52	519	53	518	54	517	55	516	56	515	57	514	58	513	59	512	60	511
120-139	61	510	62	509	63	508	64	507	65	506	66	505	67	504	68	503	69	502	70	501
140-159	71	500	72	499	73	498	74	497	75	496	76	495	77	494	78	493	79	492	80	491
160-179	81	490	82	489	83	488	84	487	85	486	86	485	87	484	88	483	89	482	90	481
180-199	91	480	92	479	93	478	94	477	95	476	96	475	97	474	98	473	99	472	100	471
200-219	101	470	102	469	103	468	104	467	105	466	106	465	107	464	108	463	109	462	110	461
220-239	111	460	112	459	113	458	114	457	115	456	116	455	117	454	118	453	119	452	120	451
240-259	121	450	122	449	123	448	124	447	125	446	126	445	127	444	128	443	129	442	130	441
260-279	131	440	132	439	133	438	134	437	135	436	136	435	137	434	138	433	139	432	140	431
280-299	141	430	142	429	143	428	144	427	145	426	146	425	147	424	148	423	149	422	150	421
300-319	151	420	152	419	153	418	154	417	155	416	156	415	157	414	158	413	159	412	160	411
320-339	161	410	162	409	163	408	164	407	165	406	166	405	167	404	168	403	169	402	170	401
340-359	171	400	172	399	173	398	174	397	175	396	176	395	177	394	178	393	179	392	180	391
360-379	181	390	182	389	183	388	184	387	185	386	186	385	187	384	188	383	189	382	190	381
380-399	191	380	192	379	193	378	194	377	195	376	196	375	197	374	198	373	199	372	200	371
400-419	201	370	202	369	203	368	204	367	205	366	206	365	207	364	208	363	209	362	210	361
420-439	211	360	212	359	213	358	214	357	215	356	216	355	217	354	218	353	219	352	220	351
440-459	221	350	222	349	223	348	224	347	225	346	226	345	227	344	228	343	229	342	230	341
460-479	231	340	232	339	233	338	234	337	235	336	236	335	237	334	238	333	239	332	240	331
480-499	241	330	242	329	243	328	244	327	245	326	246	325	247	324	248	323	249	322	250	321
500-519	251	320	252	319	253	318	254	317	255	316	256	315	257	314	258	313	259	312	260	311
520-539	261	310	262	309	263	308	264	307	265	306	266	305	267	304	268	303	269	302	270	301
540-559	271	300	272	299	273	298	274	297	275	296	276	295	277	294	278	293	279	292	280	291
560-569	281	290	282	289	283	288	284	287	285	286	-	-	-	-	-	-	-	-	-	-

Table 6.3.3.1-5: N_{CS} for preamble formats with $\Delta f_{\text{RA}} = 1.25$ kHz.

zeroCorrelationZoneConfig*, *msgA-ZeroCorrelationZoneConfig	**N_{CS} value**		
	Unrestricted set	**Restricted set type A**	**Restricted set type B**
0	0	15	15
1	13	18	18
2	15	22	22
3	18	26	26
4	22	32	32
5	26	38	38
6	32	46	46
7	38	55	55
8	46	68	68
9	59	82	82
10	76	100	100
11	93	128	118
12	119	158	137
13	167	202	-
14	279	237	-
15	419	-	-

Table 6.3.3.1-6: N_{CS} for preamble formats with $\Delta f_{\text{RA}} = 5$ kHz.

zeroCorrelationZoneConfig*, *msgA-ZeroCorrelationZoneConfig	**N_{CS} value**		
	Unrestricted set	**Restricted set type A**	**Restricted set type B**
0	0	36	36
1	13	57	57
2	26	72	60
3	33	81	63
4	38	89	65
5	41	94	68
6	49	103	71
7	55	112	77
8	64	121	81
9	76	132	85
10	93	137	97
11	119	152	109
12	139	173	122
13	209	195	137
14	279	216	-
15	419	237	-

Table 6.3.3.1-7: N_{CS} for preamble formats with $L_{\text{RA}} \in \{139, 571, 1151\}$.

zeroCorrelationZoneConfig*, *msgA-ZeroCorrelationZoneConfig	**N_{CS} value**		
	$L_{\text{RA}} = 139$	$L_{\text{RA}} = 571$	$L_{\text{RA}} = 1151$
0	0	0	0
1	2	8	17
2	4	10	21
3	6	12	25
4	8	15	30
5	10	17	35
6	12	21	44
7	13	25	52
8	15	31	63
9	17	40	82
10	19	51	104
11	23	63	127
12	27	81	164
13	34	114	230
14	46	190	383
15	69	285	575

6.3.3.2 Mapping to physical resources

The preamble sequence shall be mapped to physical resources according to

$$a_k^{(p,\text{RA})} = \beta_{\text{PRACH}} y_{u,v}(k)$$
$$k = 0,1,...,L_{\text{RA}} - 1$$

where β_{PRACH} is an amplitude scaling factor in order to conform to the transmit power specified in [5, TS38.213], and $p = 4000$ is the antenna port. Baseband signal generation shall be done according to clause 5.3 using the parameters in Table 6.3.3.1-1 or Table 6.3.3.1-2 with $\bar{k}$ given by Table 6.3.3.2-1.

Random access preambles can only be transmitted in the time resources obtained from Tables 6.3.3.2-2 to 6.3.3.2-4 and depends on FR1 or FR2 and the spectrum type as defined in [8, TS38.104]. The PRACH configuration index in Tables 6.3.3.2-2 to 6.3.3.2-4 is

- for Table 6.3.3.2-3 given by the higher-layer parameter *prach-ConfigurationIndex*, or by *msgA-PRACH-ConfigurationIndex* if configured; and
- for Tables 6.3.3.2-2 and 6.3.3.2-4 given by the higher-layer parameter *prach-ConfigurationIndex*, or by *msgA-PRACH-ConfigurationIndex* if configured.

For the IAB-MT part of an IAB-node, the following applies:

- if the higher-layer parameter *prach-ConfigurationPeriodScaling-IAB* is configured, the variable x used in $n_\mathrm{f} \bmod x = y$ of Tables 6.3.3.2-2 to 6.3.3.2-4 shall be replaced by x_IAB , where $x_\mathrm{IAB} = \delta x$ and δ is given by the higher-layer parameter *prach-ConfigurationPeriodScaling-IAB* and the IAB-node does not expect x_IAB to be larger than 64;
- if the higher-layer parameter *prach-ConfigurationFrameOffset-IAB* is configured, the variable y used in $n_\mathrm{f} \bmod x = y$ of Tables 6.3.3.2-2 to 6.3.3.2-4 shall be replaced by $y_\mathrm{IAB} = (y + \Delta y) \bmod x$ where Δy is given by the higher-layer parameter *prach-ConfigurationFrameOffset-IAB*, and x is the value used in $n_\mathrm{f} \bmod x = y$;
- if the higher-layer parameter *prach-ConfigurationSOffset-IAB* is configured, the subframe number s_n from Tables 6.3.3.2-2 to 6.3.3.2-3 and the slot number s_n from Table 6.3.3.2-4 shall be replaced by $(s_\mathrm{n} + \Delta s) \bmod L$ where $\Delta s \in \{0,1,\dots,L-1\}$ is given by the higher-layer parameter *prach-ConfigurationSOffset-IAB*, and L is the number of subframes in a frame when using Tables 6.3.3.2-2 to 6.3.3.2-3 and the number of slots in a frame for 60 kHz subcarrier spacing when using in Table 6.3.3.2-4.

Random access preambles can only be transmitted in the frequency resources given by either the higher-layer parameter *msg1-FrequencyStart* or *msgA-RO-FrequencyStart* if configured as described in clause 8.1 of [5 TS 38.213]. The PRACH frequency resources $n_\mathrm{RA} \in \{0,1,\dots,M-1\}$, where M equals the higher-layer parameter *msg1-FDM* or *msgA-RO-FDM* if configured, are numbered in increasing order within the initial uplink bandwidth part during initial access, starting from the lowest frequency. Otherwise, n_RA are numbered in increasing order within the active uplink bandwidth part, starting from the lowest frequency.

For operation with shared spectrum channel access, for $L_{RA} = 139$, a UE expects to be provided with higher-layer parameter *msg1-FrequencyStart* or *msgA-RO-FrequencyStart* if configured, and higher-layer parameter *msg1-FDM* or *msgA-RO-FDM* if configured, such that a random-access preamble is confined within a single RB set. The UE assumes that the RB set is defined as when the UE is not provided *intraCellGuardBandsPerSCS* for an UL carrier as described in Clause 7 of [6, TS 38.214].

For operation with shared spectrum channel access, for $L_{RA} = 571$ or 1151 and Type-2 random access, a UE expects to be provided with higher-layer parameter *msgA-RO-FDM* equals to one.

For the purpose of slot numbering in the tables, the following subcarrier spacing shall be assumed:

- 15 kHz for FR1
- 60 kHz for FR2.

For handover purposes to a target cell in paired or unpaired spectrum where the target cell uses $L_\mathrm{max} = 4$, the UE may assume the absolute value of the time difference between radio frame i in the current cell and radio frame i in the target cell is less than $153600 T_\mathrm{s}$ if the association pattern period in clause 8.1 of [5, TS 38.213] is not equal to 10 ms.

For inter frequency handover purposes where the source cell is either in paired or unpaired spectrum and the target cell is in unpaired spectrum and uses $L_\mathrm{max} = 8$, the UE may assume the absolute value of the time difference between radio frame i in the current cell and radio frame i in the target cell is less than $76800 T_\mathrm{s}$.

Table 6.3.3.2-1: Supported combinations of Δf_{RA} and Δf, and the corresponding value of $\bar{k}$.

L_{RA}	Δf_{RA} for PRACH	Δf for PUSCH	$N_{\text{RB}}^{\text{RA}}$, allocation expressed in number of RBs for PUSCH	$\bar{k}$
839	1.25	15	6	7
839	1.25	30	3	1
839	1.25	60	2	133
839	5	15	24	12
839	5	30	12	10
839	5	60	6	7
139	15	15	12	2
139	15	30	6	2
139	15	60	3	2
139	30	15	24	2
139	30	30	12	2
139	30	60	6	2
139	60	60	12	2
139	60	120	6	2
139	120	60	24	2
139	120	120	12	2
139	120	480	3	1
139	120	960	2	23
139	480	120	48	2
139	480	480	12	2
139	480	960	6	2
139	960	120	96	2
139	960	480	24	2
139	960	960	12	2
571	30	15	96	2
571	30	30	48	2
571	30	60	24	2
571	120	120	48	2
571	120	480	12	1
571	120	960	7	47
571	480	120	192	2
571	480	480	48	2
571	480	960	24	2
1151	15	15	96	1
1151	15	30	48	1
1151	15	60	24	1
1151	120	120	97	6
1151	120	480	25	23
1151	120	960	13	45

Table 6.3.3.2-2: Random access configurations for FR1 and paired spectrum/supplementary uplink.

PRACH Configuration Index	Preamble format	$n_\mathrm{f} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_\mathrm{t}^\mathrm{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	$N_\mathrm{dur}^\mathrm{RA}$, PRACH duration
		x	y					
0	0	16	1	1	0	-	-	0
1	0	16	1	4	0	-	-	0
2	0	16	1	7	0	-	-	0
3	0	16	1	9	0	-	-	0
4	0	8	1	1	0	-	-	0
5	0	8	1	4	0	-	-	0
6	0	8	1	7	0	-	-	0
7	0	8	1	9	0	-	-	0
8	0	4	1	1	0	-	-	0
9	0	4	1	4	0	-	-	0
10	0	4	1	7	0	-	-	0
11	0	4	1	9	0	-	-	0
12	0	2	1	1	0	-	-	0
13	0	2	1	4	0	-	-	0
14	0	2	1	7	0	-	-	0
15	0	2	1	9	0	-	-	0
16	0	1	0	1	0	-	-	0
17	0	1	0	4	0	-	-	0
18	0	1	0	7	0	-	-	0
19	0	1	0	1,6	0	-	-	0
20	0	1	0	2,7	0	-	-	0
21	0	1	0	3,8	0	-	-	0
22	0	1	0	1,4,7	0	-	-	0
23	0	1	0	2,5,8	0	-	-	0
24	0	1	0	3, 6, 9	0	-	-	0
25	0	1	0	0,2,4,6,8	0	-	-	0
26	0	1	0	1,3,5,7,9	0	-	-	0
27	0	1	0	0,1,2,3,4,5,6,7,8,9	0	-	-	0
28	1	16	1	1	0	-	-	0
29	1	16	1	4	0	-	-	0
30	1	16	1	7	0	-	-	0
31	1	16	1	9	0	-	-	0
32	1	8	1	1	0	-	-	0
33	1	8	1	4	0	-	-	0
34	1	8	1	7	0	-	-	0
35	1	8	1	9	0	-	-	0
36	1	4	1	1	0	-	-	0
37	1	4	1	4	0	-	-	0
38	1	4	1	7	0	-	-	0
39	1	4	1	9	0	-	-	0
40	1	2	1	1	0	-	-	0
41	1	2	1	4	0	-	-	0
42	1	2	1	7	0	-	-	0
43	1	2	1	9	0	-	-	0
44	1	1	0	1	0	-	-	0
45	1	1	0	4	0	-	-	0
46	1	1	0	7	0	-	-	0
47	1	1	0	1,6	0	-	-	0
48	1	1	0	2,7	0	-	-	0
49	1	1	0	3,8	0	-	-	0
50	1	1	0	1,4,7	0	-	-	0
51	1	1	0	2,5,8	0	-	-	0
52	1	1	0	3,6,9	0	-	-	0
53	2	16	1	1	0	-	-	0
54	2	8	1	1	0	-	-	0
55	2	4	0	1	0	-	-	0

56	2	2	0	1	0	-	-	0
57	2	2	0	5	0	-	-	0
58	2	1	0	1	0	-	-	0
59	2	1	0	5	0	-	-	0
60	3	16	1	1	0	-	-	0
61	3	16	1	4	0	-	-	0
62	3	16	1	7	0	-	-	0
63	3	16	1	9	0	-	-	0
64	3	8	1	1	0	-	-	0
65	3	8	1	4	0	-	-	0
66	3	8	1	7	0	-	-	0
67	3	4	1	1	0	-	-	0
68	3	4	1	4	0	-	-	0
69	3	4	1	7	0	-	-	0
70	3	4	1	9	0	-	-	0
71	3	2	1	1	0	-	-	0
72	3	2	1	4	0	-	-	0
73	3	2	1	7	0	-	-	0
74	3	2	1	9	0	-	-	0
75	3	1	0	1	0	-	-	0
76	3	1	0	4	0	-	-	0
77	3	1	0	7	0	-	-	0
78	3	1	0	1,6	0	-	-	0
79	3	1	0	2,7	0	-	-	0
80	3	1	0	3,8	0	-	-	0
81	3	1	0	1,4,7	0	-	-	0
82	3	1	0	2,5,8	0	-	-	0
83	3	1	0	3, 6, 9	0	-	-	0
84	3	1	0	0,2,4,6,8	0	-	-	0
85	3	1	0	1,3,5,7,9	0	-	-	0
86	3	1	0	0,1,2,3,4,5,6,7,8,9	0	-	-	0
87	A1	16	0	4,9	0	1	6	2
88	A1	16	1	4	0	2	6	2
89	A1	8	0	4,9	0	1	6	2
90	A1	8	1	4	0	2	6	2
91	A1	4	0	4,9	0	1	6	2
92	A1	4	1	4,9	0	1	6	2
93	A1	4	0	4	0	2	6	2
94	A1	2	0	4,9	0	1	6	2
95	A1	2	0	1	0	2	6	2
96	A1	2	0	4	0	2	6	2
97	A1	2	0	7	0	2	6	2
98	A1	1	0	4	0	1	6	2
99	A1	1	0	1,6	0	1	6	2
100	A1	1	0	4,9	0	1	6	2
101	A1	1	0	1	0	2	6	2
102	A1	1	0	7	0	2	6	2
103	A1	1	0	2,7	0	2	6	2
104	A1	1	0	1,4,7	0	2	6	2
105	A1	1	0	0,2,4,6,8	0	2	6	2
106	A1	1	0	0,1,2,3,4,5,6,7,8,9	0	2	6	2
107	A1	1	0	1,3,5,7,9	0	2	6	2
108	A1/B1	2	0	4,9	0	1	7	2
109	A1/B1	2	0	4	0	2	7	2
110	A1/B1	1	0	4	0	1	7	2
111	A1/B1	1	0	1,6	0	1	7	2
112	A1/B1	1	0	4,9	0	1	7	2
113	A1/B1	1	0	1	0	2	7	2
114	A1/B1	1	0	7	0	2	7	2
115	A1/B1	1	0	1,4,7	0	2	7	2
116	A1/B1	1	0	0,2,4,6,8	0	2	7	2
117	A2	16	1	2,6,9	0	1	3	4
118	A2	16	1	4	0	2	3	4
119	A2	8	1	2,6,9	0	1	3	4
120	A2	8	1	4	0	2	3	4

121	A2	4	0	2,6,9	0	1	3	4
122	A2	4	0	4	0	2	3	4
123	A2	2	1	2,6,9	0	1	3	4
124	A2	2	0	1	0	2	3	4
125	A2	2	0	4	0	2	3	4
126	A2	2	0	7	0	2	3	4
127	A2	1	0	4	0	1	3	4
128	A2	1	0	1,6	0	1	3	4
129	A2	1	0	4,9	0	1	3	4
130	A2	1	0	1	0	2	3	4
131	A2	1	0	7	0	2	3	4
132	A2	1	0	2,7	0	2	3	4
133	A2	1	0	1,4,7	0	2	3	4
134	A2	1	0	0,2,4,6,8	0	2	3	4
135	A2	1	0	0,1,2,3,4,5,6,7,8,9	0	2	3	4
136	A2	1	0	1,3,5,7,9	0	2	3	4
137	A2/B2	2	1	2,6,9	0	1	3	4
138	A2/B2	2	0	4	0	2	3	4
139	A2/B2	1	0	4	0	1	3	4
140	A2/B2	1	0	1,6	0	1	3	4
141	A2/B2	1	0	4,9	0	1	3	4
142	A2/B2	1	0	1	0	2	3	4
143	A2/B2	1	0	7	0	2	3	4
144	A2/B2	1	0	1,4,7	0	2	3	4
145	A2/B2	1	0	0,2,4,6,8	0	2	3	4
146	A2/B2	1	0	0,1,2,3,4,5,6,7,8,9	0	2	3	4
147	A3	16	1	4,9	0	1	2	6
148	A3	16	1	4	0	2	2	6
149	A3	8	1	4,9	0	1	2	6
150	A3	8	1	4	0	2	2	6
151	A3	4	0	4,9	0	1	2	6
152	A3	4	0	4	0	2	2	6
153	A3	2	1	2,6,9	0	2	2	6
154	A3	2	0	1	0	2	2	6
155	A3	2	0	4	0	2	2	6
156	A3	2	0	7	0	2	2	6
157	A3	1	0	4	0	1	2	6
158	A3	1	0	1,6	0	1	2	6
159	A3	1	0	4,9	0	1	2	6
160	A3	1	0	1	0	2	2	6
161	A3	1	0	7	0	2	2	6
162	A3	1	0	2,7	0	2	2	6
163	A3	1	0	1,4,7	0	2	2	6
164	A3	1	0	0,2,4,6,8	0	2	2	6
165	A3	1	0	0,1,2,3,4,5,6,7,8,9	0	2	2	6
166	A3	1	0	1,3,5,7,9	0	2	2	6
167	A3/B3	2	1	2,6,9	0	2	2	6
168	A3/B3	2	0	4	0	2	2	6
169	A3/B3	1	0	4	0	1	2	6
170	A3/B3	1	0	1,6	0	1	2	6
171	A3/B3	1	0	4,9	0	1	2	6
172	A3/B3	1	0	1	0	2	2	6
173	A3/B3	1	0	7	0	2	2	6
174	A3/B3	1	0	1,4,7	0	2	2	6
175	A3/B3	1	0	0,2,4,6,8	0	2	2	6
176	A3/B3	1	0	0,1,2,3,4,5,6,7,8,9	0	2	2	6
177	B1	16	0	4,9	0	1	7	2
178	B1	16	1	4	0	2	7	2
179	B1	8	0	4,9	0	1	7	2
180	B1	8	1	4	0	2	7	2
181	B1	4	0	4,9	0	1	7	2
182	B1	4	1	4,9	0	1	7	2
183	B1	4	0	4	0	2	7	2
184	B1	2	0	4,9	0	1	7	2
185	B1	2	0	1	0	2	7	2

186	B1	2	0	4	0	2	7	2
187	B1	2	0	7	0	2	7	2
188	B1	1	0	4	0	1	7	2
189	B1	1	0	1,6	0	1	7	2
190	B1	1	0	4,9	0	1	7	2
191	B1	1	0	1	0	2	7	2
192	B1	1	0	7	0	2	7	2
193	B1	1	0	2,7	0	2	7	2
194	B1	1	0	1,4,7	0	2	7	2
195	B1	1	0	0,2,4,6,8	0	2	7	2
196	B1	1	0	0,1,2,3,4,5,6,7,8,9	0	2	7	2
197	B1	1	0	1,3,5,7,9	0	2	7	2
198	B4	16	0	4,9	0	2	1	12
199	B4	16	1	4	0	2	1	12
200	B4	8	0	4,9	0	2	1	12
201	B4	8	1	4	0	2	1	12
202	B4	4	0	4,9	0	2	1	12
203	B4	4	0	4	0	2	1	12
204	B4	4	1	4,9	0	2	1	12
205	B4	2	0	4,9	0	2	1	12
206	B4	2	0	1	0	2	1	12
207	B4	2	0	4	0	2	1	12
208	B4	2	0	7	0	2	1	12
209	B4	1	0	1	0	2	1	12
210	B4	1	0	4	0	2	1	12
211	B4	1	0	7	0	2	1	12
212	B4	1	0	1,6	0	2	1	12
213	B4	1	0	2,7	0	2	1	12
214	B4	1	0	4,9	0	2	1	12
215	B4	1	0	1,4,7	0	2	1	12
216	B4	1	0	0,2,4,6,8	0	2	1	12
217	B4	1	0	0,1,2,3,4,5,6,7,8,9	0	2	1	12
218	B4	1	0	1,3,5,7,9	0	2	1	12
219	C0	8	1	4	0	2	7	2
220	C0	4	1	4,9	0	1	7	2
221	C0	4	0	4	0	2	7	2
222	C0	2	0	4,9	0	1	7	2
223	C0	2	0	1	0	2	7	2
224	C0	2	0	4	0	2	7	2
225	C0	2	0	7	0	2	7	2
226	C0	1	0	4	0	1	7	2
227	C0	1	0	1,6	0	1	7	2
228	C0	1	0	4,9	0	1	7	2
229	C0	1	0	1	0	2	7	2
230	C0	1	0	7	0	2	7	2
231	C0	1	0	2,7	0	2	7	2
232	C0	1	0	1,4,7	0	2	7	2
233	C0	1	0	0,2,4,6,8	0	2	7	2
234	C0	1	0	0,1,2,3,4,5,6,7,8,9	0	2	7	2
235	C0	1	0	1,3,5,7,9	0	2	7	2
236	C2	16	1	4,9	0	1	2	6
237	C2	16	1	4	0	2	2	6
238	C2	8	1	4,9	0	1	2	6
239	C2	8	1	4	0	2	2	6
240	C2	4	0	4,9	0	1	2	6
241	C2	4	0	4	0	2	2	6
242	C2	2	1	2,6,9	0	2	2	6
243	C2	2	0	1	0	2	2	6
244	C2	2	0	4	0	2	2	6
245	C2	2	0	7	0	2	2	6
246	C2	1	0	4	0	1	2	6
247	C2	1	0	1,6	0	1	2	6
248	C2	1	0	4,9	0	1	2	6
249	C2	1	0	1	0	2	2	6
250	C2	1	0	7	0	2	2	6

251	C2	1	0	2,7	0	2	2	6
252	C2	1	0	1,4,7	0	2	2	6
253	C2	1	0	0,2,4,6,8	0	2	2	6
254	C2	1	0	0,1,2,3,4,5,6,7,8,9	0	2	2	6
255	C2	1	0	1,3,5,7,9	0	2	2	6

Table 6.3.3.2-3: Random access configurations for FR1 and unpaired spectrum.

PRACH Configuration Index	Preamble format	n_f mod $x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_\mathrm{t}^\mathrm{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	$N_\mathrm{dur}^\mathrm{RA}$, PRACH duration
		x	y					
0	0	16	1	9	0	-	-	0
1	0	8	1	9	0	-	-	0
2	0	4	1	9	0	-	-	0
3	0	2	0	9	0	-	-	0
4	0	2	1	9	0	-	-	0
5	0	2	0	4	0	-	-	0
6	0	2	1	4	0	-	-	0
7	0	1	0	9	0	-	-	0
8	0	1	0	8	0	-	-	0
9	0	1	0	7	0	-	-	0
10	0	1	0	6	0	-	-	0
11	0	1	0	5	0	-	-	0
12	0	1	0	4	0	-	-	0
13	0	1	0	3	0	-	-	0
14	0	1	0	2	0	-	-	0
15	0	1	0	1,6	0			0
16	0	1	0	1,6	7	-	-	0
17	0	1	0	4,9	0	-	-	0
18	0	1	0	3,8	0	-	-	0
19	0	1	0	2,7	0	-	-	0
20	0	1	0	8,9	0	-	-	0
21	0	1	0	4,8,9	0	-	-	0
22	0	1	0	3,4,9	0	-	-	0
23	0	1	0	7,8,9	0	-	-	0
24	0	1	0	3,4,8,9	0	-	-	0
25	0	1	0	6,7,8,9	0	-	-	0
26	0	1	0	1,4,6,9	0	-	-	0
27	0	1	0	1,3,5,7,9	0	-	-	0
28	1	16	1	7	0	-	-	0
29	1	8	1	7	0	-	-	0
30	1	4	1	7	0	-	-	0
31	1	2	0	7	0	-	-	0
32	1	2	1	7	0	-	-	0
33	1	1	0	7	0	-	-	0
34	2	16	1	6	0	-	-	0
35	2	8	1	6	0	-	-	0
36	2	4	1	6	0	-	-	0
37	2	2	0	6	7	-	-	0
38	2	2	1	6	7	-	-	0
39	2	1	0	6	7	-	-	0
40	3	16	1	9	0	-	-	0
41	3	8	1	9	0	-	-	0
42	3	4	1	9	0	-	-	0
43	3	2	0	9	0	-	-	0
44	3	2	1	9	0	-	-	0
45	3	2	0	4	0	-	-	0
46	3	2	1	4	0	-	-	0
47	3	1	0	9	0	-	-	0
48	3	1	0	8	0	-	-	0
49	3	1	0	7	0	-	-	0
50	3	1	0	6	0	-	-	0
51	3	1	0	5	0	-	-	0
52	3	1	0	4	0	-	-	0
53	3	1	0	3	0	-	-	0
54	3	1	0	2	0	-	-	0
55	3	1	0	1,6	0	-	-	0

56	3	1	0	1,6	7	-	-	0
57	3	1	0	4,9	0	-	-	0
58	3	1	0	3,8	0	-	-	0
59	3	1	0	2,7	0	-	-	0
60	3	1	0	8,9	0	-	-	0
61	3	1	0	4,8,9	0	-	-	0
62	3	1	0	3,4,9	0	-	-	0
63	3	1	0	7,8,9	0	-	-	0
64	3	1	0	3,4,8,9	0	-	-	0
65	3	1	0	1,4,6,9	0	-	-	0
66	3	1	0	1,3,5,7,9	0	-	-	0
67	A1	16	1	9	0	2	6	2
68	A1	8	1	9	0	2	6	2
69	A1	4	1	9	0	1	6	2
70	A1	2	1	9	0	1	6	2
71	A1	2	1	4,9	7	1	3	2
72	A1	2	1	7,9	7	1	3	2
73	A1	2	1	7,9	0	1	6	2
74	A1	2	1	8,9	0	2	6	2
75	A1	2	1	4,9	0	2	6	2
76	A1	2	1	2,3,4,7,8,9	0	1	6	2
77	A1	1	0	9	0	2	6	2
78	A1	1	0	9	7	1	3	2
79	A1	1	0	9	0	1	6	2
80	A1	1	0	8,9	0	2	6	2
81	A1	1	0	4,9	0	1	6	2
82	A1	1	0	7,9	7	1	3	2
83	A1	1	0	3,4,8,9	0	1	6	2
84	A1	1	0	3,4,8,9	0	2	6	2
85	A1	1	0	1,3,5,7,9	0	1	6	2
86	A1	1	0	0,1,2,3,4,5,6,7,8,9	7	1	3	2
87	A2	16	1	9	0	2	3	4
88	A2	8	1	9	0	2	3	4
89	A2	4	1	9	0	1	3	4
90	A2	2	1	7,9	0	1	3	4
91	A2	2	1	8,9	0	2	3	4
92	A2	2	1	7,9	9	1	1	4
93	A2	2	1	4,9	9	1	1	4
94	A2	2	1	4,9	0	2	3	4
95	A2	2	1	2,3,4,7,8,9	0	1	3	4
96	A2	1	0	2	0	1	3	4
97	A2	1	0	7	0	1	3	4
98	A2	2	1	9	0	1	3	4
99	A2	1	0	9	0	2	3	4
100	A2	1	0	9	9	1	1	4
101	A2	1	0	9	0	1	3	4
102	A2	1	0	2,7	0	1	3	4
103	A2	1	0	8,9	0	2	3	4
104	A2	1	0	4,9	0	1	3	4
105	A2	1	0	7,9	9	1	1	4
106	A2	1	0	3,4,8,9	0	1	3	4
107	A2	1	0	3,4,8,9	0	2	3	4
108	A2	1	0	1,3,5,7,9	0	1	3	4
109	A2	1	0	0,1,2,3,4,5,6,7,8,9	9	1	1	4
110	A3	16	1	9	0	2	2	6
111	A3	8	1	9	0	2	2	6
112	A3	4	1	9	0	1	2	6
113	A3	2	1	4,9	7	1	1	6
114	A3	2	1	7,9	7	1	1	6
115	A3	2	1	7,9	0	1	2	6
116	A3	2	1	4,9	0	2	2	6
117	A3	2	1	8,9	0	2	2	6
118	A3	2	1	2,3,4,7,8,9	0	1	2	6
119	A3	1	0	2	0	1	2	6
120	A3	1	0	7	0	1	2	6

121	A3	2	1	9	0	1	2	6
122	A3	1	0	9	0	2	2	6
123	A3	1	0	9	7	1	1	6
124	A3	1	0	9	0	1	2	6
125	A3	1	0	2,7	0	1	2	6
126	A3	1	0	8,9	0	2	2	6
127	A3	1	0	4,9	0	1	2	6
128	A3	1	0	7,9	7	1	1	6
129	A3	1	0	3,4,8,9	0	1	2	6
130	A3	1	0	3,4,8,9	0	2	2	6
131	A3	1	0	1,3,5,7,9	0	1	2	6
132	A3	1	0	0,1,2,3,4,5,6,7,8,9	7	1	1	6
133	B1	4	1	9	2	1	6	2
134	B1	2	1	9	2	1	6	2
135	B1	2	1	7,9	2	1	6	2
136	B1	2	1	4,9	8	1	3	2
137	B1	2	1	4,9	2	2	6	2
138	B1	1	0	9	2	2	6	2
139	B1	1	0	9	8	1	3	2
140	B1	1	0	9	2	1	6	2
141	B1	1	0	8,9	2	2	6	2
142	B1	1	0	4,9	2	1	6	2
143	B1	1	0	7,9	8	1	3	2
144	B1	1	0	1,3,5,7,9	2	1	6	2
145	B4	16	1	9	0	2	1	12
146	B4	8	1	9	0	2	1	12
147	B4	4	1	9	2	1	1	12
148	B4	2	1	9	0	1	1	12
149	B4	2	1	9	2	1	1	12
150	B4	2	1	7,9	2	1	1	12
151	B4	2	1	4,9	2	1	1	12
152	B4	2	1	4,9	0	2	1	12
153	B4	2	1	8,9	0	2	1	12
154	B4	2	1	2,3,4,7,8,9	0	1	1	12
155	B4	1	0	1	0	1	1	12
156	B4	1	0	2	0	1	1	12
157	B4	1	0	4	0	1	1	12
158	B4	1	0	7	0	1	1	12
159	B4	1	0	9	0	1	1	12
160	B4	1	0	9	2	1	1	12
161	B4	1	0	9	0	2	1	12
162	B4	1	0	4,9	2	1	1	12
163	B4	1	0	7,9	2	1	1	12
164	B4	1	0	8,9	0	2	1	12
165	B4	1	0	3,4,8,9	2	1	1	12
166	B4	1	0	1,3,5,7,9	2	1	1	12
167	B4	1	0	0,1,2,3,4,5,6,7,8,9	0	2	1	12
168	B4	1	0	0,1,2,3,4,5,6,7,8,9	2	1	1	12
169	C0	16	1	9	2	2	6	2
170	C0	8	1	9	2	2	6	2
171	C0	4	1	9	2	1	6	2
172	C0	2	1	9	2	1	6	2
173	C0	2	1	8,9	2	2	6	2
174	C0	2	1	7,9	2	1	6	2
175	C0	2	1	7,9	8	1	3	2
176	C0	2	1	4,9	8	1	3	2
177	C0	2	1	4,9	2	2	6	2
178	C0	2	1	2,3,4,7,8,9	2	1	6	2
179	C0	1	0	9	2	2	6	2
180	C0	1	0	9	8	1	3	2
181	C0	1	0	9	2	1	6	2
182	C0	1	0	8,9	2	2	6	2
183	C0	1	0	4,9	2	1	6	2
184	C0	1	0	7,9	8	1	3	2
185	C0	1	0	3,4,8,9	2	1	6	2

186	C0	1	0	3,4,8,9	2	2	6	2
187	C0	1	0	1,3,5,7,9	2	1	6	2
188	C0	1	0	0,1,2,3,4,5,6,7,8,9	8	1	3	2
189	C2	16	1	9	2	2	2	6
190	C2	8	1	9	2	2	2	6
191	C2	4	1	9	2	1	2	6
192	C2	2	1	9	2	1	2	6
193	C2	2	1	8,9	2	2	2	6
194	C2	2	1	7,9	2	1	2	6
195	C2	2	1	7,9	8	1	1	6
196	C2	2	1	4,9	8	1	1	6
197	C2	2	1	4,9	2	2	2	6
198	C2	2	1	2,3,4,7,8,9	2	1	2	6
199	C2	8	1	9	8	2	1	6
200	C2	4	1	9	8	1	1	6
201	C2	1	0	9	2	2	2	6
202	C2	1	0	9	8	1	1	6
203	C2	1	0	9	2	1	2	6
204	C2	1	0	8,9	2	2	2	6
205	C2	1	0	4,9	2	1	2	6
206	C2	1	0	7,9	8	1	1	6
207	C2	1	0	3,4,8,9	2	1	2	6
208	C2	1	0	3,4,8,9	2	2	2	6
209	C2	1	0	1,3,5,7,9	2	1	2	6
210	C2	1	0	0,1,2,3,4,5,6,7,8,9	8	1	1	6
211	A1/B1	2	1	9	2	1	6	2
212	A1/B1	2	1	4,9	8	1	3	2
213	A1/B1	2	1	7,9	8	1	3	2
214	A1/B1	2	1	7,9	2	1	6	2
215	A1/B1	2	1	4,9	2	2	6	2
216	A1/B1	2	1	8,9	2	2	6	2
217	A1/B1	1	0	9	2	2	6	2
218	A1/B1	1	0	9	8	1	3	2
219	A1/B1	1	0	9	2	1	6	2
220	A1/B1	1	0	8,9	2	2	6	2
221	A1/B1	1	0	4,9	2	1	6	2
222	A1/B1	1	0	7,9	8	1	3	2
223	A1/B1	1	0	3,4,8,9	2	2	6	2
224	A1/B1	1	0	1,3,5,7,9	2	1	6	2
225	A1/B1	1	0	0,1,2,3,4,5,6,7,8,9	8	1	3	2
226	A2/B2	2	1	9	0	1	3	4
227	A2/B2	2	1	4,9	6	1	2	4
228	A2/B2	2	1	7,9	6	1	2	4
229	A2/B2	2	1	4,9	0	2	3	4
230	A2/B2	2	1	8,9	0	2	3	4
231	A2/B2	1	0	9	0	2	3	4
232	A2/B2	1	0	9	6	1	2	4
233	A2/B2	1	0	9	0	1	3	4
234	A2/B2	1	0	8,9	0	2	3	4
235	A2/B2	1	0	4,9	0	1	3	4
236	A2/B2	1	0	7,9	6	1	2	4
237	A2/B2	1	0	3,4,8,9	0	1	3	4
238	A2/B2	1	0	3,4,8,9	0	2	3	4
239	A2/B2	1	0	1,3,5,7,9	0	1	3	4
240	A2/B2	1	0	0,1,2,3,4,5,6,7,8,9	6	1	2	4
241	A3/B3	2	1	9	0	1	2	6
242	A3/B3	2	1	4,9	2	1	2	6
243	A3/B3	2	1	7,9	0	1	2	6
244	A3/B3	2	1	7,9	2	1	2	6
245	A3/B3	2	1	4,9	0	2	2	6
246	A3/B3	2	1	8,9	0	2	2	6
247	A3/B3	1	0	9	0	2	2	6
248	A3/B3	1	0	9	2	1	2	6
249	A3/B3	1	0	9	0	1	2	6
250	A3/B3	1	0	8,9	0	2	2	6

251	A3/B3	1	0	4,9	0	1	2	6
252	A3/B3	1	0	7,9	2	1	2	6
253	A3/B3	1	0	3,4,8,9	0	2	2	6
254	A3/B3	1	0	1,3,5,7,9	0	1	2	6
255	A3/B3	1	0	0,1,2,3,4,5,6,7,8,9	2	1	2	6
256	0	16	1	7	0	-	-	0
257	0	8	1	7	0	-	-	0
258	0	4	1	7	0	-	-	0
259	0	2	0	7	0	-	-	0
260	0	2	1	7	0	-	-	0
261	0	2	0	2	0	-	-	0
262	0	2	1	2	0	-	-	0

Table 6.3.3.2-4: Random access configurations for FR2 and unpaired spectrum.

PRACH Config. Index	Preamble format	$n_\mathrm{f} \bmod x = y$		Slot number	Starting symbol	Number of PRACH slots within a 60 kHz slot	$N_\mathrm{t}^\mathrm{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	$N_\mathrm{dur}^\mathrm{RA}$, PRACH duration
		x	y					
0	A1	16	1	4,9,14,19,24,29,34,39	0	2	6	2
1	A1	16	1	3,7,11,15,19,23,27,31,35,39	0	1	6	2
2	A1	8	1,2	9,19,29,39	0	2	6	2
3	A1	8	1	4,9,14,19,24,29,34,39	0	2	6	2
4	A1	8	1	3,7,11,15,19,23,27,31,35,39	0	1	6	2
5	A1	4	1	4,9,14,19,24,29,34,39	0	1	6	2
6	A1	4	1	4,9,14,19,24,29,34,39	0	2	6	2
7	A1	4	1	3,7,11,15,19,23,27,31,35,39	0	1	6	2
8	A1	2	1	7,15,23,31,39	0	2	6	2
9	A1	2	1	4,9,14,19,24,29,34,39	0	1	6	2
10	A1	2	1	4,9,14,19,24,29,34,39	0	2	6	2
11	A1	2	1	3,7,11,15,19,23,27,31,35,39	0	1	6	2
12	A1	1	0	19,39	7	1	3	2
13	A1	1	0	3,5,7	0	1	6	2
14	A1	1	0	24,29,34,39	7	1	3	2
15	A1	1	0	9,19,29,39	7	2	3	2
16	A1	1	0	17,19,37,39	0	1	6	2
17	A1	1	0	9,19,29,39	0	2	6	2
18	A1	1	0	4,9,14,19,24,29,34,39	0	1	6	2
19	A1	1	0	4,9,14,19,24,29,34,39	7	1	3	2
20	A1	1	0	3,5,7,9,11,13	7	1	3	2
21	A1	1	0	23,27,31,35,39	7	1	3	2
22	A1	1	0	7,15,23,31,39	0	1	6	2
23	A1	1	0	23,27,31,35,39	0	1	6	2
24	A1	1	0	13,14,15, 29,30,31,37,38,39	7	2	3	2
25	A1	1	0	3,7,11,15,19,23,27,31,35,39	7	1	3	2
26	A1	1	0	3,7,11,15,19,23,27,31,35,39	0	1	6	2
27	A1	1	0	1,3,5,7,…,37,39	0	1	6	2
28	A1	1	0	0,1,2,…,39	7	1	3	2
29	A2	16	1	4,9,14,19,24,29,34,39	0	2	3	4
30	A2	16	1	3,7,11,15,19,23,27,31,35,39	0	1	3	4
31	A2	8	1	4,9,14,19,24,29,34,39	0	2	3	4
32	A2	8	1	3,7,11,15,19,23,27,31,35,39	0	1	3	4
33	A2	8	1,2	9,19,29,39	0	2	3	4
34	A2	4	1	4,9,14,19,24,29,34,39	0	1	3	4
35	A2	4	1	4,9,14,19,24,29,34,39	0	2	3	4
36	A2	4	1	3,7,11,15,19,23,27,31,35,39	0	1	3	4
37	A2	2	1	7,15,23,31,39	0	2	3	4
38	A2	2	1	4,9,14,19,24,29,34,39	0	1	3	4
39	A2	2	1	4,9,14,19,24,29,34,39	0	2	3	4
40	A2	2	1	3,7,11,15,19,23,27,31,35,39	0	1	3	4
41	A2	1	0	19,39	5	1	2	4
42	A2	1	0	3,5,7	0	1	3	4
43	A2	1	0	24,29,34,39	5	1	2	4
44	A2	1	0	9,19,29,39	5	2	2	4
45	A2	1	0	17,19,37,39	0	1	3	4
46	A2	1	0	9, 19, 29, 39	0	2	3	4
47	A2	1	0	7,15,23,31,39	0	1	3	4
48	A2	1	0	23,27,31,35,39	5	1	2	4
49	A2	1	0	23,27,31,35,39	0	1	3	4
50	A2	1	0	3,5,7,9,11,13	5	1	2	4
51	A2	1	0	3,5,7,9,11,13	0	1	3	4
52	A2	1	0	4,9,14,19,24,29,34,39	5	1	2	4
53	A2	1	0	4,9,14,19,24,29,34,39	0	1	3	4
54	A2	1	0	13,14,15, 29,30,31,37,38,39	5	2	2	4
55	A2	1	0	3,7,11,15,19,23,27,31,35,39	5	1	2	4

56	A2	1	0	3,7,11,15,19,23,27,31,35,39	0	1	3	4
57	A2	1	0	1,3,5,7,…,37,39	0	1	3	4
58	A2	1	0	0,1,2,…,39	5	1	2	4
59	A3	16	1	4,9,14,19,24,29,34,39	0	2	2	6
60	A3	16	1	3,7,11,15,19,23,27,31,35,39	0	1	2	6
61	A3	8	1	4,9,14,19,24,29,34,39	0	2	2	6
62	A3	8	1	3,7,11,15,19,23,27,31,35,39	0	1	2	6
63	A3	8	1,2	9,19,29,39	0	2	2	6
64	A3	4	1	4,9,14,19,24,29,34,39	0	1	2	6
65	A3	4	1	4,9,14,19,24,29,34,39	0	2	2	6
66	A3	4	1	3,7,11,15,19,23,27,31,35,39	0	1	2	6
67	A3	2	1	4,9,14,19,24,29,34,39	0	1	2	6
68	A3	2	1	4,9,14,19,24,29,34,39	0	2	2	6
69	A3	2	1	3,7,11,15,19,23,27,31,35,39	0	1	2	6
70	A3	1	0	19,39	7	1	1	6
71	A3	1	0	3,5,7	0	1	2	6
72	A3	1	0	9,11,13	2	1	2	6
73	A3	1	0	24,29,34,39	7	1	1	6
74	A3	1	0	9,19,29,39	7	2	1	6
75	A3	1	0	17,19,37,39	0	1	2	6
76	A3	1	0	9,19,29,39	0	2	2	6
77	A3	1	0	7,15,23,31,39	0	1	2	6
78	A3	1	0	23,27,31,35,39	7	1	1	6
79	A3	1	0	23,27,31,35,39	0	1	2	6
80	A3	1	0	3,5,7,9,11,13	0	1	2	6
81	A3	1	0	3,5,7,9,11,13	7	1	1	6
82	A3	1	0	4,9,14,19,24,29,34,39	0	1	2	6
83	A3	1	0	4,9,14,19,24,29,34,39	7	1	1	6
84	A3	1	0	13,14,15, 29,30,31,37,38,39	7	2	1	6
85	A3	1	0	3,7,11,15,19,23,27,31,35,39	7	1	1	6
86	A3	1	0	3,7,11,15,19,23,27,31,35,39	0	1	2	6
87	A3	1	0	1,3,5,7,…,37,39	0	1	2	6
88	A3	1	0	0,1,2,…,39	7	1	1	6
89	B1	16	1	4,9,14,19,24,29,34,39	2	2	6	2
90	B1	8	1	4,9,14,19,24,29,34,39	2	2	6	2
91	B1	8	1,2	9,19,29,39	2	2	6	2
92	B1	4	1	4,9,14,19,24,29,34,39	2	2	6	2
93	B1	2	1	4,9,14,19,24,29,34,39	2	2	6	2
94	B1	2	1	3,7,11,15,19,23,27,31,35,39	2	1	6	2
95	B1	1	0	19,39	8	1	3	2
96	B1	1	0	3,5,7	2	1	6	2
97	B1	1	0	24,29,34,39	8	1	3	2
98	B1	1	0	9,19,29,39	8	2	3	2
99	B1	1	0	17,19,37,39	2	1	6	2
100	B1	1	0	9,19,29,39	2	2	6	2
101	B1	1	0	7,15,23,31,39	2	1	6	2
102	B1	1	0	23,27,31,35,39	8	1	3	2
103	B1	1	0	23,27,31,35,39	2	1	6	2
104	B1	1	0	3,5,7,9,11,13	8	1	3	2
105	B1	1	0	4,9,14,19,24,29,34,39	8	1	3	2
106	B1	1	0	4,9,14,19,24,29,34,39	2	1	6	2
107	B1	1	0	3,7,11,15,19,23,27,31,35,39	8	1	3	2
108	B1	1	0	13,14,15, 29,30,31,37,38,39	8	2	3	2
109	B1	1	0	3,7,11,15,19,23,27,31,35,39	2	1	6	2
110	B1	1	0	1,3,5,7,…,37,39	2	1	6	2
111	B1	1	0	0,1,2,…,39	8	1	3	2
112	B4	16	1,2	4,9,14,19,24,29,34,39	0	2	1	12
113	B4	16	1,2	3,7,11,15,19,23,27,31,35,39	0	1	1	12
114	B4	8	1,2	4,9,14,19,24,29,34,39	0	2	1	12
115	B4	8	1,2	3,7,11,15,19,23,27,31,35,39	0	1	1	12
116	B4	8	1,2	9,19,29,39	0	2	1	12
117	B4	4	1	4,9,14,19,24,29,34,39	0	1	1	12
118	B4	4	1	4,9,14,19,24,29,34,39	0	2	1	12
119	B4	4	1,2	3,7,11,15,19,23,27,31,35,39	0	1	1	12
120	B4	2	1	7,15,23,31,39	2	2	1	12

121	B4	2	1	4,9,14,19,24,29,34,39	0	1	1	12
122	B4	2	1	4,9,14,19,24,29,34,39	0	2	1	12
123	B4	2	1	3,7,11,15,19,23,27,31,35,39	0	1	1	12
124	B4	1	0	19, 39	2	2	1	12
125	B4	1	0	17, 19, 37, 39	0	1	1	12
126	B4	1	0	24,29,34,39	2	1	1	12
127	B4	1	0	9,19,29,39	2	2	1	12
128	B4	1	0	9,19,29,39	0	2	1	12
129	B4	1	0	7,15,23,31,39	0	1	1	12
130	B4	1	0	7,15,23,31,39	0	2	1	12
131	B4	1	0	23,27,31,35,39	0	1	1	12
132	B4	1	0	23,27,31,35,39	2	2	1	12
133	B4	1	0	9,11,13,15,17,19	0	1	1	12
134	B4	1	0	3,5,7,9,11,13	2	1	1	12
135	B4	1	0	4,9,14,19,24,29,34,39	0	1	1	12
136	B4	1	0	4,9,14,19,24,29,34,39	2	2	1	12
137	B4	1	0	13,14,15, 29,30,31,37,38,39	2	2	1	12
138	B4	1	0	3,7,11,15,19,23,27,31,35,39	0	1	1	12
139	B4	1	0	3,7,11,15,19,23,27,31,35,39	2	1	1	12
140	B4	1	0	3, 5, 7, …, 23,25	2	1	1	12
141	B4	1	0	3, 5, 7, …, 23,25	0	2	1	12
142	B4	1	0	1,3,5,7,…,37,39	0	1	1	12
143	B4	1	0	0, 1, 2,…, 39	2	1	1	12
144	C0	16	1	4,9,14,19,24,29,34,39	0	2	7	2
145	C0	16	1	3,7,11,15,19,23,27,31,35,39	0	1	7	2
146	C0	8	1	4,9,14,19,24,29,34,39	0	1	7	2
147	C0	8	1	3,7,11,15,19,23,27,31,35,39	0	1	7	2
148	C0	8	1,2	9,19,29,39	0	2	7	2
149	C0	4	1	4,9,14,19,24,29,34,39	0	1	7	2
150	C0	4	1	4,9,14,19,24,29,34,39	0	2	7	2
151	C0	4	1	3,7,11,15,19,23,27,31,35,39	0	1	7	2
152	C0	2	1	7,15,23,31,39	0	2	7	2
153	C0	2	1	4,9,14,19,24,29,34,39	0	1	7	2
154	C0	2	1	4,9,14,19,24,29,34,39	0	2	7	2
155	C0	2	1	3,7,11,15,19,23,27,31,35,39	0	1	7	2
156	C0	1	0	19,39	8	1	3	2
157	C0	1	0	3,5,7	0	1	7	2
158	C0	1	0	24,29,34,39	8	1	3	2
159	C0	1	0	9,19,29,39	8	2	3	2
160	C0	1	0	17,19,37,39	0	1	7	2
161	C0	1	0	9,19,29,39	0	2	7	2
162	C0	1	0	23,27,31,35,39	8	1	3	2
163	C0	1	0	7,15,23,31,39	0	1	7	2
164	C0	1	0	23,27,31,35,39	0	1	7	2
165	C0	1	0	3,5,7,9,11,13	8	1	3	2
166	C0	1	0	4,9,14,19,24,29,34,39	8	1	3	2
167	C0	1	0	4,9,14,19,24,29,34,39	0	1	7	2
168	C0	1	0	13,14,15, 29,30,31,37,38,39	8	2	3	2
169	C0	1	0	3,7,11,15,19,23,27,31,35,39	8	1	3	2
170	C0	1	0	3,7,11,15,19,23,27,31,35,39	0	1	7	2
171	C0	1	0	1,3,5,7,…,37,39	0	1	7	2
172	C0	1	0	0,1,2,…,39	8	1	3	2
173	C2	16	1	4,9,14,19,24,29,34,39	0	2	2	6
174	C2	16	1	3,7,11,15,19,23,27,31,35,39	0	1	2	6
175	C2	8	1	4,9,14,19,24,29,34,39	0	2	2	6
176	C2	8	1	3,7,11,15,19,23,27,31,35,39	0	1	2	6
177	C2	8	1,2	9,19,29,39	0	2	2	6
178	C2	4	1	4,9,14,19,24,29,34,39	0	1	2	6
179	C2	4	1	4,9,14,19,24,29,34,39	0	2	2	6
180	C2	4	1	3,7,11,15,19,23,27,31,35,39	0	1	2	6
181	C2	2	1	7,15,23,31,39	2	2	2	6
182	C2	2	1	4,9,14,19,24,29,34,39	0	1	2	6
183	C2	2	1	4,9,14,19,24,29,34,39	0	2	2	6
184	C2	2	1	3,7,11,15,19,23,27,31,35,39	0	1	2	6
185	C2	1	0	19,39	2	1	2	6

186	C2	1	0	3,5,7	0	1	2	6
187	C2	1	0	24,29,34,39	7	1	1	6
188	C2	1	0	9,19,29,39	7	2	1	6
189	C2	1	0	17,19,37,39	0	1	2	6
190	C2	1	0	9,19,29,39	2	2	2	6
191	C2	1	0	7,15,23,31,39	2	1	2	6
192	C2	1	0	3,5,7,9,11,13	7	1	1	6
193	C2	1	0	23,27,31,35,39	7	2	1	6
194	C2	1	0	23,27,31,35,39	0	1	2	6
195	C2	1	0	4,9,14,19,24,29,34,39	7	2	1	6
196	C2	1	0	4,9,14,19,24,29,34,39	2	1	2	6
197	C2	1	0	13,14,15, 29,30,31,37,38,39	7	2	1	6
198	C2	1	0	3,7,11,15,19,23,27,31,35,39	7	1	1	6
199	C2	1	0	3,7,11,15,19,23,27,31,35,39	0	1	2	6
200	C2	1	0	1,3,5,7,…,37,39	0	1	2	6
201	C2	1	0	0,1,2,…,39	7	1	1	6
202	A1/B1	16	1	4,9,14,19,24,29,34,39	2	1	6	2
203	A1/B1	16	1	3,7,11,15,19,23,27,31,35,39	2	1	6	2
204	A1/B1	8	1	4,9,14,19,24,29,34,39	2	1	6	2
205	A1/B1	8	1	3,7,11,15,19,23,27,31,35,39	2	1	6	2
206	A1/B1	4	1	4,9,14,19,24,29,34,39	2	1	6	2
207	A1/B1	4	1	3,7,11,15,19,23,27,31,35,39	2	1	6	2
208	A1/B1	2	1	4,9,14,19,24,29,34,39	2	1	6	2
209	A1/B1	1	0	19,39	8	1	3	2
210	A1/B1	1	0	9,19,29,39	8	1	3	2
211	A1/B1	1	0	17,19,37,39	2	1	6	2
212	A1/B1	1	0	9,19,29,39	2	2	6	2
213	A1/B1	1	0	23,27,31,35,39	8	1	3	2
214	A1/B1	1	0	7,15,23,31,39	2	1	6	2
215	A1/B1	1	0	23,27,31,35,39	2	1	6	2
216	A1/B1	1	0	4,9,14,19,24,29,34,39	8	1	3	2
217	A1/B1	1	0	4,9,14,19,24,29,34,39	2	1	6	2
218	A1/B1	1	0	3,7,11,15,19,23,27,31,35,39	2	1	6	2
219	A1/B1	1	0	1,3,5,7,…,37,39	2	1	6	2
220	A2/B2	16	1	4,9,14,19,24,29,34,39	2	1	3	4
221	A2/B2	16	1	3,7,11,15,19,23,27,31,35,39	2	1	3	4
222	A2/B2	8	1	4,9,14,19,24,29,34,39	2	1	3	4
223	A2/B2	8	1	3,7,11,15,19,23,27,31,35,39	2	1	3	4
224	A2/B2	4	1	4,9,14,19,24,29,34,39	2	1	3	4
225	A2/B2	4	1	3,7,11,15,19,23,27,31,35,39	2	1	3	4
226	A2/B2	2	1	4,9,14,19,24,29,34,39	2	1	3	4
227	A2/B2	1	0	19,39	6	1	2	4
228	A2/B2	1	0	9,19,29,39	6	1	2	4
229	A2/B2	1	0	17,19,37,39	2	1	3	4
230	A2/B2	1	0	9,19,29,39	2	2	3	4
231	A2/B2	1	0	23,27,31,35,39	6	1	2	4
232	A2/B2	1	0	7,15,23,31,39	2	1	3	4
233	A2/B2	1	0	23,27,31,35,39	2	1	3	4
234	A2/B2	1	0	4,9,14,19,24,29,34,39	6	1	2	4
235	A2/B2	1	0	4,9,14,19,24,29,34,39	2	1	3	4
236	A2/B2	1	0	3,7,11,15,19,23,27,31,35,39	2	1	3	4
237	A2/B2	1	0	1,3,5,7,…,37,39	2	1	3	4
238	A3/B3	16	1	4,9,14,19,24,29,34,39	2	1	2	6
239	A3/B3	16	1	3,7,11,15,19,23,27,31,35,39	2	1	2	6
240	A3/B3	8	1	4,9,14,19,24,29,34,39	2	1	2	6
241	A3/B3	8	1	3,7,11,15,19,23,27,31,35,39	2	1	2	6
242	A3/B3	4	1	4,9,14,19,24,29,34,39	2	1	2	6
243	A3/B3	4	1	3,7,11,15,19,23,27,31,35,39	2	1	2	6
244	A3/B3	2	1	4,9,14,19,24,29,34,39	2	1	2	6
245	A3/B3	1	0	19,39	2	1	2	6
246	A3/B3	1	0	9,19,29,39	2	1	2	6
247	A3/B3	1	0	17,19,37,39	2	1	2	6
248	A3/B3	1	0	9,19,29,39	2	2	2	6
249	A3/B3	1	0	7,15,23,31,39	2	1	2	6
250	A3/B3	1	0	23,27,31,35,39	2	1	2	6

251	A3/B3	1	0	23,27,31,35,39	2	2	2	6
252	A3/B3	1	0	4,9,14,19,24,29,34,39	2	1	2	6
253	A3/B3	1	0	4,9,14,19,24,29,34,39	2	2	2	6
254	A3/B3	1	0	3,7,11,15,19,23,27,31,35,39	2	1	2	6
255	A3/B3	1	0	1,3,5,7,…,37,39	2	1	2	6

6.4 Physical signals

6.4.1 Reference signals

6.4.1.1 Demodulation reference signal for PUSCH

6.4.1.1.1 Sequence generation

6.4.1.1.1.1 Sequence generation when transform precoding is disabled

If transform precoding for PUSCH is not enabled, the sequence $r(n)$ shall be generated according to

$$r(n)=\frac{1}{\sqrt{2}}\left(1-2\cdot c(2n)\right)+j\frac{1}{\sqrt{2}}\left(1-2\cdot c(2n+1)\right).$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialized with

$$c_{\text{init}}=\left(2^{17}\left(N_{\text{symb}}^{\text{slot}}n_{\text{s,f}}^{\mu}+l+1\right)\left(2N_{\text{ID}}^{\bar{n}_{\text{SCID}}^{\bar{\lambda}}}+1\right)+2^{17}\left\lfloor\frac{\bar{\lambda}}{2}\right\rfloor+2N_{\text{ID}}^{\bar{n}_{\text{SCID}}^{\bar{\lambda}}}+\bar{n}_{\text{SCID}}^{\bar{\lambda}}\right)\bmod 2^{31}$$

where l is the OFDM symbol number within the slot, $n_{\text{s,f}}^{\mu}$ is the slot number within a frame, and

- $N_{\text{ID}}^{0},N_{\text{ID}}^{1}\in\{0,1,\ldots,65535\}$ are given by the higher-layer parameters *scramblingID0* and *scramblingID1*, respectively, in the *DMRS-UplinkConfig* IE if provided and the PUSCH is scheduled by DCI format 0_1, 0_2, or 0_3, or by a PUSCH transmission with a configured grant;

- $N_{\text{ID}}^{0}\in\{0,1,\ldots,65535\}$ is given by the higher-layer parameter *scramblingID0* in the *DMRS-UplinkConfig* IE if provided and the PUSCH is scheduled by DCI format 0_0 with the CRC scrambled by C-RNTI, MCS-C-RNTI, or CS-RNTI;

- $N_{\text{ID}}^{0},N_{\text{ID}}^{1}\in\{0,1,\ldots,65535\}$ are, for each msgA PUSCH configuration, given by the higher-layer parameters *msgA-ScramblingID0* and *msgA-ScramblingID1*, respectively, in the *msgA-DMRS-Config* IE if provided and the PUSCH transmission is triggered by a Type-2 random access procedure as described in clause 8.1A of [5, TS 38.213];

- $N_{\text{ID}}^{\bar{n}_{\text{SCID}}^{\bar{\lambda}}}=N_{\text{ID}}^{\text{cell}}$ otherwise;

- $\bar{n}_{\text{SCID}}^{\bar{\lambda}}$ and $\bar{\lambda}$ are given by

  - if the higher-layer parameter *dmrs-Uplink* in the *DMRS-UplinkConfig* IE is provided

$$\bar{n}_{\text{SCID}}^{\bar{\lambda}}=\begin{cases}n_{\text{SCID}} & \lambda=0 \text{ or } \lambda=2\\ 1-n_{\text{SCID}} & \lambda=1\end{cases}$$
$$\bar{\lambda}=\lambda$$

  where λ is the CDM group defined in clause 6.4.1.1.3.

  - otherwise

$$\bar{n}_{\text{SCID}}^{\bar{\lambda}}=n_{\text{SCID}}$$
$$\bar{\lambda}=0$$

The quantity $n_{\mathrm{SCID}} \in \{0,1\}$ is

- indicated by the DM-RS initialization field, if present, either in the DCI associated with the PUSCH transmission if DCI format 0_1, 0_2, or 0_3, in [4, TS 38.212] is used;
- indicated by the higher layer parameter *dmrs-SeqInitialization*, if present, for a Type 1 PUSCH transmission with a configured grant;
- determined by the mapping between preamble(s) and a PUSCH occasion and the associated DMRS resource for a PUSCH transmission of Type-2 random access process in [5, TS 38.213];
- determined by the mapping between SS/PBCH block(s) and a PUSCH occasion and the associated DMRS resource for a configured-grant based PUSCH transmission in RRC_INACTIVE state [5, TS 38.213];
- otherwise $n_{\mathrm{SCID}} = 0$.

6.4.1.1.1.2 Sequence generation when transform precoding is enabled

If transform precoding for PUSCH is enabled, the reference-signal sequence $r(n)$ shall be generated according to

$$
\begin{aligned}
r(n) &= r_{u,v}^{(\alpha,\delta)}(n) \\
n &= 0,1,\ldots,M_{\mathrm{sc}}^{\mathrm{PUSCH}} / 2^{\delta} - 1
\end{aligned}
$$

where $r_{u,v}^{(\alpha,\delta)}(n)$ with $\delta = 1$ depends on the configuration:

- if the higher-layer parameter *dmrs-UplinkTransformPrecoding* is configured, π/2-BPSK modulation is used for PUSCH, and the PUSCH transmission is not a msg3 transmission, and the transmission is not scheduled using DCI format 0_0 in a common search space, $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 5.2.3 with c_{init} given by

  $$c_{\mathrm{init}} = \left(2^{17}\left(N_{\mathrm{symb}}^{\mathrm{slot}} n_{\mathrm{s,f}}^{\mu} + l + 1\right)\left(2N_{\mathrm{ID}}^{n_{\mathrm{SCID}}} + 1\right) + 2N_{\mathrm{ID}}^{n_{\mathrm{SCID}}} + n_{\mathrm{SCID}}\right) \bmod 2^{31}$$

  where $n_{\mathrm{SCID}} = 0$ unless given by the DCI according to clause 7.3.1.1.2 in [4, TS38.212] for a transmission scheduled by DCI format 0_1, or given by the DCI according to clause 7.3.1.1.3 in [4, TS38.212] for a transmission scheduled by DCI format 0_2 if the antenna ports field in the DCI format 0_2 is not 0 bit, or given by the DCI according to clause 7.3.1.1.4 in [4, TS38.212] for a transmission scheduled by DCI format 0_3, or given by the higher-layer parameter *antennaPort* for a PUSCH transmission scheduled by a type-1 configured grant; and

  - $N_{\mathrm{ID}}^{0}, N_{\mathrm{ID}}^{1} \in \{0,1,\ldots,65535\}$ are given by the higher-layer parameters *pi2BPSK-ScramblingID0* and *pi2BPSK-ScramblingID1*, respectively, in the *DMRS-UplinkConfig* IE if provided and the PUSCH is scheduled by DCI format 0_1, or by DCI format 0_2 if the antenna ports field in the DCI format 0_2 is not 0 bit, or by DCI format 0_3, or by a PUSCH transmission with a configured grant;
  - $N_{\mathrm{ID}}^{0} \in \{0,1,\ldots,65535\}$ is given by the higher-layer parameter *pi2BPSK-ScramblingID0* in the *DMRS-UplinkConfig* IE if provided and the PUSCH is scheduled by DCI format 0_0 with the CRC scrambled by C-RNTI, MCS-C-RNTI, or CS-RNTI, or by DCI format 0_2 if the antenna ports field in the DCI format 0_2 is 0 bit;
  - $N_{\mathrm{ID}}^{n_{\mathrm{SCID}}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ otherwise;
- otherwise, $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 5.2.2 with $\alpha = 0$.

The sequence group $u = \left(f_{\mathrm{gh}} + n_{\mathrm{ID}}^{\mathrm{RS}}\right) \bmod 30$, where $n_{\mathrm{ID}}^{\mathrm{RS}}$ is given by

- $n_{\mathrm{ID}}^{\mathrm{RS}} = n_{\mathrm{ID}}^{\mathrm{PUSCH}}$ if $n_{\mathrm{ID}}^{\mathrm{PUSCH}}$ is configured by the higher-layer parameter *nPUSCH-Identity* in the *DMRS-UplinkConfig* IE, and
  - the higher-layer parameter *dmrs-UplinkTransformPrecoding* is not configured or the higher-layer parameter *dmrs-UplinkTransformPrecoding* is configured and π/2-BPSK modulation is not used for PUSCH, and
  - the PUSCH is neither scheduled by RAR UL grant nor scheduled by DCI format 0_0 with CRC scrambled by TC-RNTI according to clause 8.3 in [5, TS 38.213];

- $n_{\mathrm{ID}}^{\mathrm{RS}} = N_{\mathrm{ID}}^{n_{\mathrm{SCID}}}$ if the higher-layer parameter *dmrs-UplinkTransformPrecoding* is configured, π/2-BPSK modulation is used for PUSCH, the PUSCH transmission is not a msg3 transmission, and the transmission is not scheduled using DCI format 0_0 in a common search space;

- $n_{\mathrm{ID}}^{\mathrm{RS}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ otherwise

where f_{gh} and the sequence number v are given by:

- if neither group, nor sequence hopping is enabled

$$\begin{aligned} f_{\mathrm{gh}} &= 0 \\ v &= 0 \end{aligned}$$

- if group hopping is enabled and sequence hopping is disabled

$$\begin{aligned} f_{\mathrm{gh}} &= \left(\sum_{m=0}^{7} 2^m c\left(8\left(N_{\mathrm{symb}}^{\mathrm{slot}} n_{\mathrm{s,f}}^{\mu} + l\right) + m\right)\right) \bmod 30 \\ v &= 0 \end{aligned}$$

  where the pseudo-random sequence $c(i)$ is defined by clause 5.2.1 and shall be initialized with $c_{\mathrm{init}} = \left\lfloor n_{\mathrm{ID}}^{\mathrm{RS}} / 30 \right\rfloor$ at the beginning of each radio frame

- if sequence hopping is enabled and group hopping is disabled

$$\begin{aligned} f_{\mathrm{gh}} &= 0 \\ v &= \begin{cases} c\left(N_{\mathrm{symb}}^{\mathrm{slot}} n_{\mathrm{s,f}}^{\mu} + l\right) & \text{if } M_{\mathrm{ZC}} \geq 6 N_{\mathrm{sc}}^{\mathrm{RB}} \\ 0 & \text{otherwise} \end{cases} \end{aligned}$$

  where the pseudo-random sequence $c(i)$ is defined by clause 5.2.1 and shall be initialized with $c_{\mathrm{init}} = n_{\mathrm{ID}}^{\mathrm{RS}}$ at the beginning of each radio frame.

The hopping mode is controlled by higher-layer parameters:

- for PUSCH transmission scheduled by RAR UL grant or by DCI format 0_0 with CRC scrambled by TC-RNTI, sequence hopping is disabled and group hopping is enabled or disabled by the higher-layer parameter *groupHoppingEnabledTransformPrecoding;*

- for all other transmissions, sequence hopping and group hopping are enabled or disabled by the respective higher-layer parameters *sequenceHopping* and *sequenceGroupHopping* if these parameters are provided, otherwise, the same hopping mode as for Msg3 shall be used.

The UE is not expected to handle the case of combined sequence hopping and group hopping.

The quantity l above is the OFDM symbol number in the slot except for the case of double-symbol DMRS in which case l is the OFDM symbol number in the slot of the first symbol of the double-symbol DMRS.

6.4.1.1.2 (void)

6.4.1.1.3 Precoding and mapping to physical resources

The sequence $r(m)$ shall be mapped to the intermediate quantity $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)}$ according to

- if transform precoding is not enabled,
  - if the higher-layer parameter *dmrs-TypeEnh* is configured

$$\begin{aligned} \tilde{a}_{k,l}^{(p_j,\mu)} &= w_{\mathrm{f}}(k')w_{\mathrm{t}}(l')r(4n+k') \\ k &= \begin{cases} 8n + 2k' + \Delta & \text{configuration type 1} \\ 12n + k' + \Delta & \text{configuration type 2, } k' = 0,1 \\ 12n + k' + \Delta + 4 & \text{configuration type 2, } k' = 2,3 \end{cases} \end{aligned}$$

$$\begin{aligned} k' &= 0,1,2,3 \\ l &= \bar{l} + l' \\ n &= 0,1,\ldots \\ j &= 0,1,\ldots,\upsilon-1 \end{aligned}$$

- otherwise

$$\begin{aligned} \tilde{a}_{k,l}^{(p_j,\mu)} &= w_\mathrm{f}(k')w_\mathrm{t}(l')r(2n+k') \\ k &= \begin{cases} 4n+2k'+\Delta & \text{configuration type 1} \\ 6n+k'+\Delta & \text{configuration type 2} \end{cases} \\ k' &= 0,1 \\ l &= \bar{l} + l' \\ n &= 0,1,\ldots \\ j &= 0,1,\ldots,\upsilon-1 \end{aligned}$$

- if transform precoding is enabled

$$\begin{aligned} \tilde{a}_{k,l}^{(p_0,\mu)} &= w_\mathrm{f}(k')w_\mathrm{t}(l')r(2n+k') \\ k &= 4n+2k'+\Delta \\ k' &= 0,1 \\ l &= \bar{l} + l' \\ n &= 0,1,\ldots \end{aligned}$$

where $w_\mathrm{f}(k')$, $w_\mathrm{t}(l')$, and Δ are given by Tables 6.4.1.1.3-1 and 6.4.1.1.3-2 and the configuration type is given by the higher-layer parameter *DMRS-UplinkConfig*, and both k' and Δ correspond to $\tilde{p}_0,\ldots,\tilde{p}_{\upsilon-1}$. The intermediate quantity $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)} = 0$ if Δ corresponds to any other antenna ports than $\tilde{p}_j$.

The intermediate quantity $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)}$ shall be precoded, multiplied with the amplitude scaling factor $\beta_\mathrm{PUSCH}^\mathrm{DMRS}$ in order to conform to the transmit power specified in [6, TS 38.214], and mapped to physical resources according to

$$\begin{bmatrix} a_{k,l}^{(p_0,\mu)} \\ \vdots \\ a_{k,l}^{(p_{\rho-1},\mu)} \end{bmatrix} = \beta_\mathrm{PUSCH}^\mathrm{DMRS} W \begin{bmatrix} \tilde{a}_{k,l}^{(\tilde{p}_0,\mu)} \\ \vdots \\ \tilde{a}_{k,l}^{(\tilde{p}_{\upsilon-1},\mu)} \end{bmatrix}$$

where

- the precoding matrix W is given by clause 6.3.1.5,
- the set of antenna ports $\{p_{0,\ldots,}\ p_{\rho-1}\}$ is given by clause 6.3.1.5, and
- the set of antenna ports $\{\tilde{p}_{0,\ldots,}\ \tilde{p}_{\upsilon-1}\}$ is given by [6, TS 38.214];

and the following conditions are fulfilled:

- the resource elements $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)}$ are within the common resource blocks allocated for PUSCH transmission.

The reference point for k is

- subcarrier 0 in common resource block 0 if transform precoding is not enabled, and
- subcarrier 0 of the lowest-numbered resource block of the scheduled PUSCH allocation if transform precoding is enabled.

The reference point for l and the position l_0 of the first DM-RS symbol depends on the mapping type:

- for PUSCH mapping type A:
  - l is defined relative to the start of the slot if frequency hopping is disabled and relative to the start of each hop in case frequency hopping is enabled

  - l_0 is given by the higher-layer parameter *dmrs-TypeA-Position*

- for PUSCH mapping type B:
  - l is defined relative to the start of the scheduled PUSCH resources if frequency hopping is disabled and relative to the start of each hop in case frequency hopping is enabled
  - $l_0 = 0$

The position(s) of the DM-RS symbols is given by $\bar{l}$ and duration l_d where

- l_d is the duration between the first OFDM symbol of the slot and the last OFDM symbol of the scheduled PUSCH resources in the slot for PUSCH mapping type A according to Tables 6.4.1.1.3-3 and 6.4.1.1.3-4 if intra-slot frequency hopping is not used, or
- l_d is the duration of scheduled PUSCH resources for PUSCH mapping type B according to Tables 6.4.1.1.3-3 and 6.4.1.1.3-4 if intra-slot frequency hopping is not used, or
- l_d is the duration per hop according to Table 6.4.1.1.3-6 if intra-slot frequency hopping is used.
- if the higher-layer parameter *maxLength* in *DMRS-UplinkConfig* is not configured, or for a msgA transmission *msgA-MaxLength* in *msgA-DMRS-Config* is not configured, the tables shall be used according to single-symbol DM-RS
- if the higher-layer parameter *maxLength* in *DMRS-UplinkConfig* is equal to 'len2', the associated DCI or configured grant configuration determines whether single-symbol or double-symbol DM-RS shall be used
- if the higher-layer parameter *msgA-MaxLength* in *msgA-DMRS-Config* is equal to 'len2', double-symbol DM-RS shall be used
- if the higher-layer parameter *dmrs-AdditionalPosition* is not set to 'pos0' and intra-slot frequency hopping is enabled according to clause 7.3.1.1.2 in [4, TS 38.212] and by higher layer, Tables 6.4.1.1.3-6 shall be used assuming *dmrs-AdditionalPosition* is equal to 'pos1' for each hop.

For PUSCH mapping type A,

- the case *dmrs-AdditionalPosition* is equal to 'pos3' is only supported when *dmrs-TypeA-Position* is equal to 'pos2';
- $l_\mathrm{d} = 4$ symbols in Table 6.4.1.1.3-4 is only applicable when *dmrs-TypeA-Position* is equal to 'pos2'.

For msgA transmitted using PUSCH mapping type A,

- the case *msgA-DMRS-AdditionalPosition* is equal to 'pos3' is only supported when *dmrs-TypeA-Position* is equal to 'pos2';
- '*dmrs-AdditionalPosition*' in Tables 6.4.1.1.3-3 to 6.4.1.1.3-6 shall be replaced by *msgA-DMRS-AdditionalPosition;*
- only PUSCH DM-RS configuration type 1 is supported;
- only basic DM-RS multiplexing in Table 6.4.1.1.3-5 is supported.

For msgA transmitted using PUSCH mapping type B,

- '*dmrs-AdditionalPosition*' in Tables 6.4.1.1.3-3 to 6.4.1.1.3-6 shall be replaced by *msgA-DMRS-AdditionalPosition*;
- only PUSCH DM-RS configuration type 1 is supported;
- only basic DM-RS multiplexing in Table 6.4.1.1.3-5 is supported.

The time-domain index l', and the supported antenna ports $\tilde{p}_j$ are given by Table 6.4.1.1.3-5.

Table 6.4.1.1.3-1: Parameters for PUSCH DM-RS configuration type 1.

$\tilde{p}$	CDM group λ	Δ	$[w_\mathrm{f}(0) \quad \ldots \quad w_\mathrm{f}(3)]$	$[w_\mathrm{t}(0) \quad w_\mathrm{t}(1)]$
0	0	0	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
1	0	0	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
2	1	1	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
3	1	1	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
4	0	0	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
5	0	0	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
6	1	1	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
7	1	1	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
8	0	0	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad +1]$
9	0	0	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad +1]$
10	1	1	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad +1]$
11	1	1	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad +1]$
12	0	0	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad -1]$
13	0	0	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad -1]$
14	1	1	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad -1]$
15	1	1	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad -1]$

Table 6.4.1.1.3-2: Parameters for PUSCH DM-RS configuration type 2.

$\tilde{p}$	CDM group λ	Δ	$[w_\mathrm{f}(0) \quad \ldots \quad w_\mathrm{f}(3)]$	$[w_\mathrm{t}(0) \quad w_\mathrm{t}(1)]$
0	0	0	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
1	0	0	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
2	1	2	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
3	1	2	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
4	2	4	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
5	2	4	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
6	0	0	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
7	0	0	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
8	1	2	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
9	1	2	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
10	2	4	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
11	2	4	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
12	0	0	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad +1]$
13	0	0	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad +1]$
14	1	2	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad +1]$
15	1	2	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad +1]$
16	2	4	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad +1]$
17	2	4	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad +1]$
18	0	0	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad -1]$
19	0	0	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad -1]$
20	1	2	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad -1]$
21	1	2	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad -1]$
22	2	4	$[+1 \quad +j \quad -1 \quad -j]$	$[+1 \quad -1]$
23	2	4	$[+1 \quad -j \quad -1 \quad +j]$	$[+1 \quad -1]$

Table 6.4.1.1.3-3: PUSCH DM-RS positions $\bar{l}$ within a slot for single-symbol DM-RS and intra-slot frequency hopping disabled.

l_d in symbols	**DM-RS positions $\bar{l}$**							
	PUSCH mapping type A				**PUSCH mapping type B**			
	dmrs-AdditionalPosition				***dmrs-AdditionalPosition***			
	pos0	***pos1***	***pos2***	***pos3***	***pos0***	***pos1***	***pos2***	***pos3***
<4	-	-	-	-	l_0	l_0	l_0	l_0
4	l_0	l_0	l_0	l_0	l_0	l_0	l_0	l_0
5	l_0	l_0	l_0	l_0	l_0	l_0, 4	l_0, 4	l_0, 4
6	l_0	l_0	l_0	l_0	l_0	l_0, 4	l_0, 4	l_0, 4
7	l_0	l_0	l_0	l_0	l_0	l_0, 4	l_0, 4	l_0, 4
8	l_0	l_0, 7	l_0, 7	l_0, 7	l_0	l_0, 6	l_0, 3, 6	l_0, 3, 6
9	l_0	l_0, 7	l_0, 7	l_0, 7	l_0	l_0, 6	l_0, 3, 6	l_0, 3, 6
10	l_0	l_0, 9	l_0, 6, 9	l_0, 6, 9	l_0	l_0, 8	l_0, 4, 8	l_0, 3, 6, 9
11	l_0	l_0, 9	l_0, 6, 9	l_0, 6, 9	l_0	l_0, 8	l_0, 4, 8	l_0, 3, 6, 9
12	l_0	l_0, 9	l_0, 6, 9	l_0, 5, 8, 11	l_0	l_0, 10	l_0, 5, 10	l_0, 3, 6, 9
13	l_0	l_0, 11	l_0, 7, 11	l_0, 5, 8, 11	l_0	l_0, 10	l_0, 5, 10	l_0, 3, 6, 9
14	l_0	l_0, 11	l_0, 7, 11	l_0, 5, 8, 11	l_0	l_0, 10	l_0, 5, 10	l_0, 3, 6, 9

Table 6.4.1.1.3-4: PUSCH DM-RS positions $\bar{l}$ within a slot for double-symbol DM-RS and intra-slot frequency hopping disabled.

l_d in symbols	**DM-RS positions $\bar{l}$**							
	PUSCH mapping type A				**PUSCH mapping type B**			
	dmrs-AdditionalPosition				***dmrs-AdditionalPosition***			
	pos0	***pos1***	***pos2***	***pos3***	***pos0***	***pos1***	***pos2***	***pos3***
<4	-	-			-	-		
4	l_0	l_0			-	-		
5	l_0	l_0			l_0	l_0		
6	l_0	l_0			l_0	l_0		
7	l_0	l_0			l_0	l_0		
8	l_0	l_0			l_0	l_0, 5		
9	l_0	l_0			l_0	l_0, 5		
10	l_0	l_0, 8			l_0	l_0, 7		
11	l_0	l_0, 8			l_0	l_0, 7		
12	l_0	l_0, 8			l_0	l_0, 9		
13	l_0	l_0, 10			l_0	l_0, 9		
14	l_0	l_0, 10			l_0	l_0, 9		

Table 6.4.1.1.3-5: PUSCH DM-RS time index l'.

DM-RS multiplexing	**DM-RS duration**	l'	**Supported antenna ports $\tilde{p}$**	
			Configuration type 1	**Configuration type 2**
Basic	single-symbol DM-RS	0	0 – 3	0 – 5
	double-symbol DM-RS	0, 1	0 – 7	0 – 11
Enhanced	single-symbol DM-RS	0	0 – 3, 8 – 11	0 – 5, 12 – 17
	double-symbol DM-RS	0, 1	0 – 15	0 – 23

Table 6.4.1.1.3-6: PUSCH DM-RS positions $\bar{l}$ within a slot for single-symbol DM-RS and intra-slot frequency hopping enabled.

l_d in symbols	DM-RS positions $\bar{l}$											
	PUSCH mapping type A								PUSCH mapping type B			
	$l_0 = 2$				$l_0 = 3$				$l_0 = 0$			
	dmrs-AdditionalPosition				*dmrs-AdditionalPosition*				*dmrs-AdditionalPosition*			
	pos0		*pos1*		*pos0*		*pos1*		*pos0*		*pos1*	
	1st hop	2nd hop	1st hop	2nd hop	1st hop	2nd hop	1st hop	2nd hop	1st hop	2nd hop	1st hop	2nd hop
≤3	-	-	-	-	-	-	-	-	0	0	0	0
4	2	0	2	0	3	0	3	0	0	0	0	0
5, 6	2	0	2	0, 4	3	0	3	0, 4	0	0	0, 4	0, 4
7	2	0	2, 6	0, 4	3	0	3	0, 4	0	0	0, 4	0, 4

6.4.1.2 Phase-tracking reference signals for PUSCH

6.4.1.2.1 Sequence generation

6.4.1.2.1.1 Sequence generation if transform precoding is not enabled

If transform precoding is not enabled, the precoded phase-tracking reference signal for subcarrier k on layer j is given by

$$r^{(\tilde{p}_j)}(m) = \begin{cases} r(m) & \text{if } j = j' \text{ or } j = j" \\ 0 & \text{otherwise} \end{cases}$$

where

- antenna ports $\tilde{p}_{j'}$ or $\{\tilde{p}_{j'}, \tilde{p}_{j"}\}$ associated with PT-RS transmission are given by clause 6.2.3 of [6, TS 38.214]
- $r(m)$ is given by clause 6.4.1.1.1.1
  - at the position of the first DM-RS symbol in absence of PUSCH intra-slot frequency hopping
  - at the position of the first DM-RS symbol in hop $h \in \{0,1\}$ in presence of PUSCH intra-slot frequency hopping

6.4.1.2.1.2 Sequence generation if transform precoding is enabled

If transform precoding is enabled, the phase-tracking reference signal $r_m(m')$ to be mapped in position m before transform precoding, where m depends on the number of PT-RS groups $N_\text{group}^\text{PT-RS}$, the number of samples per PT-RS group $N_\text{samp}^\text{group}$, and M_sc^PUSCH according to Table 6.4.1.2.2.2-1, shall be generated according to

$$\begin{aligned} r_m(m') &= w(k')\frac{e^{j\frac{\pi}{2}(m \bmod 2)}}{\sqrt{2}}\left[(1-2c(m')) + j(1-2c(m'))\right] \\ m' &= N_\text{samp}^\text{group} s' + k' \\ s' &= 0,1,\ldots,N_\text{group}^\text{PT-RS} - 1 \\ k' &= 0,1,N_\text{samp}^\text{group} - 1 \end{aligned} .$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2.1 and $w(i)$ is given by Table 6.4.1.2.1.2-1. The pseudo-random sequence generator shall be initialized with

$$c_\text{init} = \left(2^{17}\left(N_\text{symb}^\text{slot} n_\text{s,f}^\mu + l + 1\right)(2N_\text{ID} + 1) + 2N_\text{ID}\right) \bmod 2^{31}$$

where l is the lowest OFDM symbol number in the PUSCH allocation in slot $n_{\mathrm{s,f}}^{\mu}$ that contains PT-RS according to clause 6.4.1.2.2.2 and N_{ID} is given by the higher-layer parameter *nPUSCH-Identity*.

Table 6.4.1.2.1.2-1: The orthogonal sequence $w(i)$.

$n_{\mathrm{RNTI}} \bmod N_{\mathrm{samp}}^{\mathrm{group}}$	$N_{\mathrm{samp}}^{\mathrm{group}} = 2$ $[w(0) \quad w(1)]$	$N_{\mathrm{samp}}^{\mathrm{group}} = 4$ $[w(0) \quad w(1) \quad w(2) \quad w(3)]$
0	$[+1 \quad +1]$	$[+1 \quad +1 \quad +1 \quad +1]$
1	$[+1 \quad -1]$	$[+1 \quad -1 \quad +1 \quad -1]$
2	-	$[+1 \quad +1 \quad -1 \quad -1]$
3	-	$[+1 \quad -1 \quad -1 \quad +1]$

6.4.1.2.2 Mapping to physical resources

6.4.1.2.2.1 Precoding and mapping to physical resources if transform precoding is not enabled

The UE shall transmit phase-tracking reference signals only in the resource blocks used for the PUSCH, and only if the procedure in [6, TS 38.214] indicates that phase-tracking reference signals are being used.

The PUSCH PT-RS shall be mapped to resource elements according to

- if the higher-layer parameter *dmrs-TypeEnh* is configured

$$\begin{bmatrix} a_{k,l}^{(p_0,\mu)} \\ \vdots \\ a_{k,l}^{(p_{\rho-1},\mu)} \end{bmatrix} = \beta_{\text{PT-RS}} W \begin{bmatrix} r^{(\tilde{p}_0)}(4n+k') \\ \vdots \\ r^{(\tilde{p}_{\upsilon-1})}(4n+k') \end{bmatrix}$$

$$k = \begin{cases} 8n + 2k' + \Delta & \text{configuration type 1} \\ 12n + k' + \Delta & \text{configuration type 2, } k' \in \{0,1\} \\ 12n + k' + \Delta + 4 & \text{configuration type 2, } k' \in \{2,3\} \end{cases}$$

- otherwise

$$\begin{bmatrix} a_{k,l}^{(p_0,\mu)} \\ \vdots \\ a_{k,l}^{(p_{\rho-1},\mu)} \end{bmatrix} = \beta_{\text{PT-RS}} W \begin{bmatrix} r^{(\tilde{p}_0)}(2n+k') \\ \vdots \\ r^{(\tilde{p}_{\upsilon-1})}(2n+k') \end{bmatrix}$$

$$k = \begin{cases} 4n + 2k' + \Delta & \text{configuration type 1} \\ 6n + k' + \Delta & \text{configuration type 2} \end{cases}$$

when all the following conditions are fulfilled

- l is within the OFDM symbols allocated for the PUSCH transmission
- resource element (k,l) is not used for DM-RS
- k' and Δ correspond to $\tilde{p}_0, \ldots, \tilde{p}_{\upsilon-1}$

The quantities k' and Δ are given by Tables 6.4.1.1.3-1 and 6.4.1.1.3-2, the configuration type is given by the higher-layer parameter *dmrs-Type* in the *DMRS-UplinkConfig* IE, and the precoding matrix W is given by clause 6.3.1.5. The quantity β_{PTRS} is an amplitude scaling factor to conform with the transmit power specified in clause 6.2.2 of [6, TS 38.214].

The set of time indices l defined relative to the start of the PUSCH allocation is defined by

1. set $i = 0$ and $l_{\mathrm{ref}} = 0$

2. if any symbol in the interval $\max(l_{\text{ref}} + (i-1)L_{\text{PT-RS}} + 1, l_{\text{ref}}), \ldots, l_{\text{ref}} + iL_{\text{PT-RS}}$ overlaps with a symbol used for DM-RS according to clause 6.4.1.1.3
   - set $i = 1$
   - set l_{ref} to the symbol index of the DM-RS symbol in case of a single-symbol DM-RS or to the symbol index of the second DM-RS symbol in case of a double-symbol DM-RS
   - repeat from step 2 as long as $l_{\text{ref}} + iL_{\text{PT-RS}}$ is inside the PUSCH allocation
3. add $l_{\text{ref}} + iL_{\text{PT-RS}}$ to the set of time indices for PT-RS
4. increment i by one
5. repeat from step 2 above as long as $l_{\text{ref}} + iL_{\text{PT-RS}}$ is inside the PUSCH allocation

where $L_{\text{PT-RS}} \in \{1,2,4\}$ is defined in Table 6.2.3.1-1 of [6, TS 38.214].

For the purpose of PT-RS mapping, the resource blocks allocated for PUSCH transmission are numbered from 0 to $N_{\text{RB}} - 1$ from the lowest scheduled resource block to the highest. The corresponding subcarriers in this set of resource blocks are numbered in increasing order starting from the lowest frequency from 0 to $N_{\text{sc}}^{\text{RB}} N_{\text{RB}} - 1$. The subcarriers to which the PT-RS shall be mapped are given by

$$k = k_{\text{ref}}^{\text{RE}} + \left(iK_{\text{PT-RS}} + k_{\text{ref}}^{\text{RB}}\right) N_{\text{sc}}^{\text{RB}}$$
$$k_{\text{ref}}^{\text{RB}} = \begin{cases} n_{\text{RNTI}} \bmod K_{\text{PT-RS}} & \text{if } N_{\text{RB}} \bmod K_{\text{PT-RS}} = 0 \\ n_{\text{RNTI}} \bmod \left(N_{\text{RB}} \bmod K_{\text{PT-RS}}\right) & \text{otherwise} \end{cases}$$

where

- $i = 0,1,2,\ldots$
- $k_{\text{ref}}^{\text{RE}}$ is given by Table 6.4.1.2.2.1-1 for the DM-RS port associated with the PT-RS port according to clause 6.2.3 in [6, TS 38.214]. If the higher-layer parameter *resourceElementOffset* in *PTRS-UplinkConfig* is not configured, the column corresponding to 'offset00' shall be used.
- n_{RNTI} is the RNTI associated with the DCI scheduling the transmission using C-RNTI, CS-RNTI, MCS-C-RNTI, SP-CSI-RNTI, or is the CS-RNTI in case of configured grant
- N_{RB} is the number of resource blocks scheduled
- $K_{\text{PT-RS}} \in \{2,4\}$ is given by [6, TS 38.214].

Table 6.4.1.2.2.1-1: The parameter $k_{\text{ref}}^{\text{RE}}$.

DM-RS antenna port	$k_{\text{ref}}^{\text{RE}}$							
	DM-RS Configuration type 1				**DM-RS Configuration type 2**			
$\tilde{p}$	***resourceElementOffset***				***resourceElementOffset***			
	offset00	**offset01**	**offset10**	**offset11**	**offset00**	**offset01**	**offset10**	**offset11**
0	0	2	6	8	0	1	6	7
1	2	4	8	10	1	6	7	0
2	1	3	7	9	2	3	8	9
3	3	5	9	11	3	8	9	2
4	-	-	-	-	4	5	10	11
5	-	-	-	-	5	10	11	4
8	4	6	10	0	-	-	-	-
9	6	8	0	2	-	-	-	-
10	5	7	11	1	-	-	-	-
11	7	9	1	3	-	-	-	-
12	-	-	-	-	6	7	0	1
13	-	-	-	-	7	0	1	6
14	-	-	-	-	8	9	2	3
15	-	-	-	-	9	2	3	8
16	-	-	-	-	10	11	4	5
17	-	-	-	-	11	4	5	10

6.4.1.2.2.2 Mapping to physical resources if transform precoding is enabled

The UE shall transmit phase-tracking reference signals only in the resource blocks and OFDM symbols used for the PUSCH, and only if the procedure in [6, TS 38.214] indicates that phase-tracking reference signals are being used.

The sequence $r_m(m')$ shall be multiplied by β' and mapped to $N_{\text{samp}}^{\text{group}} N_{\text{group}}^{\text{PT-RS}}$ complex valued symbols in $\tilde{x}^{(0)}(m)$ where

- $\tilde{x}^{(0)}(m)$ are the complex-valued symbols in OFDM symbol l before transform precoding according to clause 6.3.1.4
- m depends on the number of PT-RS groups $N_{\text{group}}^{\text{PT-RS}}$, the number of samples per PT-RS group $N_{\text{samp}}^{\text{group}}$, and $M_{\text{sc}}^{\text{PUSCH}}$ according to Table 6.4.1.2.2.2-1
- β' is the ratio between amplitude of one of the outermost constellation points for the modulation scheme used for PUSCH and one of the outermost constellation points for $\pi/2$-BPSK as defined in clause 6.2.3 of [TS 38.214]

The set of time indices l for which PT-RS shall be transmitted is defined relative to the start of the PUSCH allocation and is defined by

1. set $i = 0$ and $l_{\text{ref}} = 0$
2. if any symbol in the interval $\max(l_{\text{ref}} + (i-1)L_{\text{PT-RS}} + 1, l_{\text{ref}}), \ldots, l_{\text{ref}} + iL_{\text{PT-RS}}$ overlaps with a symbol used for DM-RS according to clause 6.4.1.1.3
    - set $i = 1$
    - set l_{ref} to the symbol index of the DM-RS symbol in case of a single-symbol DM-RS and to the symbol index of the second DM-RS symbol in case of a double-symbol DM-RS
    - repeat from step 2 as long as $l_{\text{ref}} + iL_{\text{PT-RS}}$ is inside the PUSCH allocation
3. add $l_{\text{ref}} + iL_{\text{PT-RS}}$ to the set of time indices for PT-RS
4. increment i by one
5. repeat from step 2 above as long as $l_{\text{ref}} + iL_{\text{PT-RS}}$ is inside the PUSCH allocation

where $L_{\text{PT-RS}} \in \{1,2\}$ is given by the higher-layer parameter *timeDensityTransformPrecoding* in the *PTRS-UplinkConfig* IE.

Table 6.4.1.2.2.2-1: PT-RS symbol mapping.

Number of PT-RS groups $N_{\text{group}}^{\text{PT-RS}}$	**Number of samples per PT-RS group** $N_{\text{samp}}^{\text{group}}$	**Index m of PT-RS samples in OFDM symbol l prior to transform precoding**
2	2	$s\lfloor M_{\text{sc}}^{\text{PUSCH}}/4\rfloor + k - 1$ where $s = 1,3$ and $k = 0,1$
2	4	$sM_{\text{sc}}^{\text{PUSCH}} + k$ where $\begin{cases} s = 0 & \text{and} \quad k = 0,1,2,3 \\ s = 1 & \text{and} \quad k = -4,-3,-2,-1 \end{cases}$
4	2	$\lfloor s\, M_{\text{sc}}^{\text{PUSCH}}/8\rfloor + k - 1$ where $s = 1,3,5,7$ and $k = 0,1$
4	4	$sM_{\text{sc}}^{\text{PUSCH}}/4 + n + k$ where $\begin{cases} s = 0 & \text{and} \quad k = 0,1,2,3 & n = 0 \\ s = 1,2 & \text{and} \quad k = -2,-1,0,1 & n = \lfloor M_{\text{sc}}^{\text{PUSCH}}/8\rfloor \\ s = 4 & \text{and} \quad k = -4,-3,-2,-1 & n = 0 \end{cases}$
8	4	$\lfloor s\, M_{\text{sc}}^{\text{PUSCH}}/8\rfloor + n + k$ where $\begin{cases} s = 0 & \text{and} \quad k = 0,1,2,3 & n = 0 \\ s = 1,2,3,4,5,6 & \text{and} \quad k = -2,-1,0,1 & n = \lfloor M_{\text{sc}}^{\text{PUSCH}}/16\rfloor \\ s = 8 & \text{and} \quad k = -4,-3,-2,-1 & n = 0 \end{cases}$

6.4.1.3 Demodulation reference signal for PUCCH

6.4.1.3.1 Demodulation reference signal for PUCCH format 1

6.4.1.3.1.1 Sequence generation

The reference signal sequence is defined by

$$
\begin{aligned}
z\left(m' N_{\text{SF},0}^{\text{PUCCH},1} M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} + m M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} + n\right) &= w_i(m) r_{u,v}^{(\alpha,\delta)}(n) \\
n &= 0,1,\dots,M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} - 1 \\
m &= 0,1,\dots,N_{\text{SF},m'}^{\text{PUCCH},1} - 1 \\
m' &= \begin{cases} 0 & \text{no intra-slot frequency hopping} \\ 0,1 & \text{intra-slot frequency hopping} \end{cases}
\end{aligned}
$$

where $N_{\text{SF},m'}^{\text{PUCCH},1}$ is given by Table 6.4.1.3.1.1-1, $M_{\text{RB}}^{\text{PUCCH},1}$ by clause 9.2.1 of [5, TS 38.213], and the sequence $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 5.2.2.

Intra-slot frequency hopping shall be assumed when the higher-layer parameter *intraSlotFrequencyHopping* is enabled, regardless of whether the frequency-hop distance is zero or not, otherwise no intra-slot frequency hopping shall be assumed.

The orthogonal sequence $w_i(m)$ is given by Table 6.3.2.4.1.-2 with the same index i as used in clause 6.3.2.4.1.

Table 6.4.1.3.1.1-1: Number of DM-RS symbols and the corresponding $N_{\text{SF},m'}^{\text{PUCCH,1}}$.

PUCCH length, $N_{\text{symb}}^{\text{PUCCH,1}}$	$N_{\text{SF},m'}^{\text{PUCCH,1}}$		
	No intra-slot hopping $m'=0$	**Intra-slot hopping** $m'=0$	$m'=1$
4	2	1	1
5	3	1	2
6	3	2	1
7	4	2	2
8	4	2	2
9	5	2	3
10	5	3	2
11	6	3	3
12	6	3	3
13	7	3	4
14	7	4	3

6.4.1.3.1.2 Mapping to physical resources

The sequence shall be multiplied with the amplitude scaling factor $\beta_{\text{PUCCH,1}}$ in order to conform to the transmit power specified in [5, 38.213] and mapped in sequence starting with $z(0)$ to resource elements $(k,l)_{p,\mu}$ in a slot on antenna port $p = 2000$ according to

$$\begin{aligned} a_{k,l}^{(p,\mu)} &= \beta_{\text{PUCCH,1}} z(m) \\ l &= 0,2,4,\ldots \end{aligned}$$

where $l = 0$ corresponds to the first OFDM symbol of the PUCCH transmission and $(k,l)_{p,\mu}$ shall be within the resource blocks assigned for PUCCH transmission according to [5, TS 38.213].

For interlaced transmission, the mapping operation shall be repeated for each resource block in the interlace and in the active bandwidth part over the assigned physical resource blocks according to clause 9.2.1 of [5, TS 38.213], with the resource-block dependent sequence generated according to clause 6.3.2.2.

6.4.1.3.2 Demodulation reference signal for PUCCH format 2

6.4.1.3.2.1 Sequence generation

The reference-signal sequence $z_l(m)$ shall be generated according to

$$\begin{aligned} z_l\left(mN_{\text{SF}}^{\text{PUCCH,2}} + i\right) &= w_n(i) r_l(m) \\ r_l(m) &= \frac{1}{\sqrt{2}}\left(1 - 2c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2c(2m+1)\right) \\ i &= 0,1,\ldots,N_{\text{SF}}^{\text{PUCCH,2}} - 1 \\ m &= 0,1,\ldots \end{aligned}$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2. The pseudo-random sequence generator shall be initialized with

$$c_{\text{init}} = \left(2^{17}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)\left(2N_{\text{ID}}^{0} + 1\right) + 2N_{\text{ID}}^{0}\right) \bmod 2^{31}$$

where l is the OFDM symbol number within the slot, $n_{\text{s,f}}^{\mu}$ is the slot number within the radio frame, and $w_n(i)$ and $N_{\text{SF}}^{\text{PUCCH,2}}$ are defind in clause 6.3.2.5.2A.

The quantity $N_{\text{ID}}^{0} \in \{0,1,\ldots,65535\}$ is given by the higher-layer parameter *scramblingID0* in the *DMRS-UplinkConfig* IE if provided and by $N_{\text{ID}}^{\text{cell}}$ otherwise. If a UE is configured with both *dmrs-UplinkForPUSCH-MappingTypeA* and *dmrs-UplinkForPUSCH-MappingTypeB*, *scramblingID0* is obtained from *dmrs-UplinkForPUSCH-MappingTypeB*.

6.4.1.3.2.2 Mapping to physical resources

The sequence shall be multiplied with the amplitude scaling factor $\beta_{\text{PUCCH},2}$ in order to conform to the transmit power specified in [5, 38.213] and mapped in sequence starting with $z_l(0)$ to resource elements $(k,l)_{p,\mu}$ in a slot on antenna port $p = 2000$ according to

$$a_{k,l}^{(p,\mu)} = \beta_{\text{PUCCH},2} z_l(m)$$
$$k = 3m + 1$$

where k is defined relative to subcarrier 0 of common resource block 0 and $(k,l)_{p,\mu}$ shall be within the resource blocks assigned for PUCCH transmission according to clause 9.2.1 of [5, TS 38.213].

6.4.1.3.3 Demodulation reference signal for PUCCH formats 3 and 4

6.4.1.3.3.1 Sequence generation

The reference-signal sequence $r_l(m)$ shall be generated according to

$$r_l(m) = r_{u,v}^{(\alpha,\delta)}(m)$$
$$m = 0,1,\ldots,M_{\text{sc}}^{\text{PUCCH},s} - 1$$

where $M_{\text{sc}}^{\text{PUCCH},s}$ is given by clause 6.3.2.6.3 and $r_{u,v}^{(\alpha,\delta)}(m)$ depends on the configuration:

- if the higher-layer parameter *dmrs-UplinkTransformPrecodingPUCCH* is configured, and $\pi/2$-BPSK is used for PUCCH, $r_{u,v}^{(\alpha,\delta)}(m)$ is given by clause 5.2.3 with $\delta = 0$ and c_{init} given by clause 6.4.1.3.2.1. The sequence group u and the sequence number v depend on the sequence hopping in clause 6.3.2.2.1.
- otherwise, for PUCCH format 3, PUCCH format 4 with $M_{\text{RB}}^{\text{PUCCH},4}$=1, and PUCCH format 4 with $M_{\text{RB}}^{\text{PUCCH},4}$>1 when $\pi/2$-BPSK is not used for PUCCH, $r_{u,v}^{(\alpha,\delta)}(m)$ is given by clause 6.3.2.2 and the cyclic shift α varies with the symbol number and slot number according to clause 6.3.2.2.2 with
  - $m_0 = 0$ for PUCCH format 3 without interlaced mapping;
  - m_0 obtained from Table 6.4.1.3.3.1-1 with the orthogonal sequence index n given by clause 6.3.2.6.3 for PUCCH format 3 with interlaced mapping and PUCCH format 4.

Table 6.4.1.3.3.1-1: Cyclic shift index m_0 for PUCCH format 3 with interlaced mapping and PUCCH format 4.

Orthogonal sequence index n	Cyclic shift index m_0		
	$N_{\text{SF}}^{\text{PUCCH},s} = 1$	$N_{\text{SF}}^{\text{PUCCH},s} = 2$	$N_{\text{SF}}^{\text{PUCCH},s} = 4$
0	0	0	0
1	-	6	6
2	-	-	3
3	-	-	9

6.4.1.3.3.2 Mapping to physical resources

The sequence shall be multiplied with the amplitude scaling factor $\beta_{\text{PUCCH},s}$, $s \in \{3,4\}$, in order to conform to the transmit power specified in [5, 38.213] and mapped in sequence starting with $r_l(0)$ to resource elements $(k,l)_{p,\mu}$ on antenna port $p = 2000$ according to

$$a_{k,l}^{(p,\mu)} = \beta_{\text{PUCCH,s}} \cdot r_l(m).$$
$$m = 0,1,\ldots,M_{\text{sc}}^{\text{PUCCH},s} - 1$$

where

- k is defined relative to subcarrier 0 of the lowest-numbered resource block assigned for PUCCH transmission,
- l is given by Table 6.4.1.3.3.2-1 for the case with and without intra-slot frequency hopping and with and without additional DM-RS as described in clause 9.2.1 of [TS 38.213], where $l = 0$ corresponds to the first OFDM symbol of the PUCCH transmission.

The resource elements $(k, l)_{p,\mu}$ shall be within the resource blocks assigned for PUCCH transmission according to clause 9.2.1 of [5, TS 38.213].

Table 6.4.1.3.3.2-1: DM-RS positions for PUCCH format 3 and 4.

PUCCH length	**DM-RS position l within PUCCH span**			
	No additional DM-RS		**Additional DM-RS**	
	No hopping	**Hopping**	**No hopping**	**Hopping**
4	1	0, 2	1	0, 2
5	0, 3		0, 3	
6	1, 4		1, 4	
7	1, 4		1, 4	
8	1, 5		1, 5	
9	1, 6		1, 6	
10	2, 7		1, 3, 6, 8	
11	2, 7		1, 3, 6, 9	
12	2, 8		1, 4, 7, 10	
13	2, 9		1, 4, 7, 11	
14	3, 10		1, 5, 8, 12	

6.4.1.4 Sounding reference signal

6.4.1.4.1 SRS resource

An SRS resource is configured by the *SRS-Resource* IE or the *SRS-PosResource* IE and consists of

- $N_{\text{ap}}^{\text{SRS}} \in \{1,2,4,8\}$ antenna ports $\{p_i\}_{i=0}^{N_{\text{ap}}^{\text{SRS}}-1}$, where the number of antenna ports is given by the higher layer parameter *nrofSRS-Ports* or *nrofSRS-Ports-n8* if configured, otherwise $N_{\text{ap}}^{\text{SRS}} = 1$, and $p_i = 1000 + i$ when the SRS resource is in a SRS resource set with higher-layer parameter *usage* in *SRS-ResourceSet* not set to 'nonCodebook', or determined according to [6, TS 38.214] when the SRS resource is in a SRS resource set with higher-layer parameter *usage* in *SRS-ResourceSet* set to 'nonCodebook'.
- N_{hop}, the number of hops for SRS Tx hopping for an SRS resource configured by *SRS-PosResource* given by the higher layer parameter *SRShoppingNrofHops* if configured, otherwise $N_{\text{hop}} = 1$.
- $N_{\text{symb}}^{\text{SRS}} \in \{1,2,4,8,10,12,14\}$ consecutive OFDM symbols given by the field *nrofSymbols* contained in the higher layer parameter *resourceMapping*. If $N_{\text{hop}} > 1$, $N_{\text{symb}}^{\text{SRS}}$ is the number of consecutive OFDM symbol per hop.
- l_0, the starting position in the time domain given by $l_0 = N_{\text{symb}}^{\text{slot}} - 1 - l_{\text{offset}}$ where the offset $l_{\text{offset}} \in \{0,1,\ldots,13\}$ counts symbols backwards from the end of the slot and is given by the field *startPosition* contained in the higher layer parameter *resourceMapping* and $l_{\text{offset}} \geq N_{\text{symb}}^{\text{SRS}} - 1$. If $N_{\text{hop}} > 1\_l_0$ is the starting position of each hop in the time domain, determined by the field *startPosition* for each SRS transmission hop.
- k_0, the frequency-domain starting position of the sounding reference signal.

6.4.1.4.2 Sequence generation

The sounding reference signal sequence for an SRS resource, or if *SRShoppingNrofHops* for *SRS-PosResource* is provided, for a given hop within an SRS resource, shall be generated according to

$$r^{(p_i)}(n, l') = \mathrm{w}_{\text{TDM}}^{(p_i)}(l') r_{u,v}^{(\alpha_i,\delta)}(n)$$

$$0 \le n \le M_{\mathrm{sc},b}^{\mathrm{SRS}} - 1$$

$$l' \in \left\{0,1,\ldots,N_{\mathrm{symb}}^{\mathrm{SRS}} - 1\right\}$$

where $M_{\mathrm{sc},b}^{\mathrm{SRS}}$ is given by clause 6.4.1.4.3, $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 5.2.2 with $\delta = \log_2(K_{\mathrm{TC}})$ and the transmission comb number $K_{\mathrm{TC}} \in \{2,4,8\}$ is contained in the higher-layer parameter *transmissionComb*. The quantity $l' \in \left\{0,1,\ldots,N_{\mathrm{symb}}^{\mathrm{SRS}} - 1\right\}$ is the OFDM symbol number within the SRS resource.

The quantity $\mathrm{w}_{\mathrm{TDM}}^{(p_i)}(l')$ is given by

- if the higher-layer parameter *nrofSRS-Ports-n8* equals *ports8tdm*

$$\mathrm{w}_{\mathrm{TDM}}^{(p_i)}(l') = \begin{cases} 1 & \text{if } l' \in \left\{0,2,\ldots,N_{\mathrm{symb}}^{\mathrm{SRS}} - 2\right\} \text{ and } p_i \in \{1000,1001,1004,1005\} \\ 1 & \text{if } l' \in \left\{1,3,\ldots,N_{\mathrm{symb}}^{\mathrm{SRS}} - 1\right\} \text{ and } p_i \in \{1002,1003,1006,1007\} \\ 0 & \text{otherwise} \end{cases}$$

- otherwise

$$\mathrm{w}_{\mathrm{TDM}}^{(p_i)}(l') = 1$$

The cyclic shift α_i for antenna port p_i is given as

$$\alpha_i = 2\pi\left(\frac{n_{\mathrm{SRS}}^{\mathrm{cs},i}}{n_{\mathrm{SRS}}^{\mathrm{cs,max}}} + \frac{f_{\mathrm{csh}}\left(n_{\mathrm{f}}, n_{\mathrm{s,f}}^{\mu}, l'\right)}{K n_{\mathrm{SRS}}^{\mathrm{cs,max}}}\right)$$

where

$$n_{\mathrm{SRS}}^{\mathrm{cs},i} = \begin{cases} \left(n_{\mathrm{SRS}}^{\mathrm{cs}} + \dfrac{n_{\mathrm{SRS}}^{\mathrm{cs,max}}\left\lfloor\left(\bar{p}_i - 1000\right)/4\right\rfloor}{\bar{N}_{\mathrm{ap}}^{\mathrm{SRS}}/4}\right) \bmod n_{\mathrm{SRS}}^{\mathrm{cs,max}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 8 \text{ and } n_{\mathrm{SRS}}^{\mathrm{cs,max}} = 6 \\ \left(n_{\mathrm{SRS}}^{\mathrm{cs}} + \dfrac{n_{\mathrm{SRS}}^{\mathrm{cs,max}}\left\lfloor\left(\bar{p}_i - 1000\right)/2\right\rfloor}{\bar{N}_{\mathrm{ap}}^{\mathrm{SRS}}/2}\right) \bmod n_{\mathrm{SRS}}^{\mathrm{cs,max}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 4 \text{ and } n_{\mathrm{SRS}}^{\mathrm{cs,max}}=6\text{; or if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 8 \text{ and } n_{\mathrm{SRS}}^{\mathrm{cs,max}}=12 \\ \left(n_{\mathrm{SRS}}^{\mathrm{cs}} + \dfrac{n_{\mathrm{SRS}}^{\mathrm{cs,max}}\left(\bar{p}_i - 1000\right)}{\bar{N}_{\mathrm{ap}}^{\mathrm{SRS}}}\right) \bmod n_{\mathrm{SRS}}^{\mathrm{cs,max}} & \text{otherwise} \end{cases}$$

where $n_{\mathrm{SRS}}^{\mathrm{cs}} \in \left\{0,1,\ldots,n_{\mathrm{SRS}}^{\mathrm{cs,max}} - 1\right\}$ is contained in the higher layer parameter *transmissionComb*. The maximum number of cyclic shifts $n_{\mathrm{SRS}}^{\mathrm{cs,max}}$ is given by Table 6.4.1.4.2-1.

The quantities $\bar{p}_i$ and $\bar{N}_{\mathrm{ap}}^{\mathrm{SRS}}$ are given by

- if the higher-layer parameter *nrofSRS-Ports-n8* equals *ports8tdm*

$$\bar{p}_i = \begin{cases} 1000 + p_i \bmod 2 & \text{if } p_i - 1000 < 4 \\ 1000 + p_i \bmod 2 + 2 & \text{if } p_i - 1000 \ge 4 \end{cases}$$

$$\bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 4$$

- otherwise

$$\bar{p}_i = p_i$$

$$\bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = N_{\mathrm{ap}}^{\mathrm{SRS}}$$

The quantity $f_{\mathrm{csh}}\left(n_{\mathrm{f}}, n_{\mathrm{s,f}}^{\mu}, l'\right)$ is given by

- if the higher-layer parameter *cyclicShiftHopping* is not configured:

$$f_{\mathrm{csh}}\left(n_{\mathrm{f}}, n_{\mathrm{s,f}}^{\mu}, l'\right) = 0$$

- if the higher-layer parameter *cyclicShiftHopping* is configured:

$$f_{\text{csh}}\left(n_{\text{f}}, n_{\text{s,f}}^{\mu}, l'\right) =$$
$$s_{\text{csh}}^{\text{SRS}}\left(\left(\sum_{m=0}^{7}\left(c\left(8\left((n_{\text{f}} \bmod 128)N_{\text{slot}}^{\text{frame},\mu}N_{\text{symb}}^{\text{slot}} + n_{\text{s,f}}^{\mu}N_{\text{symb}}^{\text{slot}} + l_0 + l'\right) + m\right)2^m\right)\right) \bmod n_{\text{csh}}^{\text{SRS}}\right)$$

where $s_{\text{csh}}^{\text{SRS}}(n)$ and $n_{\text{csh}}^{\text{SRS}}$ is the $(n+1)$th entry and the cardinality of the set

$$\mathcal{S}_{\text{csh}} = \{s_{\text{csh}}^{\text{SRS}}(0), s_{\text{csh}}^{\text{SRS}}(1), \ldots, s_{\text{csh}}^{\text{SRS}}(n_{\text{csh}}^{\text{SRS}} - 1)\}$$

respectively, where $\mathcal{S}_{\text{csh}}$ is given by the higher-layer parameter *hoppingSubset* in the *cyclicShiftHopping* IE if configured, otherwise $\mathcal{S}_{\text{csh}} = \{0, 1, \ldots, Kn_{SRS}^{\text{cs,max}} - 1\}$. The higher-layer parameter *hoppingSubset* in the *cyclicShiftHopping* IE includes a bitmap of $n_{\text{SRS}}^{\text{cs,max}}$ bits with $1 < n_{\text{csh}}^{\text{SRS}} < n_{\text{SRS}}^{\text{cs,max}}$ non-zero bits, where if the $(n+1)$th non-zero bit is the t:th bit in the bitmap, then $s_{\text{csh}}^{\text{SRS}}(n) = t - 1$.

The pseudo-random sequence $c(i)$ is defined by clause 5.2.1 and shall be initialized with $c_{\text{init}} = n_{\text{ID}}^{\text{hop}}$ at the beginning of each radio frame for which $n_{\text{f}} \bmod 128 = 0$, where the cyclic-shift hopping identity $n_{\text{ID}}^{\text{hop}}$ is contained in the higher-layer parameter *cyclicShiftHopping*.

If the higher-layer parameter *hoppingFinerGranularity* is configured, $K = 2$, otherwise $K = 1$.

The sequence group $u = \left(f_{\text{gh}}\left(n_{\text{s,f}}^{\mu}, l'\right) + n_{\text{ID}}^{\text{SRS}}\right) \bmod 30$ and the sequence number v in clause 5.2.2 depends on the higher-layer parameter *groupOrSequenceHopping* in the *SRS-Resource* IE or the *SRS-PosResource* IE. The SRS sequence identity $n_{\text{ID}}^{\text{SRS}}$ is given by the higher layer parameter *sequenceId* in the *SRS-Resource* IE, in which case $n_{\text{ID}}^{\text{SRS}} \in \{0, 1, \ldots, 1023\}$, or the *SRS-PosResource-r16* IE, in which case $n_{\text{ID}}^{\text{SRS}} \in \{0, 1, \ldots, 65535\}$.

- if *groupOrSequenceHopping* equals 'neither', neither group, nor sequence hopping shall be used and

$$f_{\text{gh}}\left(n_{\text{s,f}}^{\mu}, l'\right) = 0$$
$$v = 0$$

- if *groupOrSequenceHopping* equals 'groupHopping', group hopping but not sequence hopping shall be used and

$$f_{\text{gh}}\left(n_{\text{s,f}}^{\mu}, l'\right) = \left(\sum_{m=0}^{7} c\left(8\left(n_{\text{s,f}}^{\mu} N_{\text{symb}}^{\text{slot}} + l_0 + l'\right) + m\right) \cdot 2^m\right) \bmod 30$$
$$v = 0$$

where the pseudo-random sequence $c(i)$ is defined by clause 5.2.1 and shall be initialized with $c_{\text{init}} = n_{\text{ID}}^{\text{SRS}}$ at the beginning of each radio frame.

- if *groupOrSequenceHopping* equals 'sequenceHopping', sequence hopping but not group hopping shall be used and

$$f_{\text{gh}}\left(n_{\text{s,f}}^{\mu}, l'\right) = 0$$
$$v = \begin{cases} c\left(n_{\text{s,f}}^{\mu} N_{\text{symb}}^{\text{slot}} + l_0 + l'\right) & M_{\text{sc},b}^{\text{SRS}} \geq 6N_{\text{sc}}^{\text{RB}} \\ 0 & \text{otherwise} \end{cases}$$

where the pseudo-random sequence $c(i)$ is defined by clause 5.2.1 and shall be initialized with $c_{\text{init}} = n_{\text{ID}}^{\text{SRS}}$ at the beginning of each radio frame.

Table 6.4.1.4.2-1: Maximum number of cyclic shifts $n_{\text{SRS}}^{\text{cs,max}}$ as a function of K_{TC}.

K_{TC}	$n_{\text{SRS}}^{\text{cs,max}}$
2	8
4	12
8	6

6.4.1.4.3 Mapping to physical resources

Throughout this clause, when the higher layer parameter *SRShoppingNrofHops* is provided for *SRS-PosResource*, the sounding reference signal sequence definitions applies to a given hop.

When SRS is transmitted on a given SRS resource, the sequence $r^{(p_i)}(n,l')$ for each OFDM symbol l' and for each of the antenna ports of the SRS resource shall be multiplied with the amplitude scaling factor β_{SRS} in order to conform to the transmit power specified in [5, 38.213] and mapped in sequence starting with $r^{(p_i)}(0,l')$ to resource elements (k,l) in a slot for each of the antenna ports p_i according to

$$a^{(p_i)}_{K_{\mathrm{TC}}k'+k_0^{(p_i)},l'+l_0} = \begin{cases} \frac{1}{\sqrt{N_{\mathrm{ap}}}}\beta_{\mathrm{SRS}} r^{(p_i)}(k',l') & \text{if } k' = 0,1,\dots,M_{\mathrm{sc},b}^{\mathrm{SRS}}-1 \text{ and } l' = 0,1,\dots,N_{\mathrm{symb}}^{\mathrm{SRS}}-1 \\ 0 & \text{otherwise} \end{cases}$$

The length of the sounding reference signal sequence is given by

$$M_{\mathrm{sc},b}^{\mathrm{SRS}} = m_{\mathrm{SRS},b} N_{\mathrm{sc}}^{\mathrm{RB}} / (K_{\mathrm{TC}} P_{\mathrm{F}})$$

where $m_{\mathrm{SRS},b}$ is given by a selected row of Table 6.4.1.4.3-1 with $b = B_{\mathrm{SRS}}$ where $B_{\mathrm{SRS}} \in \{0,1,2,3\}$ is given by the field *b-SRS* contained in the higher-layer parameter *freqHopping* if configured, otherwise $B_{\mathrm{SRS}} = 0$. The row of the table is selected according to the index $C_{\mathrm{SRS}} \in \{0,1,\dots,63\}$ given by the field *c-SRS* contained in the higher-layer parameter *freqHopping*. The quantity $P_{\mathrm{F}} \in \{2,4\}$ is given by the higher-layer parameter *FreqScalingFactor* if configured, otherwise $P_{\mathrm{F}} = 1$. When *FreqScalingFactor* is configured, the UE expects the length of the SRS sequence to be a multiple of 6.

The frequency-domain starting position $k_0^{(p_i)}$ is defined by

$$k_0^{(p_i)} = \bar{k}_0^{(p_i)} + n_{\mathrm{offset}}^{\mathrm{FH}} + n_{\mathrm{offset}}^{\mathrm{RPFS}} + n_{\mathrm{offset2}}^{\mathrm{FH}}$$

where

$$\bar{k}_0^{(p_i)} = n_{\mathrm{shift}} N_{\mathrm{sc}}^{\mathrm{RB}} + \left(k_{\mathrm{TC}}^{(p_i)} + k_{\mathrm{offset}}^{l'} + f_{\mathrm{coh}}\left(n_{\mathrm{f}}, n_{\mathrm{s,f}}^{\mu}, l''\right)\right) \bmod K_{\mathrm{TC}}$$

and

$$k_{\mathrm{TC}}^{(p_i)} = \begin{cases} \left(\bar{k}_{\mathrm{TC}} + 3K_{\mathrm{TC}}/4\right) \bmod K_{\mathrm{TC}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 8, \bar{p}_i \in \{1003, 1007\}, \text{and } n_{\mathrm{SRS}}^{\mathrm{cs,max}} = 6 \\ \left(\bar{k}_{\mathrm{TC}} + K_{\mathrm{TC}}/2\right) \bmod K_{\mathrm{TC}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 8, \bar{p}_i \in \{1002, 1006\}, \text{and } n_{\mathrm{SRS}}^{\mathrm{cs,max}} = 6 \\ \left(\bar{k}_{\mathrm{TC}} + K_{\mathrm{TC}}/4\right) \bmod K_{\mathrm{TC}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 8, \bar{p}_i \in \{1001, 1005\}, \text{and } n_{\mathrm{SRS}}^{\mathrm{cs,max}} = 6 \\ \left(\bar{k}_{\mathrm{TC}} + K_{\mathrm{TC}}/2\right) \bmod K_{\mathrm{TC}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 8, \bar{p}_i \in \{1001, 1003, 1005, 1007\}, \text{and } n_{\mathrm{SRS}}^{\mathrm{cs,max}} = 12 \\ \left(\bar{k}_{\mathrm{TC}} + K_{\mathrm{TC}}/2\right) \bmod K_{\mathrm{TC}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 8, \bar{p}_i \in \{1001, 1003, 1005, 1007\}, n_{\mathrm{SRS}}^{\mathrm{cs,max}} = 8, \text{and } n_{\mathrm{SRS}}^{\mathrm{cs}} \geq n_{\mathrm{SRS}}^{\mathrm{cs,max}}/2 \\ \left(\bar{k}_{\mathrm{TC}} + K_{\mathrm{TC}}/2\right) \bmod K_{\mathrm{TC}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 4, \bar{p}_i \in \{1001, 1003\}, \text{and } n_{\mathrm{SRS}}^{\mathrm{cs,max}} = 6 \\ \left(\bar{k}_{\mathrm{TC}} + K_{\mathrm{TC}}/2\right) \bmod K_{\mathrm{TC}} & \text{if } \bar{N}_{\mathrm{ap}}^{\mathrm{SRS}} = 4, \bar{p}_i \in \{1001, 1003\}, \ n_{\mathrm{SRS}}^{\mathrm{cs,max}} \in \{8, 12\}, \text{and } n_{\mathrm{SRS}}^{\mathrm{cs}} \geq n_{\mathrm{SRS}}^{\mathrm{cs,max}}/2 \\ \bar{k}_{\mathrm{TC}} & \text{otherwise} \end{cases}$$

$$n_{\mathrm{offset}}^{\mathrm{FH}} = \sum_{b=0}^{B_{\mathrm{SRS}}} m_{\mathrm{SRS},b} N_{\mathrm{sc}}^{\mathrm{RB}} n_b$$

$$n_{\mathrm{offset}}^{\mathrm{RPFS}} = N_{\mathrm{sc}}^{\mathrm{RB}} m_{\mathrm{SRS},B_{\mathrm{SRS}}} \left(\left(k_{\mathrm{F}} + k_{\mathrm{hop}}\right) \bmod P_{\mathrm{F}}\right) / P_{\mathrm{F}}$$

$$n_{\mathrm{offset2}}^{\mathrm{FH}} = \left(\left(n_{\mathrm{init}}^{\mathrm{hop}} + n_{\mathrm{SRS}}^{\mathrm{TxHopping}}\right) \bmod N_{\mathrm{hop}} - n_{\mathrm{init}}^{\mathrm{hop}}\right)\left(m_{\mathrm{SRS},0} - m_{\mathrm{overlap}}^{\mathrm{hop}}\right) N_{\mathrm{sc}}^{\mathrm{RB}}$$

and

- $k_{\mathrm{F}} \in \{0,1,\dots,P_{\mathrm{F}}-1\}$ is given by the higher-layer parameter *StartRBIndex* if configured, otherwise $k_{\mathrm{F}} = 0$;

- k_{hop} is given by Table 6.4.1.4.3-3 with

$$\bar{k}_{\mathrm{hop}} = \left\lfloor \frac{n_{\mathrm{SRS}}}{\prod_{b'=b_{\mathrm{hop}}}^{B_{\mathrm{SRS}}} N_{b'}} \right\rfloor \bmod P_{\mathrm{F}}$$

$$N_{b_{\mathrm{hop}}} = 1$$

if the higher-layer parameter *EnableStartRBHopping* is configured, otherwise $k_{\text{hop}} = 0$.

- $m_{\text{overlap}}^{\text{hop}} \in \{0,1,2,4\}$ is given by the higher-layer parameter YYY.
- $n_{\text{SRS}}^{\text{TxHopping}} = 0,1,\dots,N_{\text{hops}}^{\text{SRS}} - 1$is the hop transmission counter in the time domain, which corresponds to the order of the higher-layer parameter *SlotOffsetForRemainingHops*.
- $n_{\text{init}}^{\text{hop}} = \left\lfloor n_{\text{shift}} / \left(m_{\text{SRS},0} - m_{\text{overlap}}^{\text{hop}} \right) \right\rfloor$ is the initial hop index.

The quantity $f_{\text{coh}}\left(n_{\text{f}}, n_{\text{s,f}}^{\mu}, l''\right)$ is given by

- if the higher-layer parameter *combOffsetHopping* is not configured:

$$f_{\text{coh}}\left(n_{\text{f}}, n_{\text{s,f}}^{\mu}, l''\right) = 0$$

- if the higher-layer parameter *combOffsetHopping* is configured:

$$f_{\text{coh}}\left(n_{\text{f}}, n_{\text{s,f}}^{\mu}, l''\right) = \\ s_{\text{coh}}^{\text{SRS}}\left(\left(\sum_{m=0}^{7}\left(c\left(8\left((n_{\text{f}} \bmod 128) N_{\text{slot}}^{\text{frame},\mu} N_{\text{symb}}^{\text{slot}} + n_{\text{s,f}}^{\mu} N_{\text{symb}}^{\text{slot}} + l_0 + l''\right) + m\right) 2^m\right)\right) \bmod n_{\text{coh}}^{\text{SRS}}\right)$$

where $s_{\text{coh}}^{\text{SRS}}(n)$ and $n_{\text{coh}}^{\text{SRS}}$ is the $(n+1)$th entry and the cardinality of the set

$$\mathcal{S}_{\text{coh}} = \{s_{\text{coh}}^{\text{SRS}}(0), s_{\text{coh}}^{\text{SRS}}(1), \dots, s_{\text{coh}}^{\text{SRS}}\left(n_{\text{coh}}^{\text{SRS}} - 1\right)\}$$

respectively, where $\mathcal{S}_{\text{coh}}$ is given by the higher-layer parameter *hoppingSubset* in the *combOffsetHopping* IE if configured, otherwise $\mathcal{S}_{\text{coh}} = \{0, 1, \dots, K_{TC} - 1\}$. The higher-layer parameter *hoppingSubset* in the *combOffsetHopping* IE includes a bitmap of K_{TC} bits with $1 < n_{\text{coh}}^{\text{SRS}} < K_{\text{TC}}$ non-zero bits, where if the $(n+1)$th non-zero bit is the t:th bit in the bitmap, then $s_{\text{coh}}^{\text{SRS}}(n) = t - 1$.

The pseudo-random sequence $c(i)$ is defined by clause 5.2.1 and shall be initialized with $c_{\text{init}} = n_{\text{ID}}^{\text{hop}}$ at the beginning of each radio frame for which $n_{\text{f}} \bmod 128 = 0$, where the comb offset hopping identity $n_{\text{ID}}^{\text{hop}}$ is contained in the higher-layer parameter *combOffsetHopping*.

If the higher-layer parameter *hoppingWithRepetition* is set to *Repetition*, $l'' = \lfloor l'/R \rfloor R$, otherwise $l'' = l'$.

If *SRShoppingNrofHops* is configured:

- The reference point for $k_0^{(p_i)} = 0$ is the lowest subcarrier of the configured bandwidth for SRS with Tx hopping configured by the parameter XXX in *TxhoppingBandwidth*.

otherwise:

- If $N_{\text{BWP}}^{\text{start}} \leq n_{\text{shift}}$ the reference point for $k_0^{(p_i)} = 0$ is subcarrier 0 in common resource block 0, otherwise the reference point is the lowest subcarrier of the BWP.

If the SRS is configured by the IE *SRS-PosResource*, the quantity $k_{\text{offset}}^{l'}$ is given by Table 6.4.1.4.3-2, otherwise $k_{\text{offset}}^{l'} = 0$.

The frequency domain shift value n_{shift} adjusts the SRS allocation with respect to the reference point grid and is contained in the higher-layer parameter *freqDomainShift* in the *SRS-Resource* IE or the *SRS-PosResource* IE. The transmission comb offset $\bar{k}_{\text{TC}} \in \{0,1,\dots,K_{\text{TC}} - 1\}$ is contained in the higher-layer parameter *transmissionComb* in the *SRS-Resource* IE or the *SRS-PosResource* IE and n_b is a frequency position index.

Frequency hopping of the sounding reference signal is configured by the parameter $b_{\text{hop}} \in \{0,1,2,3\}$, given by the field *b-hop* contained in the higher-layer parameter *freqHopping* if configured, otherwise $b_{\text{hop}} = 0$.

If $b_{\mathrm{hop}} \geq B_{\mathrm{SRS}}$, frequency hopping is disabled and the frequency position index n_b remains constant (unless re-configured) and is defined by

$$n_{\mathrm{b}} = \lfloor 4 n_{\mathrm{RRC}} / m_{\mathrm{SRS},b} \rfloor \bmod N_{\mathrm{b}}$$

for all $N_{\mathrm{symb}}^{\mathrm{SRS}}$ OFDM symbols of the SRS resource. The quantity n_{RRC} is given by the higher-layer parameter *freqDomainPosition* if configured, otherwise $n_{\mathrm{RRC}} = 0$, and the values of $m_{\mathrm{SRS},b}$ and N_{b} for $b = B_{\mathrm{SRS}}$ are given by the selected row of Table 6.4.1.4.3-1 corresponding to the configured value of C_{SRS} .

If $b_{\mathrm{hop}} < B_{\mathrm{SRS}}$, frequency hopping is enabled and the frequency position indices n_b are defined by

$$n_b = \begin{cases} \lfloor 4 n_{\mathrm{RRC}} / m_{\mathrm{SRS},b} \rfloor \bmod N_{\mathrm{b}} & b \leq b_{\mathrm{hop}} \\ \left(F_b(n_{\mathrm{SRS}}) + \lfloor 4 n_{\mathrm{RRC}} / m_{\mathrm{SRS},b} \rfloor \right) \bmod N_{\mathrm{b}} & \text{otherwise} \end{cases}$$

where N_{b} is given by Table 6.4.1.4.3-1,

$$F_b(n_{\mathrm{SRS}}) = \begin{cases} (N_b/2) \left\lfloor \dfrac{n_{\mathrm{SRS}} \bmod \Pi_{b'=b_{\mathrm{hop}}}^{b} N_{b'}}{\Pi_{b'=b_{\mathrm{hop}}}^{b-1} N_{b'}} \right\rfloor + \left\lfloor \dfrac{n_{\mathrm{SRS}} \bmod \Pi_{b'=b_{\mathrm{hop}}}^{b} N_{b'}}{2\Pi_{b'=b_{\mathrm{hop}}}^{b-1} N_{b'}} \right\rfloor & \text{if } N_b \text{ even} \\ \lfloor N_b/2 \rfloor \left\lfloor n_{\mathrm{SRS}} / \Pi_{b'=b_{\mathrm{hop}}}^{b-1} N_{b'} \right\rfloor & \text{if } N_b \text{ odd} \end{cases}$$

and where $N_{b_{\mathrm{hop}}} = 1$ regardless of the value of N_{b}. The quantity n_{SRS} counts the number of SRS transmissions. For the case of an SRS resource configured as aperiodic by the higher-layer parameter *resourceType*, it is given by $n_{\mathrm{SRS}} = \lfloor l'/(sR) \rfloor$ within the slot in which the $N_{\mathrm{symb}}^{\mathrm{SRS}}$ symbol SRS resource is transmitted. The quantity s is given by $s = 2$ if the higher-layer parameter *nrofSRS-Ports-n8* equals 'ports8tdm', otherwise $s = 1$. The quantity $R \leq N_{\mathrm{symb}}^{\mathrm{SRS}}/s$ is the repetition factor given by the field *repetitionFactor* if configured, otherwise $R = N_{\mathrm{symb}}^{\mathrm{SRS}}$.

For the case of an SRS resource configured as periodic or semi-persistent by the higher-layer parameter *resourceType*, the SRS counter is given by

$$n_{\mathrm{SRS}} = \left(\frac{N_{\mathrm{slot}}^{\mathrm{frame},\mu} n_{\mathrm{f}} + n_{\mathrm{s,f}}^{\mu} - T_{\mathrm{offset}}}{T_{\mathrm{SRS}}} \right) \left(\frac{N_{\mathrm{symb}}^{\mathrm{SRS}}}{sR} \right) + \left\lfloor \frac{l'}{sR} \right\rfloor$$

for slots that satisfy $\left(N_{\mathrm{slot}}^{\mathrm{frame},\mu} n_{\mathrm{f}} + n_{\mathrm{s,f}}^{\mu} - T_{\mathrm{offset}} \right) \bmod T_{\mathrm{SRS}} = 0$. The periodicity T_{SRS} in slots and slot offset T_{offset} are given in clause 6.4.1.4.4.

Table 6.4.1.4.3-1: SRS bandwidth configuration.

C_{SRS}	$B_{\text{SRS}}=0$		$B_{\text{SRS}}=1$		$B_{\text{SRS}}=2$		$B_{\text{SRS}}=3$	
	$m_{\text{SRS},0}$	N_0	$m_{\text{SRS},1}$	N_1	$m_{\text{SRS},2}$	N_2	$m_{\text{SRS},3}$	N_3
0	4	1	4	1	4	1	4	1
1	8	1	4	2	4	1	4	1
2	12	1	4	3	4	1	4	1
3	16	1	4	4	4	1	4	1
4	16	1	8	2	4	2	4	1
5	20	1	4	5	4	1	4	1
6	24	1	4	6	4	1	4	1
7	24	1	12	2	4	3	4	1
8	28	1	4	7	4	1	4	1
9	32	1	16	2	8	2	4	2
10	36	1	12	3	4	3	4	1
11	40	1	20	2	4	5	4	1
12	48	1	16	3	8	2	4	2
13	48	1	24	2	12	2	4	3
14	52	1	4	13	4	1	4	1
15	56	1	28	2	4	7	4	1
16	60	1	20	3	4	5	4	1
17	64	1	32	2	16	2	4	4
18	72	1	24	3	12	2	4	3
19	72	1	36	2	12	3	4	3
20	76	1	4	19	4	1	4	1
21	80	1	40	2	20	2	4	5
22	88	1	44	2	4	11	4	1
23	96	1	32	3	16	2	4	4
24	96	1	48	2	24	2	4	6
25	104	1	52	2	4	13	4	1
26	112	1	56	2	28	2	4	7
27	120	1	60	2	20	3	4	5
28	120	1	40	3	8	5	4	2
29	120	1	24	5	12	2	4	3
30	128	1	64	2	32	2	4	8
31	128	1	64	2	16	4	4	4
32	128	1	16	8	8	2	4	2
33	132	1	44	3	4	11	4	1
34	136	1	68	2	4	17	4	1
35	144	1	72	2	36	2	4	9
36	144	1	48	3	24	2	12	2
37	144	1	48	3	16	3	4	4
38	144	1	16	9	8	2	4	2
39	152	1	76	2	4	19	4	1
40	160	1	80	2	40	2	4	10
41	160	1	80	2	20	4	4	5
42	160	1	32	5	16	2	4	4
43	168	1	84	2	28	3	4	7
44	176	1	88	2	44	2	4	11
45	184	1	92	2	4	23	4	1
46	192	1	96	2	48	2	4	12
47	192	1	96	2	24	4	4	6
48	192	1	64	3	16	4	4	4
49	192	1	24	8	8	3	4	2
50	208	1	104	2	52	2	4	13
51	216	1	108	2	36	3	4	9
52	224	1	112	2	56	2	4	14
53	240	1	120	2	60	2	4	15
54	240	1	80	3	20	4	4	5
55	240	1	48	5	16	3	8	2
56	240	1	24	10	12	2	4	3
57	256	1	128	2	64	2	4	16
58	256	1	128	2	32	4	4	8
59	256	1	16	16	8	2	4	2
60	264	1	132	2	44	3	4	11
61	272	1	136	2	68	2	4	17
62	272	1	68	4	4	17	4	1

63	272	1	16	17	8	2	4	2

Table 6.4.1.4.3-2: The offset $k_{\text{offset}}^{l'}$ for SRS as a function of K_{TC} and l'.

K_{TC}	$k_{\text{offset}}^{0},\dots,k_{\text{offset}}^{N_{\text{symb}}^{\text{SRS}}-1}$				
	$N_{\text{symb}}^{\text{SRS}}=1$	$N_{\text{symb}}^{\text{SRS}}=2$	$N_{\text{symb}}^{\text{SRS}}=4$	$N_{\text{symb}}^{\text{SRS}}=8$	$N_{\text{symb}}^{\text{SRS}}=12$
2	0	0,1	0,1,0,1	-	-
4	-	0, 2	0, 2, 1, 3	0, 2, 1, 3, 0, 2, 1, 3	0, 2, 1, 3, 0, 2, 1, 3, 0, 2, 1, 3
8	-	-	0, 4, 2, 6	0, 4, 2, 6, 1, 5, 3, 7	0, 4, 2, 6, 1, 5, 3, 7, 0, 4, 2, 6

Table 6.4.1.4.3-3: The quantity k_{hop} as a function of $\bar{k}_{\text{hop}}$.

$\bar{k}_{\text{hop}}$	k_{hop}		
	$P_{\text{F}}=1$	$P_{\text{F}}=2$	$P_{\text{F}}=4$
0	0	0	0
1	-	1	2
2	-	-	1
3	-	-	3

6.4.1.4.4 Sounding reference signal slot configuration

Throughout this clause, when the higher layer parameter *SRShoppingNrofHops* is provided for *SRS-PosResource*, the sounding reference signal slot configuration applies to a given hop.

For an SRS resource configured as periodic or semi-persistent by the higher-layer parameter *resourceType*, a periodicity T_{SRS} (in slots) and slot offset T_{offset} are configured according to the higher-layer parameter *periodicityAndOffset-p* or *periodicityAndOffset-sp* in the *SRS-Resource* IE, or *periodicityAndOffset-p* or *periodicityAndOffset-sp* in the *SRS-PosResource* IE. Candidate slots in which the configured SRS resource may be used for SRS transmission are the slots satisfying

$$\left(N_{\text{slot}}^{\text{frame},\mu} n_{\text{f}} + n_{\text{s,f}}^{\mu} - T_{\text{offset}}\right) \bmod T_{\text{SRS}} = 0$$

and, if the higher-layer parameter *srs-PosHyperSFN-Index* is configured for a periodicity larger than or equal to $2^{\mu}\cdot 10240$ slots, also

$$\left(n_{\text{HFN}} + N_{\text{SRS}}^{\text{HFN}}\right) \bmod 2 = 0$$

where $N_{\text{SRS}}^{\text{HFN}} \in \{0,1\}$ is given by the higher-layer parameter *srs-PosHyperSFN-Index* and n_{HFN} is the hyper-frame number.

SRS is transmitted as described in clause 6.2.1 of [6, TS 38.214].

7 Downlink

7.1 Overview

7.1.1 Overview of physical channels

A downlink physical channel corresponds to a set of resource elements carrying information originating from higher layers. The following downlink physical channels are defined:

- Physical Downlink Shared Channel, PDSCH
- Physical Broadcast Channel, PBCH

- Physical Downlink Control Channel, PDCCH.

7.1.2 Overview of physical signals

A downlink physical signal corresponds to a set of resource elements used by the physical layer but does not carry information originating from higher layers.

The following downlink physical signals are defined:

- Demodulation reference signals, DM-RS
- Phase-tracking reference signals, PT-RS
- Positioning reference signal, PRS
- Channel-state information reference signal, CSI-RS
- Primary synchronization signal, PSS
- Secondary synchronization signal, SSS

7.2 Physical resources

The frame structure and physical resources the UE shall assume when receiving downlink transmissions are defined in Clause 4.

The following antenna ports are defined for the downlink:

- Antenna ports starting with 1000 for PDSCH
- Antenna ports starting with 2000 for PDCCH
- Antenna ports starting with 3000 for channel-state information reference signals
- Antenna ports starting with 4000 for SS/PBCH block transmission
- Antenna ports starting with 5000 for positioning reference signals

The UE shall not assume that two antenna ports are quasi co-located with respect to any QCL type unless specified otherwise.

For DM-RS associated with a PDSCH, the channel over which a PDSCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within the same resource as the scheduled PDSCH, in the same slot, and in the same PRG as described in clause 5.1.2.3 of [6, TS 38.214].

For DM-RS associated with a PDCCH, the channel over which a PDCCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within resources for which the UE may assume the same precoding being used as described in clause 7.3.2.2.

For DM-RS associated with a PBCH, the channel over which a PBCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within a SS/PBCH block transmitted within the same slot, and with the same block index according to clause 7.4.3.1.

7.3 Physical channels

7.3.1 Physical downlink shared channel

7.3.1.1 Scrambling

Up to two codewords $q \in \{0,1\}$ can be transmitted. In case of single-codeword transmission, $q = 0$.

For each codeword q, the UE shall assume the block of bits $b^{(q)}(0),\dots,b^{(q)}(M_{\text{bit}}^{(q)}-1)$, where $M_{\text{bit}}^{(q)}$ is the number of bits in codeword q transmitted on the physical channel, are scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}^{(q)}(0),\dots,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)}-1)$according to

$$\tilde{b}^{(q)}(i) = \left(b^{(q)}(i) + c^{(q)}(i)\right) \bmod 2$$

where the scrambling sequence $c^{(q)}(i)$ is given by clause 5.2.1. The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{15} + q \cdot 2^{14} + n_{\text{ID}}$$

where

- $n_{\text{ID}} \in \{0,1,\dots,1023\}$ equals the higher-layer parameter *dataScramblingIdentityPDSCH* if configured and the RNTI equals the C-RNTI, MCS-C-RNTI, or CS-RNTI, and the transmission is not scheduled using DCI format 1_0 in a common search space;

- $n_{\text{ID}} \in \{0,1,\dots,1023\}$ equals the higher-layer parameter *dataScramblingIdentityPDSCH* if configured in a common MBS frequency resource and the RNTI equals the G-RNTI, G-CS-RNTI, MCCH-RNTI, or multicast-MCCH-RNTI, and the transmission is scheduled using DCI in a common search space configured in the common MBS frequency resource;

- $n_{\text{ID}} \in \{0,1,\dots,1023\}$ equals

  - the higher-layer parameter *dataScramblingIdentityPDSCH* if the codeword is scheduled using a CORESET with *CORESETPoolIndex* equal to 0;

  - the higher-layer parameter *dataScramblingIdentityPDSCH2* if the codeword is scheduled using a CORESET with *CORESETPoolIndex* equal to 1;

  if the higher-layer parameters *dataScramblingIdentityPDSCH* and *dataScramblingIdentityPDSCH2* are configured together with the higher-layer parameter *CORESETPoolIndex* containing two different values, and the RNTI equals the C-RNTI, MCS-C-RNTI, or CS-RNTI, and the transmission is not scheduled using DCI format 1_0 in a common search space;

- $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ otherwise

and where n_{RNTI} corresponds to the RNTI associated with the PDSCH transmission as described in clause 5.1 of [6, TS 38.214].

7.3.1.2 Modulation

For each codeword q, the UE shall assume the block of scrambled bits $\tilde{b}^{(q)}(0),\dots,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)}-1)$ are modulated as described in clause 5.1 using one of the modulation schemes in Table 7.3.1.2-1, resulting in a block of complex-valued modulation symbols $d^{(q)}(0),\dots,d^{(q)}(M_{\text{symb}}^{(q)}-1)$.

Table 7.3.1.2-1: Supported modulation schemes.

Modulation scheme	Modulation order Q_m
QPSK	2
16QAM	4
64QAM	6
256QAM	8
1024QAM	10

7.3.1.3 Layer mapping

The UE shall assume that complex-valued modulation symbols for each of the codewords to be transmitted are mapped onto one or several layers according to Table 7.3.1.3-1. Complex-valued modulation symbols $d^{(q)}(0),\dots,d^{(q)}(M_\mathrm{symb}^{(q)}-1)$ for codeword q shall be mapped onto the layers $x(i)=[x^{(0)}(i) \quad \dots \quad x^{(\upsilon-1)}(i)]^\mathrm{T}$, $i=0,1,\dots,M_\mathrm{symb}^\mathrm{layer}-1$ where υ is the number of layers and $M_\mathrm{symb}^\mathrm{layer}$ is the number of modulation symbols per layer.

Table 7.3.1.3-1: Codeword-to-layer mapping for spatial multiplexing.

Number of layers	Number of codewords	Codeword-to-layer mapping $i=0,1,...,M_{\text{symb}}^{\text{layer}}-1$
1	1	$x^{(0)}(i)=d^{(0)}(i)$ $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}$
2	1	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$ $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/2$
3	1	$x^{(0)}(i)=d^{(0)}(3i)$ $x^{(1)}(i)=d^{(0)}(3i+1)$ $x^{(2)}(i)=d^{(0)}(3i+2)$ $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/3$
4	1	$x^{(0)}(i)=d^{(0)}(4i)$ $x^{(1)}(i)=d^{(0)}(4i+1)$ $x^{(2)}(i)=d^{(0)}(4i+2)$ $x^{(3)}(i)=d^{(0)}(4i+3)$ $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/4$
5	2	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$ $x^{(2)}(i)=d^{(1)}(3i)$ $x^{(3)}(i)=d^{(1)}(3i+1)$ $x^{(4)}(i)=d^{(1)}(3i+2)$ $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/2=M_{\text{symb}}^{(1)}/3$
6	2	$x^{(0)}(i)=d^{(0)}(3i)$ $x^{(1)}(i)=d^{(0)}(3i+1)$ $x^{(2)}(i)=d^{(0)}(3i+2)$ $x^{(3)}(i)=d^{(1)}(3i)$ $x^{(4)}(i)=d^{(1)}(3i+1)$ $x^{(5)}(i)=d^{(1)}(3i+2)$ $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/3=M_{\text{symb}}^{(1)}/3$
7	2	$x^{(0)}(i)=d^{(0)}(3i)$ $x^{(1)}(i)=d^{(0)}(3i+1)$ $x^{(2)}(i)=d^{(0)}(3i+2)$ $x^{(3)}(i)=d^{(1)}(4i)$ $x^{(4)}(i)=d^{(1)}(4i+1)$ $x^{(5)}(i)=d^{(1)}(4i+2)$ $x^{(6)}(i)=d^{(1)}(4i+3)$ $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/3=M_{\text{symb}}^{(1)}/4$
8	2	$x^{(0)}(i)=d^{(0)}(4i)$ $x^{(1)}(i)=d^{(0)}(4i+1)$ $x^{(2)}(i)=d^{(0)}(4i+2)$ $x^{(3)}(i)=d^{(0)}(4i+3)$ $x^{(4)}(i)=d^{(1)}(4i)$ $x^{(5)}(i)=d^{(1)}(4i+1)$ $x^{(6)}(i)=d^{(1)}(4i+2)$ $x^{(7)}(i)=d^{(1)}(4i+3)$ $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/4=M_{\text{symb}}^{(1)}/4$

7.3.1.4 Antenna port mapping

The block of vectors $[x^{(0)}(i) \quad \ldots \quad x^{(\upsilon-1)}(i)]^{\mathrm{T}}$, $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$ shall be mapped to antenna ports according to

$$\begin{bmatrix} y^{(p_0)}(i) \\ \vdots \\ y^{(p_{\upsilon-1})}(i) \end{bmatrix} = \begin{bmatrix} x^{(0)}(i) \\ \vdots \\ x^{(\upsilon-1)}(i) \end{bmatrix}$$

where $i = 0,1,\ldots,M_{\text{symb}}^{\text{ap}} - 1$, $M_{\text{symb}}^{\text{ap}} = M_{\text{symb}}^{\text{layer}}$. The set of antenna ports $\{p_{0,\ldots,}\,p_{\upsilon-1}\}$ shall be determined according to the procedure in [4, TS 38.212].

7.3.1.5 Mapping to virtual resource blocks

The UE shall, for each of the antenna ports used for transmission of the physical channel, assume the block of complex-valued symbols $y^{(p)}(0),\ldots,y^{(p)}(M_{\text{symb}}^{\text{ap}} - 1)$ conform to the downlink power allocation specified in [6, TS 38.214] and are mapped in sequence starting with $y^{(p)}(0)$ to resource elements $(k',l)_{p,\mu}$ in the virtual resource blocks assigned for transmission which meet all of the following criteria:

- they are in the virtual resource blocks assigned for transmission;
- the corresponding physical resource blocks are declared as available for PDSCH according to clause 5.1.4 of [6, TS 38.214];
- the corresponding resource elements in the corresponding physical resource blocks are
  - not used for transmission of the associated DM-RS or DM-RS intended for other co-scheduled UEs as described in clause 7.4.1.1.2;
  - not used for non-zero-power CSI-RS, which is according to clause 7.4.1.5 and not configured by *TRS-ResourceSet* IE, if the corresponding physical resource blocks are for a PDSCH scheduled by a PDCCH with the CRC scrambled by C-RNTI, MCS-C-RNTI, CS-RNTI, G-RNTI for multicast, G-CS-RNTI, or a PDSCH with SPS, except if the non-zero-power CSI-RS is a CSI-RS configured by the higher-layer parameter *CSI-RS-Resource-Mobility* in the *MeasObjectNR* IE or except if the non-zero-power CSI-RS is an aperiodic non-zero-power CSI-RS resource;
  - not used for PT-RS according to clause 7.4.1.2;
  - not declared as 'not available for PDSCH according to clause 5.1.4 of [6, TS 38.214].

The mapping to resource elements $(k',l)_{p,\mu}$ allocated for PDSCH according to [6, TS 38.214] and not reserved for other purposes shall be in increasing order of first the index k' over the assigned virtual resource blocks, where $k' = 0$ is the first subcarrier in the lowest-numbered virtual resource block assigned for transmission, and then the index l.

7.3.1.6 Mapping from virtual to physical resource blocks

The UE shall assume the virtual resource blocks are mapped to physical resource blocks according to the indicated mapping scheme, non-interleaved or interleaved mapping. If no mapping scheme is indicated, the UE shall assume non-interleaved mapping.

For non-interleaved VRB-to-PRB mapping, virtual resource block n is mapped to physical resource block n, except for PDSCH transmissions scheduled with DCI format 1_0 in a common search space in which case virtual resource block n is mapped to physical resource block $n + N_{\text{start}}^{\text{CORESET}}$ where $N_{\text{start}}^{\text{CORESET}}$ is the lowest-numbered physical resource block in the control resource set where the corresponding DCI was received. When two PDCCH candidates from two linked common search space sets as indicated by the higher-layer parameter *searchSpaceLinking* are detected, and the two linked common search space sets are associated with different control resource sets, the control resource set with the lowest number among the two linked control resource sets is used to determine $N_{\text{start}}^{\text{CORESET}}$.

For interleaved VRB-to-PRB mapping, the mapping process is defined by:

- Resource block bundles are defined as
  - for PDSCH transmissions scheduled with DCI format 1_0 with the CRC scrambled by SI-RNTI in Type0-PDCCH common search space in CORESET 0, the set of $N_{\text{BWP,init}}^{\text{size}}$ resource blocks in CORESET 0 are

divided into $N_{\text{bundle}} = \lceil N_{\text{BWP,init}}^{\text{size}}/L \rceil$ resource-block bundles in increasing order of the resource-block number and bundle number where $L = 2$ is the bundle size and $N_{\text{BWP,init}}^{\text{size}}$ is the size of CORESET 0.

  - resource block bundle $N_{\text{bundle}} - 1$ consists of $N_{\text{BWP,init}}^{\text{size}} \bmod L$ resource blocks if $N_{\text{BWP,init}}^{\text{size}} \bmod L > 0$ and L resource blocks otherwise,
  - all other resource block bundles consists of L resource blocks.

- for PDSCH transmissions scheduled with DCI format 1_0 in any common search space in bandwidth part i with starting position $N_{\text{BWP},i}^{\text{start}}$, other than Type0-PDCCH common search space in CORESET 0, the set of $N_{\text{BWP,init}}^{\text{size}}$ virtual resource blocks $\{0,1,\dots,N_{\text{BWP,init}}^{\text{size}} - 1\}$, where $N_{\text{BWP,init}}^{\text{size}}$ is the size of CORESET 0 if CORESET 0 is configured for the cell and the size of initial downlink bandwidth part if CORESET 0 is not configured for the cell, are divided into N_{bundle} virtual resource-block bundles in increasing order of the virtual resource-block number and virtual bundle number and the set of $N_{\text{BWP,init}}^{\text{size}}$ physical resource blocks $\{N_{\text{start}}^{\text{CORESET}}, N_{\text{start}}^{\text{CORESET}} + 1, \dots, N_{\text{start}}^{\text{CORESET}} + N_{\text{BWP,init}}^{\text{size}} - 1\}$ are divided into N_{bundle} physical resource-block bundles in increasing order of the physical resource-block number and physical bundle number, where $N_{\text{bundle}} = \lceil (N_{\text{BWP,init}}^{\text{size}} + (N_{\text{BWP},i}^{\text{start}} + N_{\text{start}}^{\text{CORESET}}) \bmod L)/L \rceil$, $L = 2$ is the bundle size, and $N_{\text{start}}^{\text{CORESET}}$ is the lowest-numbered physical resource block in the control resource set where the corresponding DCI was received. When two PDCCH candidates from two linked search space sets as indicated by the higher-layer parameter *searchSpaceLinking* are detected, and the two linked search space sets are associated with different control resource sets, the control resource set with the lowest number among the two linked control resource sets is used to determine $N_{\text{start}}^{\text{CORESET}}$.

  - resource block bundle 0 consists of $L - \left((N_{\text{BWP},i}^{\text{start}} + N_{\text{start}}^{\text{CORESET}}) \bmod L \right)$ resource blocks,
  - resource block bundle $N_{\text{bundle}} - 1$ consists of $(N_{\text{BWP,init}}^{\text{size}} + N_{\text{BWP},i}^{\text{start}} + N_{\text{start}}^{\text{CORESET}}) \bmod L$ resource blocks if $(N_{\text{BWP,init}}^{\text{size}} + N_{\text{BWP},i}^{\text{start}} + N_{\text{start}}^{\text{CORESET}}) \bmod L > 0$ and L resource blocks otherwise,
  - all other resource block bundles consists of L resource blocks.

- for all other PDSCH transmissions, the set of $N_{\text{BWP},i}^{\text{size}}$ resource blocks in bandwidth part i with starting position $N_{\text{BWP},i}^{\text{start}}$ are divided into $N_{\text{bundle}} = \left\lceil \left(N_{\text{BWP},i}^{\text{size}} + (N_{\text{BWP},i}^{\text{start}} \bmod L_i) \right)/L_i \right\rceil$ resource-block bundles in increasing order of the resource-block number and bundle number where L_i is the bundle size for bandwidth part i provided by the higher-layer parameter *vrb-ToPRB-Interleaver* for DCI formats 1_0, 1_1, and 1_3 in a UE-specific search space, or *vrb-ToPRB-InterleaverDCI-1-2* for DCI format 1_2, and

  - resource block bundle 0 consists of $L_i - \left(N_{\text{BWP},i}^{\text{start}} \bmod L_i \right)$ resource blocks,
  - resource block bundle $N_{\text{bundle}} - 1$ consists of $\left(N_{\text{BWP},i}^{\text{start}} + N_{\text{BWP},i}^{\text{size}} \right) \bmod L_i$ resource blocks if $\left(N_{\text{BWP},i}^{\text{start}} + N_{\text{BWP},i}^{\text{size}} \right) \bmod L_i > 0$ and L_i resource blocks otherwise,
  - all other resource block bundles consists of L_i resource blocks.

- Virtual resource blocks in the interval $j \in \{0,1,\dots,N_{\text{bundle}} - 1\}$ are mapped to physical resource blocks according to

  - virtual resource block bundle $N_{\text{bundle}} - 1$ is mapped to physical resource block bundle $N_{\text{bundle}} - 1$
  - virtual resource block bundle $j \in \{0,1,\dots,N_{\text{bundle}} - 2\}$ is mapped to physical resource block bundle $f(j)$ where

$$\begin{aligned} &f(j)=rC+c \\ &j=cR+r \\ &r=0,1,\ldots,R-1 \\ &c=0,1,\ldots,C-1 \\ &R=2 \\ &C=\lfloor N_{\text{bundle}}/R \rfloor \end{aligned}$$

- The UE is not expected to be configured with $L_i = 2$ simultaneously with a PRG size of 4 as defined in [6, TS 38.214]

The UE may assume that the same precoding in the frequency domain is used within a PRB bundle and the bundle size is determined by clause 5.1.2.3 in [6, TS 38.214]. The UE shall not make any assumption that the same precoding is used for different bundles of common resource blocks.

For PDSCH transmissions scheduled by DCI format 4_1 or 4_2, and using G-RNTI or G-CS-RNTI, the quantities $N_{\text{BWP},i}^{\text{start}}$ and $N_{\text{BWP},i}^{\text{size}}$ in this clause are replaced by $N_{\text{MBS},i}^{\text{start}}$ and $N_{\text{MBS},i}^{\text{size}}$, respectively, and L_i is the bundle size for the common MBS frequency resource provided by the higher-layer parameter *vrb-ToPRB-Interleaver* in *pdsch-ConfigMulticast.*

For PDSCH transmissions scheduled by DCI format 4_0, and using G-RNTI for broadcast, MCCH-RNTI, or multicast-MCCH-RNTI, the quantities $N_{\text{BWP},i}^{\text{start}}$ and $N_{\text{BWP},i}^{\text{size}}$ in this clause are replaced by $N_{\text{MBS},i}^{\text{start}}$ and $N_{\text{MBS},i}^{\text{size}}$, respectively, and $L_i = 2$.

7.3.2 Physical downlink control channel (PDCCH)

7.3.2.1 Control-channel element (CCE)

A physical downlink control channel consists of one or more control-channel elements (CCEs) as indicated in Table 7.3.2.1-1.

Table 7.3.2.1-1: Supported PDCCH aggregation levels.

Aggregation level	Number of CCEs
1	1
2	2
4	4
8	8
16	16

7.3.2.2 Control-resource set (CORESET)

A control-resource set consists of $N_{\text{RB}}^{\text{CORESET}}$ resource blocks in the frequency domain and $N_{\text{symb}}^{\text{CORESET}} \in \{1,2,3\}$ symbols in the time domain.

A control-channel element consists of 6 resource-element groups (REGs) where a resource-element group equals one resource block during one OFDM symbol. Resource-element groups within a control-resource set are numbered in increasing order in a time-first manner, starting with 0 for the first OFDM symbol and the lowest-numbered resource block in the control resource set.

A UE can be configured with multiple control-resource sets. Each control-resource set is associated with one CCE-to-REG mapping only.

The CCE-to-REG mapping for a control-resource set can be interleaved or non-interleaved and is described by REG bundles:

- REG bundle i is defined as REGs $\{iL, iL+1, \ldots, iL+L-1\}$ where L is the REG bundle size, $i = 0,1,\ldots,N_{\text{REG}}^{\text{CORESET}}/L-1$, and $N_{\text{REG}}^{\text{CORESET}} = N_{\text{RB}}^{\text{CORESET}} N_{\text{symb}}^{\text{CORESET}}$ is the number of REGs in the CORESET

- CCE j consists of REG bundles $\{f(6j/L), f(6j/L+1), \ldots, f(6j/L+6/L-1)\}$ where $f(\cdot)$ is an interleaver

For non-interleaved CCE-to-REG mapping, $L = 6$ and $f(x) = x$.

For interleaved CCE-to-REG mapping, $L \in \{2,6\}$ for $N_{\text{symb}}^{\text{CORESET}} = 1$ and $L \in \{N_{\text{symb}}^{\text{CORESET}}, 6\}$ for $N_{\text{symb}}^{\text{CORESET}} \in \{2,3\}$. The interleaver is defined by

$$\begin{gathered} f(x) = (rC + c + n_{\text{shift}}) \bmod \left(N_{\text{REG}}^{\text{CORESET}}/L\right) \\ x = cR + r \\ r = 0,1,\dots,R-1 \\ c = 0,1,\dots,C-1 \\ C = N_{\text{REG}}^{\text{CORESET}}/(LR) \end{gathered}$$

where $R \in \{2, 3, 6\}$.

The UE is not expected to handle configurations resulting in the quantity C not being an integer.

For a CORESET configured by the *ControlResourceSet* IE:

- $N_{\text{RB}}^{\text{CORESET}}$ is given by the higher-layer parameter *frequencyDomainResources*;
- $N_{\text{symb}}^{\text{CORESET}}$ is given by the higher-layer parameter *duration*, where $N_{\text{symb}}^{\text{CORESET}} = 3$ is supported only if the higher-layer parameter *dmrs-TypeA-Position* equals 3;
- interleaved or non-interleaved mapping is given by the higher-layer parameter *cce-REG-MappingType*;
- L equals 6 for non-interleaved mapping and is given by the higher-layer parameter *reg-BundleSize* for interleaved mapping;
- R is given by the higher-layer parameter *interleaverSize*;
- $n_{\text{shift}} \in \{0,1,\dots,274\}$ is given by the higher-layer parameter *shiftIndex* if provided, otherwise $n_{\text{shift}} = N_{\text{ID}}^{\text{cell}}$;
- for both interleaved and non-interleaved mapping:
  - if the higher-layer parameter *precoderGranularity* equals *sameAsREG-bundle* the UE may assume the same precoding being used within a REG bundle
  - if the higher-layer parameter *precoderGranularity* equals *allContiguousRBs*,
    - the UE may assume the same precoding being used across the all resource-element groups within the set of contiguous resource blocks in the CORESET;
    - the UE may assume that no resource elements in the CORESET overlap with an SSB;
    - if the UE is not provided with the higher-layer parameter *pdcchCandidateReception-WithCRSOverlap*, the UE may assume that no resource elements in the CORESET overlap with LTE cell-specific reference signals as indicated by the higher-layer parameter *lte-CRS-ToMatchAround*, *lte-CRS-PatternList1*, *lte-CRS-PatternList2*, *lte-CRS-PatternList3*, or *lte-CRS-PatternList4*.

For CORESET 0 configured by the *ControlResourceSetZero* IE:

- $N_{\text{RB}}^{\text{CORESET}}$ and $N_{\text{symb}}^{\text{CORESET}}$ are defined by clause 13 of [5, TS 38.213];
- the UE may assume interleaved mapping;
- $L = 6$;
- $R = 2$;
- $n_{\text{shift}} = N_{\text{ID}}^{\text{cell}}$;
- the UE may assume normal cyclic prefix when CORESET 0 is configured by MIB or SIB1;
- the UE may assume the same precoding being used within a REG bundle.

For CORESET 0 on a carrier where the SS/PBCH block is detected at sync raster points defined in Tables 5.4.3.1-2 or 5.4.3.1-3 of [14, TS 38.101-1] and configured by the *ControlResourceSetZero* IE:

- $N_{\mathrm{RB}}^{\mathrm{CORESET}}$ and $N_{\mathrm{symb}}^{\mathrm{CORESET}}$ are defined by Table 13-0 in clause 13 of [5, TS 38.213];
- if $N_{\mathrm{RB}}^{\mathrm{CORESET}}=12$ on a carrier with a channel bandwidth of 3 MHz, the CORESET is obtained by applying the description above assuming interleaved mapping with $R=2$;
- if $N_{\mathrm{RB}}^{\mathrm{CORESET}}=24$ on a carrier with a channel bandwidth of 3 MHz, the CORESET is obtained by applying the description above assuming interleaved mapping with $R=2$ or non-interleaved mapping as defined by clause 13 of [5, TS 38.213], followed by puncturing the 9 highest-numbered resource blocks to obtain the 15 resource blocks forming CORESET 0;
- if $N_{\mathrm{RB}}^{\mathrm{CORESET}}=24$ on a carrier with a channel bandwidth of 5 MHz, the CORESET is obtained by applying the description above assuming interleaved mapping with $R=2$, followed by puncturing the 4 highest-numbered resource blocks to obtain the 20 resource blocks forming CORESET 0;
- $L=6$;
- $n_{\mathrm{shift}}=N_{\mathrm{ID}}^{\mathrm{cell}}$;
- the UE may assume normal cyclic prefix when CORESET 0 is configured by MIB or SIB1;
- the UE may assume the same precoding being used within a REG bundle.

7.3.2.3 Scrambling

The UE shall assume the block of bits $b(0),\dots,b(M_{\mathrm{bit}}-1)$, where M_{bit} is the number of bits transmitted on the physical channel, is scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0),\dots,\tilde{b}(M_{\mathrm{bit}}-1)$ according to

$$\tilde{b}(i)=\left(b(i)+c(i)\right) \bmod 2$$

where the scrambling sequence $c(i)$ is given by clause 5.2.1. The scrambling sequence generator shall be initialized with

$$c_{\mathrm{init}}=\left(n_{\mathrm{RNTI}}\cdot 2^{16}+n_{\mathrm{ID}}\right) \bmod 2^{31}$$

where

- for a UE-specific search space as defined in clause 10 of [5, TS 38.213], $n_{\mathrm{ID}}\in\{0,1,\ldots,65535\}$ equals the higher-layer parameter *pdcch-DMRS-ScramblingID* if configured;
- for a PDCCH with the CRC scrambled by G-RNTI, G-CS-RNTI, MCCH-RNTI, or multicast-MCCH-RNTI in a common search space as defined in clause 10 of [5, TS 38.213], $n_{\mathrm{ID}}\in\{0,1,\ldots,65535\}$ equals the higher-layer parameter *pdcch-DMRS-ScramblingID* if configured in a common MBS frequency resource;
- $n_{\mathrm{ID}}=N_{\mathrm{ID}}^{\mathrm{cell}}$ otherwise

and where

- n_{RNTI} is given by the C-RNTI for a PDCCH in a UE-specific search space if the higher-layer parameter *pdcch-DMRS-ScramblingID* is configured, and
- $n_{\mathrm{RNTI}}=0$ otherwise.

7.3.2.4 PDCCH modulation

The UE shall assume the block of bits $\tilde{b}(0),\dots,\tilde{b}(M_{\mathrm{bit}}-1)$ to be QPSK modulated as described in clause 5.1.3, resulting in a block of complex-valued modulation symbols $d(0),\dots,d(M_{\mathrm{symb}}-1)$.

7.3.2.5 Mapping to physical resources

The UE shall assume the block of complex-valued symbols $d(0), \ldots, d(M_{\text{symb}} - 1)$ to be scaled by a factor β_{PDCCH} and mapped to resource elements $(k, l)_{p,\mu}$ used for the monitored PDCCH and not used for the associated PDCCH DMRS in increasing order of first k, then l. The antenna port $p = 2000$.

7.3.3 Physical broadcast channel

7.3.3.1 Scrambling

The UE shall assume the block of bits $b(0), \ldots, b(M_{\text{bit}} - 1)$, where M_{bit} is the number of bits transmitted on the physical broadcast channel, are scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0), \ldots, \tilde{b}(M_{\text{bit}} - 1)$ according to

$$\tilde{b}(i) = (b(i) + c(i + vM_{\text{bit}})) \bmod 2$$

where the scrambling sequence $c(i)$ is given by clause 5.2. The scrambling sequence shall be initialized with $c_{\text{init}} = N_{\text{ID}}^{\text{cell}}$ at the start of each SS/PBCH block where

- for $\bar{L}_{\max} = 4$, v is the two least significant bits of the candidate SS/PBCH block index
- for $\bar{L}_{\max} > 4$, v is the three least significant bits of the candidate SS/PBCH block index

with $\bar{L}_{\max}$ being the maximum number of candidate SS/PBCH blocks in a half frame, as described in [5, TS 38.213].

7.3.3.2 Modulation

The UE shall assume the block of bits $\tilde{b}(0), \ldots, \tilde{b}(M_{\text{bit}} - 1)$ are QPSK modulated as described in clause 5.1.3, resulting in a block of complex-valued modulation symbols $d_{\text{PBCH}}(0), \ldots, d_{\text{PBCH}}(M_{\text{symb}} - 1)$.

7.3.3.3 Mapping to physical resources

Mapping to physical resources is described in clause 7.4.3.

7.4 Physical signals

7.4.1 Reference signals

7.4.1.1 Demodulation reference signals for PDSCH

7.4.1.1.1 Sequence generation

The UE shall assume the sequence $r(n)$ is defined by

$$r(n) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2n)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2n+1)\right).$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialized with

$$c_{\text{init}} = \left(2^{17}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)\left(2N_{\text{ID}}^{\bar{n}_{\text{SCID}}^{\bar{\lambda}}} + 1\right) + 2^{17}\left\lfloor \frac{\bar{\lambda}}{2} \right\rfloor + 2N_{\text{ID}}^{\bar{n}_{\text{SCID}}^{\bar{\lambda}}} + \bar{n}_{\text{SCID}}^{\bar{\lambda}}\right) \bmod 2^{31}$$

where l is the OFDM symbol number within the slot, $n_{\text{s,f}}^{\mu}$ is the slot number within a frame, and

- $N_{\mathrm{ID}}^0, N_{\mathrm{ID}}^1 \in \{0,1,\ldots,65535\}$ are given by the higher-layer parameters *scramblingID0* and *scramblingID1*, respectively, in the *DMRS-DownlinkConfig* IE if provided and the PDSCH is scheduled by PDCCH using DCI format 1_1, 1_2, or 1_3 with the CRC scrambled by C-RNTI, MCS-C-RNTI, or CS-RNTI;

- $N_{\mathrm{ID}}^0 \in \{0,1,\ldots,65535\}$ is given by the higher-layer parameter *scramblingID0* in the *DMRS-DownlinkConfig* IE if provided and the PDSCH is scheduled by PDCCH using DCI format 1_0 with the CRC scrambled by C-RNTI, MCS-C-RNTI, or CS-RNTI;

- $N_{\mathrm{ID}}^0, N_{\mathrm{ID}}^1 \in \{0,1,\ldots,65535\}$ are given by the higher-layer parameters *scramblingID0* and *scramblingID1*, respectively, in the *DMRS-DownlinkConfig* IE if provided in a common MBS frequency resource for multicast and the PDSCH is scheduled by PDCCH using DCI format 4_2 with the CRC scrambled by G-RNTI or G-CS-RNTI;

- $N_{\mathrm{ID}}^0 \in \{0,1,\ldots,65535\}$ is given by the higher-layer parameter *scramblingID0* in the *DMRS-DownlinkConfig* IE if provided in a common MBS frequency resource and the PDSCH is scheduled by PDCCH with the CRC scrambled by G-RNTI, G-CS-RNTI, MCCH-RNTI, or multicast-MCCH-RNTI;

- $N_{\mathrm{ID}}^{\bar{n}_{\mathrm{SCID}}^{\bar{\lambda}}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ otherwise;

- $\bar{n}_{\mathrm{SCID}}^{\bar{\lambda}}$ and $\bar{\lambda}$ are given by

  - if the higher-layer parameter *dmrs-Downlink* in the *DMRS-DownlinkConfig* IE is provided

$$\bar{n}_{\mathrm{SCID}}^{\bar{\lambda}} = \begin{cases} n_{\mathrm{SCID}} & \lambda = 0 \text{ or } \lambda = 2 \\ 1 - n_{\mathrm{SCID}} & \lambda = 1 \end{cases}$$

$$\bar{\lambda} = \lambda$$

where λ is the CDM group defined in clause 7.4.1.1.2.

  - otherwise by

$$\bar{n}_{\mathrm{SCID}}^{\bar{\lambda}} = n_{\mathrm{SCID}}$$

$$\bar{\lambda} = 0$$

The quantity $n_{\mathrm{SCID}} \in \{0,1\}$ is given by the DM-RS sequence initialization field, if present, in the DCI associated with the PDSCH transmission if DCI format 1_1, 1_2, 1_3, or 4_2 in [4, TS 38.212] is used, otherwise $n_{\mathrm{SCID}} = 0$.

7.4.1.1.2 Mapping to physical resources

The UE shall assume the PDSCH DM-RS being mapped to physical resources according to configuration type 1 or configuration type 2 as given by the higher-layer parameter *dmrs-Type*.

The UE shall assume the sequence $r(m)$ is scaled by a factor $\beta_{\mathrm{PDSCH}}^{\mathrm{DMRS}}$ to conform with the transmission power specified in [6, TS 38.214] and mapped to resource elements $(k,l)_{p,\mu}$ according to

- if the higher-layer parameter *dmrs-TypeEnh* is configured

$$\begin{aligned} \tilde{a}_{k,l}^{(p_j,\mu)} &= \beta_{\mathrm{PDSCH}}^{\mathrm{DMRS}} w_{\mathrm{f}}(k') w_{\mathrm{t}}(l') r(4n+k') \\ k &= \begin{cases} 8n + 2k' + \Delta & \text{configuration type 1} \\ 12n + k' + \Delta & \text{configuration type 2, } k' = 0,1 \\ 12n + k' + \Delta + 4 & \text{configuration type 2, } k' = 2,3 \end{cases} \\ k' &= 0,1,2,3 \\ l &= \bar{l} + l' \\ n &= 0,1,\ldots \\ j &= 0,1,\ldots,\upsilon - 1 \end{aligned}$$

- otherwise

$$\tilde{a}_{k,l}^{(p_j,\mu)} = \beta_{\mathrm{PDSCH}}^{\mathrm{DMRS}} w_{\mathrm{f}}(k') w_{\mathrm{t}}(l') r(2n+k')$$

$$\begin{aligned} k &= \begin{cases} 4n + 2k' + \Delta & \text{configuration type 1} \\ 6n + k' + \Delta & \text{configuration type 2} \end{cases} \\ k' &= 0,1 \\ l &= \bar{l} + l' \\ n &= 0,1,... \\ j &= 0,1,...,\upsilon - 1 \end{aligned}$$

where $w_\mathrm{f}(k')$, $w_\mathrm{t}(l')$, and Δ are given by Tables 7.4.1.1.2-1 and 7.4.1.1.2-2 and the following conditions are fulfilled:

- the resource elements are within the common resource blocks allocated for PDSCH transmission

The reference point for k is

- subcarrier 0 of the lowest-numbered resource block in CORESET 0 if the corresponding PDCCH is associated with CORESET 0 and Type0-PDCCH common search space and is addressed to SI-RNTI;
- otherwise, subcarrier 0 in common resource block 0

The reference point for l and the position l_0 of the first DM-RS symbol depends on the mapping type:

- for PDSCH mapping type A:
    - l is defined relative to the start of the slot
    - $l_0 = 3$ if the higher-layer parameter *dmrs-TypeA-Position* is equal to 'pos3' and $l_0 = 2$ otherwise
- for PDSCH mapping type B:
    - l is defined relative to the start of the scheduled PDSCH resources
    - $l_0 = 0$

The position(s) of the DM-RS symbols is given by $\bar{l}$ and duration l_d where

- for PDSCH mapping type A, l_d is the duration between the first OFDM symbol of the slot and the last OFDM symbol of the scheduled PDSCH resources in the slot
- for PDSCH mapping type B, l_d is the duration of the scheduled PDSCH resources

and according to Tables 7.4.1.1.2-3 and 7.4.1.1.2-4.

For PDSCH mapping type A

- the case *dmrs-AdditionalPosition* equals to 'pos3' is only supported when *dmrs-TypeA-Position* is equal to 'pos2';
- $l_\mathrm{d} = 3$ and $l_\mathrm{d} = 4$ symbols in Tables 7.4.1.1.2-3 and 7.4.1.1.2-4 respectively is only applicable when *dmrs-TypeA-Position* is equal to 'pos2';
- single-symbol DM-RS, $l_1 = 11$ except if all of the following conditions are fulfilled in which case $l_1 = 12$:
    - the higher-layer parameter *lte-CRS-ToMatchAround*, *lte-CRS-PatternList1*, *lte-CRS-PatternList2*, *lte-CRS-PatternList3*, or *lte-CRS-PatternList4* is configured; and
    - the higher-layer parameter *dmrs-AdditionalPosition* is equal to 'pos1' and $l_0 = 3$; and
    - the UE has indicated it is capable of *additionalDMRS-DL-Alt*

For PDSCH mapping type B

- if the PDSCH duration $l_\mathrm{d} \in \{2,3,4,5,6,7,8,9,10,11,12,13\}$ OFDM symbols for normal cyclic prefix or $l_\mathrm{d} \in \{2,4,6\}$ OFDM symbols for extended cyclic prefix, and the front-loaded DM-RS of the PDSCH allocation collides with resources reserved for a search space set associated with a CORESET, $\bar{l}$ shall be incremented such that the first DM-RS symbol occurs immediately after the CORESET and until no collision with any CORESET occurs, and

  - if the PDSCH duration l_d is 2 symbols, the UE is not expected to receive a DM-RS symbol beyond the second symbol;
  - if the PDSCH duration l_d is 5 symbols and if one additional single-symbol DMRS is configured, the UE only expects the additional DM-RS to be transmitted on the 5th symbol when the front-loaded DM-RS symbol is in the 1st symbol of the PDSCH duration, otherwise the UE should expect that the additional DM-RS is not transmitted;
  - if the PDSCH duration l_d is 7 symbols for normal cyclic prefix or 6 symbols for extended cyclic prefix:
    - if one additional single-symbol DM-RS is configured, the UE only expects the additional DM-RS to be transmitted on the 5th or 6th symbol when the front-loaded DM-RS symbol is in the 1st or 2nd symbol, respectively, of the PDSCH duration, otherwise the UE should expect that the additional DM-RS is not transmitted;
  - if the PDSCH duration $l_\mathrm{d} \in \{5,6,7,8,9,10,11,12,13\}$ OFDM symbols, the UE is not expected to receive the front-loaded DM-RS beyond the 4th symbol;
  - if the PDSCH duration l_d is 12 or 13 symbols, the UE is not expected to receive DM-RS mapped to symbol 12 or later in the slot;
  - for all values of the PDSCH duration l_d other than 2, 5, and 7 symbols, the UE is not expected to receive DM-RS beyond the $(l_\mathrm{d} - 1)$:th symbol;
- if the PDSCH duration l_d is less than or equal to 4 OFDM symbols, only single-symbol DM-RS is supported.
- if the higher-layer parameter *lte-CRS-ToMatchAround*, *lte-CRS-PatternList1*, *lte-CRS-PatternList2*, *lte-CRS-PatternList3,* or *lte-CRS-PatternList4* is configured, the PDSCH duration $l_\mathrm{d} = 10$ symbols for normal cyclic prefix, the subcarrier spacing configuration $\mu = 0$, single-symbol DM-RS is configured, and at least one PDSCH DM-RS symbol in the PDSCH allocation collides with a symbol containing resource elements as indicated by the higher-layer parameter *lte-CRS-ToMatchAround*, *lte-CRS-PatternList1*, *lte-CRS-PatternList2*, *lte-CRS-PatternList3*, or *lte-CRS-PatternList4*, then $\bar{l}$ shall be incremented by one in all slots.

The time-domain index l' and the supported antenna ports p are given by Table 7.4.1.1.2-5 where

- single-symbol DM-RS is used if the higher-layer parameter *maxLength* in the *DMRS-DownlinkConfig* IE is not configured;
- single-symbol or double-symbol DM-RS is determined by the associated DCI if the higher-layer parameter *maxLength* in the *DMRS-DownlinkConfig* IE is equal to 'len2';
- basic or enhanced DM-RS multiplexing is controlled by the higher-layer parameter *dmrs-TypeEnh.*

In absence of CSI-RS configuration, and unless otherwise configured, the UE may assume PDSCH DM-RS and SS/PBCH block to be quasi co-located with respect to Doppler shift, Doppler spread, average delay, delay spread, and, when applicable, spatial Rx parameters. Unless specified otherwise, the UE may assume that the PDSCH DM-RS within the same CDM group are quasi co-located with respect to Doppler shift, Doppler spread, average delay, delay spread, and spatial Rx (when applicable). The UE may assume that DMRS ports associated with a TCI state as described in clause 5.1.6.2 of [6, TS 38.214] of a PDSCH are QCL with QCL Type A, Type D (when applicable) and average gain.

The UE may assume that no DM-RS collides with the SS/PBCH block.

Table 7.4.1.1.2-1: Parameters for PDSCH DM-RS configuration type 1.

p	CDM group λ	Δ	$[w_f(0) \quad \dots \quad w_f(3)]$	$[w_t(0) \quad w_t(1)]$
1000	0	0	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
1001	0	0	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
1002	1	1	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
1003	1	1	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
1004	0	0	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
1005	0	0	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
1006	1	1	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
1007	1	1	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
1008	0	0	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad +1]$
1009	0	0	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad +1]$
1010	1	1	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad +1]$
1011	1	1	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad +1]$
1012	0	0	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad -1]$
1013	0	0	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad -1]$
1014	1	1	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad -1]$
1015	1	1	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad -1]$

Table 7.4.1.1.2-2: Parameters for PDSCH DM-RS configuration type 2.

p	CDM group λ	Δ	$[w_f(0) \quad \dots \quad w_f(3)]$	$[w_t(0) \quad w_t(1)]$
0	0	0	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
1	0	0	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
2	1	2	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
3	1	2	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
4	2	4	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad +1]$
5	2	4	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad +1]$
6	0	0	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
7	0	0	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
8	1	2	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
9	1	2	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
10	2	4	$[+1 \quad +1 \quad +1 \quad +1]$	$[+1 \quad -1]$
11	2	4	$[+1 \quad -1 \quad +1 \quad -1]$	$[+1 \quad -1]$
12	0	0	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad +1]$
13	0	0	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad +1]$
14	1	2	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad +1]$
15	1	2	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad +1]$
16	2	4	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad +1]$
17	2	4	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad +1]$
18	0	0	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad -1]$
19	0	0	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad -1]$
20	1	2	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad -1]$
21	1	2	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad -1]$
22	2	4	$[+1 \quad +1 \quad -1 \quad -1]$	$[+1 \quad -1]$
23	2	4	$[+1 \quad -1 \quad -1 \quad +1]$	$[+1 \quad -1]$

Table 7.4.1.1.2-3: PDSCH DM-RS positions $\bar{l}$ for single-symbol DM-RS.

l_d in symbols	DM-RS positions $\bar{l}$							
	PDSCH mapping type A				PDSCH mapping type B			
	dmrs-AdditionalPosition				*dmrs-AdditionalPosition*			
	pos0	*pos1*	*pos2*	*pos3*	*pos0*	*pos1*	*pos2*	*pos3*
2	-	-	-	-	l_0	l_0	l_0	l_0
3	l_0	l_0	l_0	l_0	l_0	l_0	l_0	l_0
4	l_0	l_0	l_0	l_0	l_0	l_0	l_0	l_0
5	l_0	l_0	l_0	l_0	l_0	$l_0, 4$	$l_0, 4$	$l_0, 4$
6	l_0	l_0	l_0	l_0	l_0	l_0,4	$l_0, 4$	$l_0, 4$
7	l_0	l_0	l_0	l_0	l_0	l_0,4	$l_0, 4$	$l_0, 4$
8	l_0	l_0 , 7	l_0 , 7	l_0 , 7	l_0	$l_0, 6$	$l_0, 3, 6$	$l_0, 3, 6$
9	l_0	l_0 , 7	l_0 , 7	l_0 , 7	l_0	$l_0, 7$	$l_0, 4, 7$	$l_0, 4, 7$
10	l_0	l_0 , 9	l_0 , 6, 9	l_0 , 6, 9	l_0	$l_0, 7$	$l_0, 4, 7$	$l_0, 4, 7$
11	l_0	l_0 , 9	l_0 , 6, 9	l_0 , 6, 9	l_0	$l_0, 8$	$l_0, 4, 8$	$l_0, 3, 6, 9$
12	l_0	l_0 , 9	l_0 , 6, 9	l_0 , 5, 8, 11	l_0	$l_0, 9$	$l_0, 5, 9$	$l_0, 3, 6, 9$
13	l_0	l_0 , l_1	l_0 , 7, 11	l_0 , 5, 8, 11	l_0	$l_0, 9$	$l_0, 5, 9$	$l_0, 3, 6, 9$
14	l_0	l_0 , l_1	l_0 , 7, 11	l_0 , 5, 8, 11	-	-	-	-

Table 7.4.1.1.2-4: PDSCH DM-RS positions $\bar{l}$ for double-symbol DM-RS.

l_d in symbols	DM-RS positions $\bar{l}$					
	PDSCH mapping type A			PDSCH mapping type B		
	dmrs-AdditionalPosition			*dmrs-AdditionalPosition*		
	pos0	*pos1*	*pos2*	*pos0*	*pos1*	*pos2*
<4				-	-	
4	l_0	l_0		-	-	
5	l_0	l_0		l_0	l_0	
6	l_0	l_0		l_0	l_0	
7	l_0	l_0		l_0	l_0	
8	l_0	l_0		l_0	$l_0, 5$	
9	l_0	l_0		l_0	$l_0, 5$	
10	l_0	l_0 , 8		l_0	$l_0, 7$	
11	l_0	l_0 , 8		l_0	$l_0, 7$	
12	l_0	l_0 , 8		l_0	$l_0, 8$	
13	l_0	l_0 , 10		l_0	$l_0, 8$	
14	l_0	l_0 , 10		-	-	

Table 7.4.1.1.2-5: PDSCH DM-RS time index l' and antenna ports p.

DM-RS multiplexing	DM-RS duration	l'	Supported antenna ports p	
			Configuration type 1	Configuration type 2
Basic	single-symbol DM-RS	0	1000 – 1003	1000 – 1005
	double-symbol DM-RS	0, 1	1000 – 1007	1000 – 1011
Enhanced	single-symbol DM-RS	0	1000 – 1003, 1008 – 1011	1000 – 1005, 1012 – 1017
	double-symbol DM-RS	0, 1	1000 – 1015	1000 – 1023

7.4.1.2 Phase-tracking reference signals for PDSCH

7.4.1.2.1 Sequence generation

The phase-tracking reference signal for subcarrier k is given by

- If the higher-layer parameter *dmrs-TypeEnh* is configured

$$r_k = r(4m + k')$$

- otherwise

$$r_k = r(2m + k')$$

where $r(\cdot)$ is the demodulation reference signal given by clause 7.4.1.1.2 at position l_0 and subcarrier k.

7.4.1.2.2 Mapping to physical resources

The UE shall assume phase-tracking reference signals being present only in the resource blocks used for the PDSCH, and only if the procedure in [6, TS 38.214] indicates phase-tracking reference signals being used.

If present, the UE shall assume the PDSCH PT-RS is scaled by a factor $\beta_{\text{PT-RS},i}$ to conform with the transmission power specified in clause 4.1 of [6, TS 38.214] and mapped to resource elements $(k,l)_{p,\mu}$ according to

$$a_{k,l}^{(p,\mu)} = \beta_{\text{PT-RS},i} r_k$$

when all the following conditions are fulfilled

- l is within the OFDM symbols allocated for the PDSCH transmission
- resource element $(k,l)_{p,\mu}$ is not used for DM-RS, non-zero-power CSI-RS (except for those configured for mobility measurements or with *resourceType* in corresponding *CSI-ResourceConfig* configured as 'aperiodic'), zero-power CSI-RS, SS/PBCH block, a detected PDCCH according to clause 5.1.4.1 of [6, TS38.214], or is declared as 'not available' by clause 5.1.4 of [6, TS 38.214]

The set of time indices l defined relative to the start of the PDSCH allocation is defined by

1. set $i = 0$ and $l_{\text{ref}} = 0$
2. if any symbol in the interval $\max(l_{\text{ref}} + (i-1)L_{\text{PT-RS}} + 1, l_{\text{ref}}), \dots, l_{\text{ref}} + iL_{\text{PT-RS}}$ overlaps with a symbol used for DM-RS according to clause 7.4.1.1.2
    - set $i = 1$
    - set l_{ref} to the symbol index of the DM-RS symbol in case of a single-symbol DM-RS and to the symbol index of the second DM-RS symbol in case of a double-symbol DM-RS
    - repeat from step 2 as long as $l_{\text{ref}} + iL_{\text{PT-RS}}$ is inside the PDSCH allocation
3. add $l_{\text{ref}} + iL_{\text{PT-RS}}$ to the set of time indices for PT-RS
4. increment i by one
5. repeat from step 2 above as long as $l_{\text{ref}} + iL_{\text{PT-RS}}$ is inside the PDSCH allocation

where $L_{\text{PT-RS}} \in \{1,2,4\}$.

For the purpose of PT-RS mapping, the resource blocks allocated for PDSCH transmission are numbered from 0 to $N_{\text{RB}} - 1$ from the lowest scheduled resource block to the highest. The corresponding subcarriers in this set of resource blocks are numbered in increasing order starting from the lowest frequency from 0 to $N_{\text{sc}}^{\text{RB}} N_{\text{RB}} - 1$. The subcarriers to which the UE shall assume the PT-RS is mapped are given by

$$k = k_{\text{ref}}^{\text{RE}} + \left(iK_{\text{PT-RS}} + k_{\text{ref}}^{\text{RB}}\right)N_{\text{sc}}^{\text{RB}}$$

$$k_{\text{ref}}^{\text{RB}} = \begin{cases} n_{\text{RNTI}} \bmod K_{\text{PT-RS}} & \text{if } N_{\text{RB}} \bmod K_{\text{PT-RS}} = 0 \\ n_{\text{RNTI}} \bmod \left(N_{\text{RB}} \bmod K_{\text{PT-RS}}\right) & \text{otherwise} \end{cases}$$

where

- $i = 0,1,2,\ldots$
- $k_{\text{ref}}^{\text{RE}}$ is given by Table 7.4.1.2.2-1 for the DM-RS port associated with the PT-RS port according to clause 5.1.6.3 in [6, TS 38.214]. If the higher-layer parameter *resourceElementOffset* in the *PTRS-DownlinkConfig* IE is not configured, the column corresponding to 'offset00' shall be used.
- n_{RNTI} is the RNTI associated with the DCI scheduling the transmission
- N_{RB} is the number of resource blocks scheduled
- $K_{\text{PT-RS}} \in \{2,4\}$ is given by [6, TS 38.214].

Table 7.4.1.2.2-1: The parameter $k_{\text{ref}}^{\text{RE}}$.

DM-RS antenna port p	$k_{\text{ref}}^{\text{RE}}$							
	DM-RS Configuration type 1				**DM-RS Configuration type 2**			
	resourceElementOffset				***resourceElementOffset***			
	offset00	**offset01**	**offset10**	**offset11**	**offset00**	**offset01**	**offset10**	**offset11**
1000	0	2	6	8	0	1	6	7
1001	2	4	8	10	1	6	7	0
1002	1	3	7	9	2	3	8	9
1003	3	5	9	11	3	8	9	2
1004	-	-	-	-	4	5	10	11
1005	-	-	-	-	5	10	11	4
1008	4	6	10	0	-	-	-	-
1009	6	8	0	2	-	-	-	-
1010	5	7	11	1	-	-	-	-
1011	7	9	1	3	-	-	-	-
1012	-	-	-	-	6	7	0	1
1013	-	-	-	-	7	0	1	6
1014	-	-	-	-	8	9	2	3
1015	-	-	-	-	9	2	3	8
1016	-	-	-	-	10	11	4	5
1017	-	-	-	-	11	4	5	10

7.4.1.3 Demodulation reference signals for PDCCH

7.4.1.3.1 Sequence generation

The UE shall assume the reference-signal sequence $r_l(m)$ for OFDM symbol l is defined by

$$r_l(m) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m+1)\right).$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialized with

$$c_{\text{init}} = \left(2^{17}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)(2N_{\text{ID}} + 1) + 2N_{\text{ID}}\right) \text{mod} 2^{31}$$

where l is the OFDM symbol number within the slot, $n_{\text{s,f}}^{\mu}$ is the slot number within a frame, and

- $N_{\text{ID}} \in \{0,1,\ldots,65535\}$ is given by the higher-layer parameter *pdcch-DMRS-ScramblingID* if provided;

- $N_{\text{ID}} \in \{0,1,\ldots,65535\}$ is given by the higher-layer parameter *pdcch-DMRS-ScramblingID* if configured for a common search space in a common MBS frequency resource;

- $N_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ otherwise.

7.4.1.3.2 Mapping to physical resources

The UE shall assume the sequence $r_l(m)$ is mapped to resource elements $(k,l)_{p,\mu}$ according to

$$\begin{aligned}
&a_{k,l}^{(p,\mu)} = \beta_{\text{DMRS}}^{\text{PDCCH}} \cdot r_l\left(3n+k'\right) \\
&k = nN_{\text{sc}}^{\text{RB}} + 4k' + 1 \\
&k' = 0,1,2 \\
&n = 0,1,\ldots
\end{aligned}$$

where the following conditions are fulfilled

- they are within the resource element groups constituting the PDCCH the UE attempts to decode if the higher-layer parameter *precoderGranularity* equals *sameAsREG-bundle*,

- all resource-element groups within the set of contiguous resource blocks in the CORESET where the UE attempts to decode the PDCCH if the higher-layer parameter *precoderGranularity* equals *allContiguousRBs*.

The reference point for k is

- subcarrier 0 of the lowest-numbered resource block in the CORESET if the CORESET is configured by the PBCH or by the *controlResourceSetZero* field in the *PDCCH-ConfigCommon* IE,

- subcarrier 0 in common resource block 0 otherwise

The quantity l is the OFDM symbol number within the slot.

The antenna port $p = 2000$.

A UE not attempting to detect a PDCCH in a CORESET shall not make any assumptions on the presence or absence of DM-RS in the CORESET.

In absence of CSI-RS configuration, and unless otherwise configured, the UE may assume PDCCH DM-RS and SS/PBCH block to be quasi co-located with respect to Doppler shift, Doppler spread, average delay, delay spread, and, when applicable, spatial Rx parameters.

7.4.1.4 Demodulation reference signals for PBCH

7.4.1.4.1 Sequence generation

The UE shall assume the reference-signal sequence $r(m)$ for an SS/PBCH block is defined by

$$r(m) = \frac{1}{\sqrt{2}}\left(1-2\cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1-2\cdot c(2m+1)\right)$$

where $c(n)$ is given by clause 5.2. The scrambling sequence generator shall be initialized at the start of each SS/PBCH block occasion with

$$c_{\text{init}} = 2^{11}\left(\bar{i}_{\text{SSB}}+1\right)\left(\left\lfloor N_{\text{ID}}^{\text{cell}}/4\right\rfloor+1\right) + 2^{6}\left(\bar{i}_{\text{SSB}}+1\right) + \left(N_{\text{ID}}^{\text{cell}} \bmod 4\right)$$

where

- for $\bar{L}_{\max} = 4$, $\bar{i}_{\text{SSB}} = i_{\text{SSB}} + 4n_{\text{hf}}$ where n_{hf} is the number of the half-frame in which the PBCH is transmitted in a frame with $n_{\text{hf}} = 0$ for the first half-frame in the frame and $n_{\text{hf}} = 1$ for the second half-frame in the frame, and i_{SSB} is the two least significant bits of the candidate SS/PBCH block index as defined in [5, TS 38.213]

- for $\bar{L}_{\max} > 4$, $\bar{i}_{\text{SSB}} = i_{\text{SSB}}$ where i_{SSB} is the three least significant bits of the candidate SS/PBCH block index as defined in [5, TS 38.213]

with $\bar{L}_{\max}$ being the maximum number of candidate SS/PBCH blocks in a half frame, as described in [5, TS 38.213].

7.4.1.4.2 Mapping to physical resources

Mapping to physical resources is described in clause 7.4.3.

7.4.1.5 CSI reference signals

7.4.1.5.1 General

Zero-power (ZP) and non-zero-power (NZP) CSI-RS are defined

- for a non-zero-power CSI-RS configured by the *NZP-CSI-RS-Resource* IE or by the *CSI-RS-Resource-Mobility* field in the *CSI-RS-ResourceConfigMobility* IE or by the *TRS-ResourceSet* IE, the sequence shall be generated according to clause 7.4.1.5.2 and mapped to resource elements according to clause 7.4.1.5.3
- for a zero-power CSI-RS configured by the *ZP-CSI-RS-Resource* IE, the UE shall assume that the resource elements defined in clause 7.4.1.5.3 are not used for PDSCH transmission subject to clause 5.1.4.2 of [6, TS 38.214]. The UE performs the same measurement/reception on channels/signals except PDSCH regardless of whether they collide with ZP CSI-RS or not.

7.4.1.5.2 Sequence generation

The UE shall assume the reference-signal sequence $r(m)$ is defined by

$$r(m) = \frac{1}{\sqrt{2}}\big(1 - 2\cdot c(2m)\big) + j\frac{1}{\sqrt{2}}\big(1 - 2\cdot c(2m+1)\big)$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}} = \left(2^{10}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)(2n_{\text{ID}} + 1) + n_{\text{ID}}\right) \bmod 2^{31}$$

at the start of each OFDM symbol where $n_{\text{s,f}}^{\mu}$ is the slot number within a radio frame, l is the OFDM symbol number within a slot, and n_{ID} equals the higher-layer parameter s*cramblingID* or *sequenceGenerationConfig*.

7.4.1.5.3 Mapping to physical resources

For each CSI-RS configured, the UE shall assume the sequence $r(m)$ being mapped to resources elements $(k,l)_{p,\mu}$ according to

$$\begin{aligned}
a_{k,l}^{(p,\mu)} &= \beta_{\text{CSIRS}} w_{\text{f}}(k')\cdot w_{\text{t}}(l')\cdot r_{l,n_{\text{s,f}}}(m') \\
m' &= \lfloor n\alpha \rfloor + k' + \left\lfloor \frac{\bar{k}\rho}{N_{\text{sc}}^{\text{RB}}} \right\rfloor \\
k &= nN_{\text{sc}}^{\text{RB}} + \bar{k} + k' \\
l &= \bar{l} + l' \\
\alpha &= \begin{cases} \rho & \text{for } X = 1 \\ 2\rho & \text{for } X > 1 \end{cases} \\
n &= 0,1,...
\end{aligned}$$

when the following conditions are fulfilled:

- the resource element $(k,l)_{p,\mu}$ is within the resource blocks occupied by the CSI-RS resource for which the UE is configured

The reference point for $k = 0$ is subcarrier 0 in common resource block 0.

The value of ρ is given by the higher-layer parameter *density* in the *CSI-RS-ResourceMapping* IE or the *CSI-RS-CellMobility* IE and the number of ports X is given by the higher-layer parameter *nrofPorts*. For NZP CSI-RS configured by the *TRS-ResourceSet* IE, the density $\rho = 3$ and number of ports $X = 1$.

The UE is not expected to receive CSI-RS and DM-RS on the same resource elements.

The UE shall assume $\beta_{\mathrm{CSIRS}} > 0$ for a non-zero-power CSI-RS where β_{CSIRS} is selected such that the power offset specified by the higher-layer parameter *powerControlOffsetSS* in the *NZP-CSI-RS-Resource* IE or in the *TRS-ResourceSet* IE, if provided, is fulfilled.

The quantities k', l', $w_{\mathrm{f}}(k')$, and $w_{\mathrm{t}}(l')$ are given by Tables 7.4.1.5.3-1 to 7.4.1.5.3-5 where each $(\bar{k},\bar{l})$ in a given row of Table 7.4.1.5.3-1 corresponds to a CDM group of size 1 (no CDM) or size 2, 4, or 8. The CDM type is provided by the higher layer parameter *cdm-Type* in the *CSI-RS-ResourceMapping* IE. For NZP CSI-RS configured by the *TRS-ResourceSet* IE, the CDM type is 'noCDM'. The indices k' and l' index resource elements within a CDM group.

The time-domain locations $l_0 \in \{0,1,\ldots,13\}$ and $l_1 \in \{2,3,\ldots,12\}$ are provided by the higher-layer parameters *firstOFDMSymbolInTimeDomain* and *firstOFDMSymbolInTimeDomain2*, respectively, in the *CSI-RS-ResourceMapping* IE or the *CSI-RS-ResourceConfigMobility* IE and defined relative to the start of a slot. For NZP CSI-RS configured by *TRS-ResourceSet* IE, the time-domain location $l_0 \in \{0,1,\ldots,13\}$ is provided by the higher-layer parameter *firstOFDMSymbolInTimeDomain* or *firstOFDMSymbolInTimeDomain*+4.

The frequency-domain location is given by a bitmap provided by the higher-layer parameter *frequencyDomainAllocation* in the *CSI-RS-ResourceMapping* IE, the *CSI-RS-ResourceConfigMobility* IE, or the *TRS-ResourceSet* IE, with the bitmap and value of k_i in Table 7.4.1.5.3-1 given by

- $[b_3 \cdots b_0]$, $k_{i-1} = f(i)$ for row 1 of Table 7.4.1.5.3-1
- $[b_{11} \cdots b_0]$, $k_{i-1} = f(i)$ for row 2 of Table 7.4.1.5.3-1
- $[b_2 \cdots b_0]$, $k_{i-1} = 4f(i)$ for row 4 of Table 7.4.1.5.3-1
- $[b_5 \cdots b_0]$, $k_{i-1} = 2f(i)$ for all other cases

where $f(i)$ is the bit number of the i^{th} bit in the bitmap set to one, repeated across every $\lceil 1/\rho \rceil$ of the resource blocks configured for CSI-RS reception by the UE. The starting position and number of the resource blocks in which the UE shall assume that CSI-RS is transmitted are given by the higher-layer parameters *freqBand* and *density* in the *CSI-RS-ResourceMapping* IE for the bandwidth part given by the higher-layer parameter *BWP-Id* in the *CSI-ResourceConfig* IE or given by the higher-layer parameters *nrofPRBs* in the *CSI-RS-CellMobility* IE where the the *startPRB* given by *csi-rs-MeasurementBW* is relative to common resource block 0. For NZP CSI-RS configured by *TRS-ResourceSet* IE, the starting position and number of the resource blocks in which the CSI-RS can be transmitted are given by the higher-layer parameters *nrofRBs*, and *startingRB* in the *TRS-ResourceSet* IE, where *startingRB* is relative to common resource block 0 and the density $\rho = 3$.

The UE shall assume that a CSI-RS is transmitted using antenna ports p numbered according to

$$\begin{aligned} &p = 3000 + s + jL; \\ &j = 0,1,\ldots,N/L-1 \\ &s = 0,1,\ldots,L-1; \end{aligned}$$

where s is the sequence index provided by Tables 7.4.1.5.3-2 to 7.4.1.5.3-5, $L \in \{1,2,4,8\}$ is the CDM group size, and N is the number of CSI-RS ports. The CDM group index j given in Table 7.4.1.5.3-1 corresponds to the time/frequency locations $(\bar{k},\bar{l})$ for a given row of the table. The CDM groups are numbered in order of increasing frequency domain allocation first and then increasing time domain allocation.

For a CSI-RS resource configured as periodic or semi-persistent by the higher-layer parameter *resourceType*, configured by the higher-layer parameter *CSI-RS-CellMobility* or configured by the higher-layer parameter *TRS-ResourceSet-r17*, the UE shall assume that the CSI-RS is transmitted in slots satisfying

$$\left(N_{\text{slot}}^{\text{frame},\mu} n_{\text{f}} + n_{\text{s,f}}^{\mu} - T_{\text{offset}}\right) \bmod T_{\text{CSI-RS}} = 0$$

where the periodicity $T_{\text{CSI-RS}}$ (in slots) and slot offset T_{offset} are obtained from the higher-layer parameter *CSI-ResourcePeriodicityAndOffset*, *slotConfig* or *periodicityAndOffset-r17*. The UE shall assume that CSI-RS is transmitted in a candidate slot as described in clause 11.1 of [5, TS 38.213], clause 10.4B of [5, TS 38.213].

The UE may assume that antenna ports within a CSI-RS resource are quasi co-located with QCL Type A, Type D (when applicable), and average gain.

Table 7.4.1.5.3-1: CSI-RS locations within a slot.

Row	**Ports** X	**Density** ρ	***cdm-Type***	$\left(\bar{k},\bar{l}\right)$	**CDM group index** j	k'	l'
1	1	3	noCDM	(k_0,l_0), (k_0+4,l_0), (k_0+8,l_0)	0,0,0	0	0
2	1	1, 0.5	noCDM	(k_0,l_0),	0	0	0
3	2	1, 0.5	fd-CDM2	(k_0,l_0),	0	0, 1	0
4	4	1	fd-CDM2	(k_0,l_0), (k_0+2,l_0)	0,1	0, 1	0
5	4	1	fd-CDM2	(k_0,l_0), (k_0,l_0+1)	0,1	0, 1	0
6	8	1	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0)	0,1,2,3	0, 1	0
7	8	1	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_0,l_0+1), (k_1,l_0+1)	0,1,2,3	0, 1	0
8	8	1	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0)	0,1	0, 1	0, 1
9	12	1	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0), (k_4,l_0), (k_5,l_0)	0,1,2,3,4,5	0, 1	0
10	12	1	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0), (k_2,l_0)	0,1,2	0, 1	0, 1
11	16	1, 0.5	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0), (k_0,l_0+1), (k_1,l_0+1), (k_2,l_0+1), (k_3,l_0+1)	0,1,2,3, 4,5,6,7	0, 1	0
12	16	1, 0.5	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0)	0,1,2,3	0, 1	0, 1
13	24	1, 0.5	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_0,l_0+1), (k_1,l_0+1), (k_2,l_0+1),(k_0,l_1), (k_1,l_1), (k_2,l_1), (k_0,l_1+1), (k_1,l_1+1), (k_2,l_1+1)	0,1,2,3,4,5, 6,7,8,9,10,11	0, 1	0
14	24	1, 0.5	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_0,l_1), (k_1,l_1), (k_2,l_1)	0,1,2,3,4,5	0, 1	0, 1
15	24	1, 0.5	cdm8-FD2-TD4	(k_0,l_0), (k_1,l_0), (k_2,l_0)	0,1,2	0, 1	0, 1, 2, 3
16	32	1, 0.5	fd-CDM2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0),(k_0,l_0+1), (k_1,l_0+1), (k_2,l_0+1), (k_3,l_0+1), (k_0,l_1), (k_1,l_1), (k_2,l_1), (k_3,l_1), (k_0,l_1+1), (k_1,l_1+1), (k_2,l_1+1), (k_3,l_1+1)	0,1,2,3, 4,5,6,7, 8,9,10,11, 12,13,14,15	0, 1	0
17	32	1, 0.5	cdm4-FD2-TD2	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0), (k_0,l_1), (k_1,l_1), (k_2,l_1), (k_3,l_1)	0,1,2,3,4,5,6,7	0, 1	0, 1
18	32	1, 0.5	cdm8-FD2-TD4	(k_0,l_0), (k_1,l_0), (k_2,l_0), (k_3,l_0)	0,1,2,3	0,1	0,1, 2, 3

Table 7.4.1.5.3-2: The sequences $w_{\text{f}}\left(k'\right)$ and $w_{\text{t}}\left(l'\right)$ for *cdm-Type* equal to 'noCDM'.

Index	$\boldsymbol{w_{\text{f}}(0)}$	$\boldsymbol{w_{\text{t}}(0)}$
0	1	1

Table 7.4.1.5.3-3: The sequences $w_\mathrm{f}(k')$ and $w_\mathrm{t}(l')$ for *cdm-Type* equal to 'fd-CDM2'.

Index	$[\boldsymbol{w}_\mathrm{f}(\mathbf{0})\quad \boldsymbol{w}_\mathrm{f}(\mathbf{1})]$	$\boldsymbol{w}_\mathrm{t}(\mathbf{0})$
0	$[+1\quad +1]$	1
1	$[+1\quad -1]$	1

Table 7.4.1.5.3-4: The sequences $w_\mathrm{f}(k')$ and $w_\mathrm{t}(l')$ for *cdm-Type* equal to 'cdm4-FD2-TD2'.

Index	$[\boldsymbol{w}_\mathrm{f}(\mathbf{0})\quad \boldsymbol{w}_\mathrm{f}(\mathbf{1})]$	$[\boldsymbol{w}_\mathrm{t}(\mathbf{0})\quad \boldsymbol{w}_\mathrm{t}(\mathbf{1})]$
0	$[+1\quad +1]$	$[+1\quad +1]$
1	$[+1\quad -1]$	$[+1\quad +1]$
2	$[+1\quad +1]$	$[+1\quad -1]$
3	$[+1\quad -1]$	$[+1\quad -1]$

Table 7.4.1.5.3-5: The sequences $w_\mathrm{f}(k')$ and $w_\mathrm{t}(l')$ for *cdm-Type* equal to 'cdm8-FD2-TD4'.

Index	$[\boldsymbol{w}_\mathrm{f}(\mathbf{0})\quad \boldsymbol{w}_\mathrm{f}(\mathbf{1})]$	$[\boldsymbol{w}_\mathrm{t}(\mathbf{0})\quad \boldsymbol{w}_\mathrm{t}(\mathbf{1})\quad \boldsymbol{w}_\mathrm{t}(\mathbf{2})\quad \boldsymbol{w}_\mathrm{t}(\mathbf{3})]$
0	$[+1\quad +1]$	$[+1\quad +1\quad +1\quad +1]$
1	$[+1\quad -1]$	$[+1\quad +1\quad +1\quad +1]$
2	$[+1\quad +1]$	$[+1\quad -1\quad +1\quad -1]$
3	$[+1\quad -1]$	$[+1\quad -1\quad +1\quad -1]$
4	$[+1\quad +1]$	$[+1\quad +1\quad -1\quad -1]$
5	$[+1\quad -1]$	$[+1\quad +1\quad -1\quad -1]$
6	$[+1\quad +1]$	$[+1\quad -1\quad -1\quad +1]$
7	$[+1\quad -1]$	$[+1\quad -1\quad -1\quad +1]$

7.4.1.6 RIM reference signals

7.4.1.6.1 General

RIM-RS can be used by an gNB to measure inter-cell interference and to provide information about the experienced interference to other gNBs. Up to two different types of RIM-RS can be configured where

- the first RIM-RS type can be used to convey information,
- the second RIM-RS type depends on configuration only.

7.4.1.6.2 Sequence generation

The RIM-RS receiver shall assume the reference-signal sequence $r(m)$ is defined by

$$r(m) = \frac{1}{\sqrt{2}}\big(1 - 2c(2m)\big) + j\frac{1}{\sqrt{2}}\big(1 - 2c(2m+1)\big)$$

where the pseudo-random sequence $c(m)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialised with

$$c_\mathrm{init} = (2^{10} f(n_\mathrm{t}^\mathrm{RIM}) + n_\mathrm{SCID}) \bmod 2^{31}$$

where

- $n_\mathrm{SCID} \in \{0,1,\dots,2^{10}-1\}$ is given by clause 7.4.1.6.4.4;

- $f(n_{\mathrm{t}}^{\mathrm{RIM}}) = \sum_{i=0}^{20} 2^{i} \bar{c}(i)$ where the pseudo-random sequence $\bar{c}(i)$ is given by clause 5.2.1, initialized with $\bar{c}_{\mathrm{init}}(i) = (\gamma n_{\mathrm{t}}^{\mathrm{RIM}} + \delta) \bmod 2^{31}$ where the multiplier factor $\gamma \in \{0,1,\dots,2^{31}-1\}$ and the offset $\delta \in \{0,1,\dots,2^{31}-1\}$;
- $n_{\mathrm{t}}^{\mathrm{RIM}} = \left\lfloor \left(t_{\mathrm{RS}}^{\mathrm{RIM}} - t_{\mathrm{ref}}^{\mathrm{RIM}}\right) / T_{\mathrm{per}}^{\mathrm{RIM}} \right\rfloor$ is the number of RIM-RS transmission periods since $t_{\mathrm{ref}}^{\mathrm{RIM}}$ where
  - $t_{\mathrm{RS}}^{\mathrm{RIM}} - t_{\mathrm{ref}}^{\mathrm{RIM}}$ is the time in seconds relative to $t_{\mathrm{ref}}^{\mathrm{RIM}}$ of 00:00:00 on 1 January 1900, calculated as continuous time without leap second and traceable to a common time reference, and
  - $T_{\mathrm{per}}^{\mathrm{RIM}} = N_{\mathrm{slot}}^{P_t} / (1000 \cdot 2^{\mu})$ is the RIM-RS transmission periodicity in seconds assuming that the first RIM-RS transmission period starts at $t_{\mathrm{ref}}^{\mathrm{RIM}}$, and where $N_{\mathrm{slot}}^{P_t}$ is given by clause 7.4.1.6.4.2.

7.4.1.6.3 Mapping to physical resources

The RIM-RS receiver shall assume the reference signal being mapped to physical resources according to

$$a_{k}^{(p,\mathrm{RIM})} = \beta_{\mathrm{RIM}} r(k)$$

$$k = 0,1,\dots,L_{\mathrm{RIM}} - 1$$

where β_{RIM} is an amplitude scaling factor in order to control the RIM-RS transmission power and p is the antenna port. Baseband signal generation shall be done according to clause 5.3.3.

The starting position l_0 for RIM-RS type $i \in \{1,2\}$ in slot $n_{\mathrm{s,f}}^{\mu}$ in a frame is given by

$$l_0 = T_{\mathrm{offset}}^{\mathrm{UD,RIM}} \bmod N_{\mathrm{symb}}^{\mathrm{slot}}$$

in slots satisfying

$$\left(1024 N_{\mathrm{slot}}^{\mathrm{frame},\mu} \bar{n}_{\mathrm{f}}^{\mathrm{RIM}} + N_{\mathrm{slot}}^{\mathrm{frame},\mu} n_{\mathrm{f}}^{\mathrm{RIM}} + n_{\mathrm{s,f}}^{\mu} - \left(\bar{T}_{\mathrm{offset}} + \left\lfloor T_{\mathrm{offset}}^{\mathrm{UD,RIM}} / N_{\mathrm{symb}}^{\mathrm{slot}} \right\rfloor\right)\right) \bmod N_{\mathrm{slot}}^{P_{\mathrm{t}}} = 0$$

where

- $\bar{n}_{\mathrm{f}}^{\mathrm{RIM}} \in \left\{0,1,\dots,N_{\mathrm{slot}}^{P_t} / \left(1024 N_{\mathrm{slot}}^{\mathrm{frame},\mu}\right) - 1\right\}$ counts the number of times the SFN periods within the RIM-RS transmission period;
- $T_{\mathrm{offset}}^{\mathrm{UD,RIM}} = N_{\mathrm{ref}}^{\mathrm{UD,RIM}} - N_{\mathrm{symb,ref}}^{\mathrm{RIM},i}$ where $N_{\mathrm{ref}}^{\mathrm{UD,RIM}} \in \{2,3,\dots,20 \cdot 2 \cdot 14 - 1\}$ is the symbol offset of the reference point after the starting boundary of the uplink-downlink switching period in which the RIM-RS is mapped to and $N_{\mathrm{symb,ref}}^{\mathrm{RIM},i}$ is obtained as described in clause 7.4.1.6.4.2;
- $N_{\mathrm{slot}}^{P_t}$ is the total number of slots in a RIM-RS transmission period as defined in clause 7.4.1.6.4.2;
- $\bar{T}_{\mathrm{offset}}$ is the slot offset of the uplink-downlink switching period with index $i_{\mathrm{t}}^{\mathrm{RIM}}$ with respect to the starting boundary of the RIM-RS transmission period and is defined in clause 7.4.1.6.4.2;
- P_{t} is the RIM-RS transmission periodicity in units of uplink-downlink switching period as defined in clause 7.4.1.6.4.2.

7.4.1.6.4 RIM-RS configuration

7.4.1.6.4.1 General

A resource for RIM-RS transmission is defined by the indices $i_{\mathrm{t}}^{\mathrm{RIM}} \in \{0,1,\dots,P_{\mathrm{t}}-1\}$, $i_{\mathrm{f}}^{\mathrm{RIM}} \in \left\{0,1,\dots,N_{\mathrm{f}}^{\mathrm{RIM}}-1\right\}$, and $i_{\mathrm{s}}^{\mathrm{RIM}} \in \left\{0,1,\dots,N_{\mathrm{s}}^{\mathrm{RIM},i}-1\right\}$ used as indices into configured lists of time, frequency, and sequence parameters, respectively.

All RIM-RS resources occupy the same number of resource blocks, $N_{\mathrm{RB}}^{\mathrm{RIM}}$. At most 32 RIM-RS resources can be configured within a 10 ms period.

7.4.1.6.4.2 Time-domain parameters and mapping from i_t to time-domain parameters

RIM-RS are transmitted periodically with the RIM-RS transmission period P_t defined in units of the uplink-downlink switching period determined from one or two configured uplink-downlink periods.

- If a single uplink-downlink period is configured for RIM-RS purposes,
  - P_t is the RIM-RS transmission periodicity in terms of uplink-downlink switching periods given by

$$P_\mathrm{t}=\left\lceil\frac{2^\mu \bar{P}_\mathrm{t} T_\mathrm{per,1}^\mathrm{RIM}}{1024 N_\mathrm{slot}^{\mathrm{frame},\mu}}\right\rceil\frac{1024 N_\mathrm{slot}^{\mathrm{frame},\mu}}{2^\mu T_\mathrm{per,1}^\mathrm{RIM}}$$

    where $T_\mathrm{per,1}^\mathrm{RIM}\in\{0.5,0.625,1,1.25,2,2.5,4,5,10,20\}$ ms;

  - $N_\mathrm{slot}^{P_t}=2^\mu P_\mathrm{t} T_\mathrm{per,1}^\mathrm{RIM}$ is the total number of slots in a RIM-RS transmission period;
  - $\bar{T}_\mathrm{offset}=2^\mu i_\mathrm{t}^\mathrm{RIM} T_\mathrm{per,1}^\mathrm{RIM}$ is the slot offset of the uplink-downlink switching period with index $i_\mathrm{t}^\mathrm{RIM}$ with respect to the starting boundary of the RIM-RS transmission period
- If two uplink-downlink periods are configured for RIM-RS purposes,
  - P_t is the RIM-RS transmission periodicity in terms of $P_\mathrm{t}/2$ pairs of uplink-downlink switching periods and is given by

$$P_\mathrm{t}=\left\lceil\frac{2^\mu \bar{P}_\mathrm{t}\left(T_\mathrm{per,1}^\mathrm{RIM}+T_\mathrm{per,2}^\mathrm{RIM}\right)/2}{1024 N_\mathrm{slot}^{\mathrm{frame},\mu}}\right\rceil\frac{1024 N_\mathrm{slot}^{\mathrm{frame},\mu}}{2^\mu\left(T_\mathrm{per,1}^\mathrm{RIM}+T_\mathrm{per,2}^\mathrm{RIM}\right)/2}$$

    where each pair consists of a first period of $T_\mathrm{per,1}^\mathrm{RIM}\in\{0.5,0.625,1,1.25,2,2.5,3,4,5,10,20\}$ ms and a second period of $T_\mathrm{per,2}^\mathrm{RIM}\in\{0.5,0.625,1,1.25,2,2.5,3,4,5,10\}$ ms and where $T_\mathrm{per,1}^\mathrm{RIM}+T_\mathrm{per,2}^\mathrm{RIM}$ divides 20 ms;

  - $N_\mathrm{slot}^{P_t}=2^\mu P_\mathrm{t}\left(T_\mathrm{per,1}^\mathrm{RIM}+T_\mathrm{per,2}^\mathrm{RIM}\right)/2$ is the total number of slots in a RIM-RS transmission period;
  - $\bar{T}_\mathrm{offset}=2^\mu\lfloor i_\mathrm{t}^\mathrm{RIM}/2\rfloor\left(T_\mathrm{per,1}^\mathrm{RIM}+T_\mathrm{per,2}^\mathrm{RIM}\right)+2^\mu\left(i_\mathrm{t}^\mathrm{RIM}\bmod 2\right)T_\mathrm{per,1}^\mathrm{RIM}$ is the slot offset of the uplink-downlink switching period with index $i_\mathrm{t}^\mathrm{RIM}$ with respect to the starting boundary of the RIM-RS transmission period

The intermediate quantity $\bar{P}_\mathrm{t}$ is given by

$$\bar{P}_\mathrm{t}=\begin{cases}\left\lceil\frac{N_\mathrm{setID}^\mathrm{RIM,1}}{N_\mathrm{f}^\mathrm{RIM}N_\mathrm{s}^\mathrm{RIM,1}}\right\rceil R_1+\left\lceil\frac{N_\mathrm{setID}^\mathrm{RIM,2}}{N_\mathrm{f}^\mathrm{RIM}N_\mathrm{s}^\mathrm{RIM,2}}\right\rceil R_2 & \text{if } \mathit{EnoughIndication} \text{ is disabled}\\ \left\lceil\frac{2N_\mathrm{setID}^\mathrm{RIM,1}}{N_\mathrm{f}^\mathrm{RIM}N_\mathrm{s}^\mathrm{RIM,1}}\right\rceil R_1+\left\lceil\frac{N_\mathrm{setID}^\mathrm{RIM,2}}{N_\mathrm{f}^\mathrm{RIM}N_\mathrm{s}^\mathrm{RIM,2}}\right\rceil R_2 & \text{if } \mathit{EnoughIndication} \text{ is enabled}\end{cases}$$

where

- $N_\mathrm{setID}^\mathrm{RIM,1}$ and $N_\mathrm{setID}^\mathrm{RIM,2}$ are the total number of setIDs for RIM-RS type 1 and RIM-RS type 2, respectively;
- $N_\mathrm{f}^\mathrm{RIM}\in\{1,2,4\}$ is the number of candidate frequency resources configured in the network;
- $N_\mathrm{s}^{\mathrm{RIM},i}\in\{1,2,\ldots,8\}$ is the number of candidate sequences assigned for RIM-RS type $i\in\{1,2\}$ in the network;
- R_1 and R_2 are the number of consecutive uplink-downlink switching periods for RIM-RS type 1 and RIM-RS type 2, respectively. If near-far functionality is not configured, $R_i\in\{1,2,4\}$, otherwise $R_i\in\{2,4,8\}$ and the first and second half of the R_i consecutive uplink-downlink switching periods are for near functionality and far functionality, respectively.

The quantity $N_\mathrm{symb,ref}^{\mathrm{RIM},\,i}$ is obtained from entry $\bar{r}$ in a list of configured symbol offsets for RIM-RS i.

7.4.1.6.4.3 Frequency-domain parameters and mapping from i_f to frequency-domain parameters

The frequency-domain parameter k_1 in clause 5.3.3 is the frequency offset relative to a configured reference point for RIM-RS and is obtained from entry $i_\mathrm{f}^\mathrm{RIM}$ in a list of configured frequency offsets expressed in units of resource blocks.

The number of candidate frequency resources configured in the network, $N_\mathrm{f}^\mathrm{RIM}$, shall fulfil

$$N_\mathrm{f}^\mathrm{RIM} \leq \left\lfloor \frac{N_\mathrm{grid}^{\mathrm{size},\mu} N_\mathrm{RB}^\mathrm{sc} \cdot 2^\mu \cdot 15}{40 \cdot 10^3} \right\rfloor + \left\lfloor \frac{N_\mathrm{grid}^{\mathrm{size},\mu} N_\mathrm{RB}^\mathrm{sc} \cdot 2^\mu \cdot 15}{80 \cdot 10^3} \right\rfloor + 1$$

If $N_\mathrm{f}^\mathrm{RIM} > 1$, the frequency difference between any pair of configured frequency offsets in the list is not smaller than $N_\mathrm{RB}^\mathrm{RIM}$.

The number of resource blocks for RIM-RS is given by

$$\begin{aligned} &N_\mathrm{RB}^\mathrm{RIM} = \min\left(96, N_\mathrm{grid,DL}^{\mathrm{size},\mu}\right) && \text{for } \mu = 0 \\ &N_\mathrm{RB}^\mathrm{RIM} \in \left\{\min\left(48, N_\mathrm{grid,DL}^{\mathrm{size},\mu}\right), \min\left(96, N_\mathrm{grid,DL}^{\mathrm{size},\mu}\right)\right\} && \text{for } \mu = 1 \end{aligned}$$

7.4.1.6.4.4 Sequence parameters and mapping from i_s to sequence parameters

The scrambling identity n_SCID clause 7.4.1.6.2 is obtained from entry $i_\mathrm{s}^\mathrm{RIM}$ in a list of configured scrambling identities.

7.4.1.6.4.5 Mapping between resource triplet and set ID

The resource indices $i_\mathrm{t}^\mathrm{RIM}$, $i_\mathrm{f}^\mathrm{RIM}$, and $i_\mathrm{s}^\mathrm{RIM}$ are determined from the index $\bar{r}$ in the set ID n_setID according to

$$\begin{aligned} i_\mathrm{t}^\mathrm{RIM} &= T_\mathrm{start} + \left(\left\lfloor \frac{n_\mathrm{setID}}{N_\mathrm{s}^\mathrm{RIM}} \right\rfloor \bmod N_\mathrm{t}^\mathrm{RIM}\right) R_i + \bar{r} \\ i_\mathrm{f}^\mathrm{RIM} &= \left(\left\lfloor \frac{n_\mathrm{setID}}{N_\mathrm{t}^\mathrm{RIM} N_\mathrm{s}^\mathrm{RIM}} \right\rfloor \bmod N_\mathrm{f}^\mathrm{RIM}\right) \\ i_\mathrm{s}^\mathrm{RIM} &= S_\mathrm{start} + \left(n_\mathrm{setID} \bmod N_\mathrm{s}^\mathrm{RIM}\right) \end{aligned}$$

where

- $N_\mathrm{t}^\mathrm{RIM}$ is given by

$$N_\mathrm{t}^\mathrm{RIM} = \begin{cases} \left\lceil \dfrac{N_\mathrm{setID}^\mathrm{RIM,1}}{N_\mathrm{f}^\mathrm{RIM} N_\mathrm{s}^\mathrm{RIM,1}} \right\rceil & \text{for RIM-RS type 1 and if } \mathit{EnoughIndication} \text{ is disabled} \\ \left\lceil \dfrac{2N_\mathrm{setID}^\mathrm{RIM,1}}{N_\mathrm{f}^\mathrm{RIM} N_\mathrm{s}^\mathrm{RIM,1}} \right\rceil & \text{for RIM-RS type 1 and if } \mathit{EnoughIndication} \text{ is enabled} \\ \left\lceil \dfrac{N_\mathrm{setID}^\mathrm{RIM,2}}{N_\mathrm{f}^\mathrm{RIM} N_\mathrm{s}^\mathrm{RIM,2}} \right\rceil & \text{for RIM-RS type 2} \end{cases}$$

- $N_\mathrm{f}^\mathrm{RIM} \in \{1,2,4\}$ is the number of candidate frequency resources configured in the network;

- $N_\mathrm{s}^\mathrm{RIM}$ is the number of sequence candidates for the current RIM-RS resource given by

$$N_\mathrm{s}^\mathrm{RIM} = \begin{cases} N_\mathrm{s}^\mathrm{RIM,1} & \text{for RIM-RS type 1 and if } \mathit{EnoughIndication} \text{ is disabled} \\ N_\mathrm{s}^\mathrm{RIM,1}/2 & \text{for RIM-RS type 1 and if } \mathit{EnoughIndication} \text{ is enabled} \\ N_\mathrm{s}^\mathrm{RIM,2} & \text{for RIM-RS type 2} \end{cases}$$

- T_start is the starting time offset given by

$$T_\mathrm{start} = \begin{cases} 0 & \text{for RIM-RS type 1} \\ \left\lceil \dfrac{N_\mathrm{setID}^\mathrm{RIM,1}}{N_\mathrm{f}^\mathrm{RIM} N_\mathrm{s}^\mathrm{RIM,1}} \right\rceil R_1 & \text{for RIM-RS type 2 and if } \mathit{EnoughIndication} \text{ is disabled} \\ \left\lceil \dfrac{2N_\mathrm{setID}^\mathrm{RIM,1}}{N_\mathrm{f}^\mathrm{RIM} N_\mathrm{s}^\mathrm{RIM,1}} \right\rceil R_1 & \text{for RIM-RS type 2 and if } \mathit{EnoughIndication} \text{ is enabled} \end{cases}$$

- S_start is given by

$$S_{\text{start}}=\begin{cases}N_{\text{s}}^{\text{RIM,1}}/2 & \text{if } \mathit{EnoughIndication} \text{ is enabled and 'enough mitigation' is to be indicated}\\ 0 & \text{otherwise}\end{cases}$$

where $N_{\text{s}}^{\text{RIM,1}}$ is the number of candidate sequences assigned for RIM-RS type 1

- R_i is the number of consecutive uplink-downlink periods for RIM-RS type i as given by clause 7.4.1.6.4.2;
- $\bar{r}\in\{0,1,\dots,R_i-1\}$.

The set ID is determined from the resource triplet according to

$$n_{\text{setID}}=\left(i_{\text{s}}^{\text{RIM}}-S_{\text{start}}\right)+N_{\text{s}}^{\text{RIM}}\left\lfloor\frac{i_{\text{t}}^{\text{RIM}}-T_{\text{start}}}{R_i}\right\rfloor+N_{\text{t}}^{\text{RIM}}N_{\text{s}}^{\text{RIM}}i_{\text{f}}^{\text{RIM}}$$

7.4.1.7 Positioning reference signals

7.4.1.7.1 General

A positioning frequency layer consists of one or more downlink PRS resource sets, each of which consists of one or more downlink PRS resources as described in [6, TS 38.214].

7.4.1.7.2 Sequence generation

The UE shall assume the reference-signal sequence $r(m)$ is defined by

$$r(m)=\frac{1}{\sqrt{2}}\big(1-2c(2m)\big)+j\frac{1}{\sqrt{2}}\big(1-2c(2m+1)\big)$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}}=\left(2^{22}\left\lfloor\frac{n_{\text{ID,seq}}^{\text{PRS}}}{1024}\right\rfloor+2^{10}\left(N_{\text{symb}}^{\text{slot}}n_{\text{s,f}}^{\mu}+l+1\right)\left(2\left(n_{\text{ID,seq}}^{\text{PRS}} \bmod 1024\right)+1\right)+\left(n_{\text{ID,seq}}^{\text{PRS}} \bmod 1024\right)\right) \bmod 2^{31}$$

where $n_{\text{s,f}}^{\mu}$ is the slot number, the downlink PRS sequence ID $n_{\text{ID,seq}}^{\text{PRS}}\in\{0,1,\dots,4095\}$ is given by the higher-layer parameter *dl-PRS-SequenceID*, and l is the OFDM symbol within the slot to which the sequence is mapped.

7.4.1.7.3 Mapping to physical resources in a downlink PRS resource

For each downlink PRS resource configured, the UE shall assume the sequence $r(m)$ is scaled with a factor β_{PRS} and mapped to resources elements $(k,l)_{p,\mu}$ according to

$$\begin{aligned}a_{k,l}^{(p,\mu)}&=\beta_{\text{PRS}}\,r(m)\\ m&=0,1,\dots\\ k&=mK_{\text{comb}}^{\text{PRS}}+\left(\left(k_{\text{offset}}^{\text{PRS}}+k'\right) \bmod K_{\text{comb}}^{\text{PRS}}\right)\\ l&=l_{\text{start}}^{\text{PRS}},l_{\text{start}}^{\text{PRS}}+1,\dots,l_{\text{start}}^{\text{PRS}}+L_{\text{PRS}}-1\end{aligned}$$

when the following conditions are fulfilled:

- the resource element $(k,l)_{p,\mu}$ is within the resource blocks occupied by the downlink PRS resource for which the UE is configured;
- the symbol l is not used by any SS/PBCH block used by a serving cell for downlink PRS transmitted from the same serving cell or any SS/PBCH block from a non-serving cell whose time frequency location is provided to the UE by higher layers for downlink PRS transmitted from the same non-serving cell;
- the slot number satisfies the conditions in clause 7.4.1.7.4.

and where

- the antenna port $p = 5000$
- $l_{\text{start}}^{\text{PRS}}$ is the first symbol of the downlink PRS within a slot and given by the higher-layer parameter *dl-PRS-ResourceSymbolOffset*;
- the size of the downlink PRS resource in the time domain $L_{\text{PRS}} \in \{1, 2, 4, 6, 12\}$ is given by the higher-layer parameter *dl-PRS-NumSymbols*;
- the comb size $K_{\text{comb}}^{\text{PRS}} \in \{2, 4, 6, 12\}$ is given by the higher-layer parameter *dl-PRS-CombSizeN-AndReOffset* for a downlink PRS resource configured for RTT-based propagation delay compensation, otherwise by the higher-layer parameter *dl-PRS-CombSizeN* such that the combination $\left\{L_{\text{PRS}}, K_{\text{comb}}^{\text{PRS}}\right\}$ is one of {1, 2}, {2, 2},{4, 2}, {6, 2}, {12, 2}, {1, 4}, {4, 4}, {12, 4}, {1, 6}, {6, 6}, {12, 6}, {1, 12} and {12, 12}*;*
- the resource-element offset $k_{\text{offset}}^{\text{PRS}} \in \left\{0, 1, \ldots, K_{\text{comb}}^{\text{PRS}} - 1\right\}$ is obtained from the higher-layer parameter *dl-PRS-CombSizeN-AndReOffset*;
- the quantity k' is given by Table 7.4.1.7.3-1.

If the downlink PRS resource is configured for RTT based propagation delay compensation as described in clause 9 of [6, TS 38.214], the reference point for $k = 0$ is subcarrier 0 in common resource block 0; Otherwise, the reference point for $k = 0$ is the location of the point A of the positioning frequency layer, in which the downlink PRS resource is configured where point A is given by the higher-layer parameter *dl-PRS-PointA*.

Table 7.4.1.7.3-1: The frequency offset k' as a function of $l - l_{\text{start}}^{\text{PRS}}$.

$K_{\text{comb}}^{\text{PRS}}$	Symbol number within the downlink PRS resource $l - l_{\text{start}}^{\text{PRS}}$											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2	0	1	0	1	0	1	0	1	0	1	0	1
4	0	2	1	3	0	2	1	3	0	2	1	3
6	0	3	1	4	2	5	0	3	1	4	2	5
12	0	6	3	9	1	7	4	10	2	8	5	11

7.4.1.7.4 Mapping to slots in a downlink PRS resource set

For a downlink PRS resource in a downlink PRS resource set, the UE shall assume the downlink PRS resource being transmitted when the slot and frame numbers fulfil

$$\left(N_{\text{slot}}^{\text{frame},\mu} n_{\text{f}} + n_{\text{s,f}}^{\mu} - T_{\text{offset}}^{\text{PRS}} - T_{\text{offset,res}}^{\text{PRS}}\right) \bmod T_{\text{per}}^{\text{PRS}} \in \left\{ i T_{\text{gap}}^{\text{PRS}} \right\}_{i=0}^{T_{\text{rep}}^{\text{PRS}}-1}$$

and one of the following conditions are fulfilled:

- the higher-layer parameters *dl-PRS-MutingOption1* and *dl-PRS-MutingOption2* are not provided;
- the higher-layer parameter *dl-PRS-MutingOption1* is provided with bitmap $\{b^1\}$ but *dl-PRS-MutingOption2* with bitmap $\{b^2\}$ is not provided, and bit b_i^1 is set;
- the higher-layer parameter *dl-PRS-MutingOption2* is provided with bitmap $\{b^2\}$ but *dl-PRS-MutingOption1* with bitmap $\{b^1\}$ is not provided, and bit b_i^2 is set;
- the higher-layer parameters *dl-PRS-MutingOption1* with bitmap $\{b^1\}$ and *dl-PRS-MutingOption2* with $\{b^2\}$ are both provided, and both bit b_i^1 and b_i^2 are set.

where

- b_i^1 is bit $i = \left\lfloor \left(N_{\text{slot}}^{\text{frame},\mu} n_{\text{f}} + n_{\text{s,f}}^{\mu} - T_{\text{offset}}^{\text{PRS}} - T_{\text{offset,res}}^{\text{PRS}}\right) / \left(T_{\text{muting}}^{\text{PRS}} T_{\text{per}}^{\text{PRS}}\right) \right\rfloor \bmod L$ in the bitmap given by the higher-layer parameter *dl-PRS-MutingOption1* where $L \in \{2, 4, 6, 8, 16, 32\}$ is the size of the bitmap;
- b_i^2 is bit $i = \left\lfloor \left(\left(N_{\text{slot}}^{\text{frame},\mu} n_{\text{f}} + n_{\text{s,f}}^{\mu} - T_{\text{offset}}^{\text{PRS}} - T_{\text{offset,res}}^{\text{PRS}}\right) \bmod T_{\text{per}}^{\text{PRS}}\right) / T_{\text{gap}}^{\text{PRS}} \right\rfloor \bmod T_{\text{rep}}^{\text{PRS}}$ in the bitmap given by the higher-layer parameter *dl-PRS-MutingOption2;*

- the periodicity $T_{\mathrm{per}}^{\mathrm{PRS}} \in 2^{\mu}\{4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 160, 320, 640, 1280, 2560, 5120, 10240\}$ and the slot offset $T_{\mathrm{offset}}^{\mathrm{PRS}} \in \{0,1, \ldots, T_{\mathrm{per}}^{\mathrm{PRS}} - 1\}$ are given by the higher-layer parameter *dl-PRS-Periodicity-and-ResourceSetSlotOffset;*
- the downlink PRS resource slot offset $T_{\mathrm{offset,res}}^{\mathrm{PRS}}$ is given by the higher-layer parameter *dl-PRS-ResourceSlotOffset*;
- the repetition factor $T_{\mathrm{rep}}^{\mathrm{PRS}} \in \{1,2,4,6,8,16,32\}$ is given by the higher-layer parameter *dl-PRS-ResourceRepetitionFactor*;
- the muting repetition factor $T_{\mathrm{muting}}^{\mathrm{PRS}}$ is given by the higher-layer parameter *dl-PRS-MutingBitRepetitionFactor*;
- the time gap $T_{\mathrm{gap}}^{\mathrm{PRS}} \in \{1,2,4,8,16,32\}$ is given by the higher-layer parameter *dl-PRS-ResourceTimeGap*;

For a downlink PRS resource in a downlink PRS resource set configured for RTT-based propagation delay compensation, the UE shall assume the downlink PRS resource being transmitted as described in clause 9 of [6, TS 38.214]; otherwise, the UE shall assume the downlink PRS resource being transmitted as described in clause 5.1.6.5 of [6, TS 38.214].

7.4.2 Synchronization signals

7.4.2.1 Physical-layer cell identities

There are 1008 unique physical-layer cell identities given by

$$N_{\mathrm{ID}}^{\mathrm{cell}} = 3N_{\mathrm{ID}}^{(1)} + N_{\mathrm{ID}}^{(2)}$$

where $N_{\mathrm{ID}}^{(1)} \in \{0,1, \ldots ,335\}$ and $N_{\mathrm{ID}}^{(2)} \in \{0,1,2\}$.

7.4.2.2 Primary synchronization signal

7.4.2.2.1 Sequence generation

The sequence $d_{\mathrm{PSS}}(n)$ for the primary synchronization signal is defined by

$$\begin{aligned} d_{\mathrm{PSS}}(n) &= 1 - 2x(m) \\ m &= \left(n + 43N_{\mathrm{ID}}^{(2)}\right) \bmod 127 \\ 0 &\le n < 127 \end{aligned}$$

where

$$x(i+7) = \left(x(i+4) + x(i)\right) \bmod 2$$

and

$$\begin{bmatrix} x(6) & x(5) & x(4) & x(3) & x(2) & x(1) & x(0) \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 0 & 1 & 1 & 0 \end{bmatrix}$$

7.4.2.2.2 Mapping to physical resources

Mapping to physical resources is described in clause 7.4.3.

7.4.2.3 Secondary synchronization signal

7.4.2.3.1 Sequence generation

The sequence $d_{\mathrm{SSS}}(n)$ for the secondary synchronization signal is defined by

$$
\begin{aligned}
d_{\mathrm{SSS}}(n) &= \left[1-2x_0\left((n+m_0)\bmod 127\right)\right]\left[1-2x_1\left((n+m_1)\bmod 127\right)\right] \\
m_0 &= 15\left\lfloor \frac{N_{\mathrm{ID}}^{(1)}}{112} \right\rfloor + 5N_{\mathrm{ID}}^{(2)} \\
m_1 &= N_{\mathrm{ID}}^{(1)} \bmod 112 \\
&0 \le n < 127
\end{aligned}
$$

where

$$
\begin{aligned}
x_0(i+7) &= \left(x_0(i+4)+x_0(i)\right)\bmod 2 \\
x_1(i+7) &= \left(x_1(i+1)+x_1(i)\right)\bmod 2
\end{aligned}
$$

and

$$
\begin{aligned}
\left[x_0(6)\quad x_0(5)\quad x_0(4)\quad x_0(3)\quad x_0(2)\quad x_0(1)\quad x_0(0)\right] &= \left[0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 1\right] \\
\left[x_1(6)\quad x_1(5)\quad x_1(4)\quad x_1(3)\quad x_1(2)\quad x_1(1)\quad x_1(0)\right] &= \left[0\quad 0\quad 0\quad 0\quad 0\quad 0\quad 1\right]
\end{aligned}
$$

7.4.2.3.2 Mapping to physical resources

Mapping to physical resources is described in clause 7.4.3.

7.4.3 SS/PBCH block

7.4.3.1 Time-frequency structure of an SS/PBCH block

In the time domain, an SS/PBCH block consists of 4 OFDM symbols, numbered in increasing order from 0 to 3 within the SS/PBCH block, where PSS, SSS, and PBCH with associated DM-RS are mapped to symbols as given by Table 7.4.3.1-1.

In the frequency domain, an SS/PBCH block consists of 240 contiguous subcarriers with the subcarriers numbered in increasing order from 0 to 239 within the SS/PBCH block. The quantities k and l represent the frequency and time indices, respectively, within one SS/PBCH block. The UE may assume that the complex-valued symbols corresponding to resource elements denoted as 'Set to 0' in Table 7.4.3.1-1 are set to zero. The quantity v in Table 7.4.3.1-1 is given by $v = N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 4$. The quantity k_{SSB} is the subcarrier offset from subcarrier 0 in common resource block $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ to the lowest-numbered subcarrier of the SS/PBCH block, or the SS/PBCH block after puncturing if applicable, where $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ is obtained from the higher-layer parameter *offsetToPointA*.

- For operation with shared spectrum channel access in FR2-2 and for operation without shared spectrum channel access, the 4 least significant bits of k_{SSB} are given by the higher-layer parameter *ssb-SubcarrierOffset* and for FR1 the most significant bit of k_{SSB} is given by $\bar{a}_{\bar{A}+5}$ in the PBCH payload as defined in clause 7.1.1 of [4, TS 38.212].
- For operation with shared spectrum channel access in FR1, the 4 least significant bits of $\bar{k}_{\mathrm{SSB}}$ are given by the higher-layer parameter *ssb-SubcarrierOffset* and the most significant bit of $\bar{k}_{\mathrm{SSB}}$ is given by $\bar{a}_{\bar{A}+5}$ in the PBCH payload as defined in clause 7.1.1 of [4, TS 38.212]. If $\bar{k}_{\mathrm{SSB}} \ge 24$, $k_{\mathrm{SSB}} = \bar{k}_{\mathrm{SSB}}$; otherwise, $k_{\mathrm{SSB}} = 2\lfloor \bar{k}_{\mathrm{SSB}}/2 \rfloor$.

If *ssb-SubcarrierOffset* is not provided, k_{SSB} is derived from the frequency difference between the SS/PBCH block and Point A.

The UE may assume that the complex-valued symbols corresponding to resource elements that are part of a common resource block partially or fully overlapping with an SS/PBCH block, or an SS/PBCH block after puncturing if applicable, and not used for SS/PBCH transmission are set to zero in the OFDM symbols partially or fully overlapping with OFDM symbols where SS/PBCH is transmitted.

For an SS/PBCH block, the UE shall assume

- antenna port $p = 4000$ is used for transmission of PSS, SSS, PBCH and DM-RS for PBCH,
- the same cyclic prefix length and subcarrier spacing for the PSS, SSS, PBCH and DM-RS for PBCH,

- for SS/PBCH block type A, $\mu \in \{0,1\}$ and $k_{\mathrm{SSB}} \in \{0,1,2,\ldots,23\}$ with the quantities k_{SSB}, and $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ expressed in terms of 15 kHz subcarrier spacing, and
- for SS/PBCH block type B in FR2-1, $\mu \in \{3,4\}$ and $k_{\mathrm{SSB}} \in \{0,1,2,\ldots,11\}$ with the quantity k_{SSB} expressed in terms of the subcarrier spacing provided by the higher-layer parameter *subCarrierSpacingCommon* and $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ expressed in terms of 60 kHz subcarrier spacing;
- for SS/PBCH block type B in FR2-2, $\mu \in \{3,5,6\}$ and $k_{\mathrm{SSB}} \in \{0,1,2,\ldots,11\}$ with the quantity k_{SSB} expressed in terms of the SS/PBCH block subcarrier spacing and $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ expressed in terms of 60 kHz subcarrier spacing;
- the centre of subcarrier 0 of resource block $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ coincides with the centre of subcarrier 0 of a common resource block with the subcarrier spacing
  - provided by the higher-layer parameter *subCarrierSpacingCommon* for operation without shared spectrum channel access in FR1 and FR2-1; and
  - same as the subcarrier spacing of the SS/PBCH block for operation without shared spectrum access in FR2-2 and for operation with shared spectrum channel access.
- This common resource block overlaps with subcarrier 0 of the lowest-numbered resource block of the SS/PBCH block, or the SS/PBCH block after puncturing if applicable.

The UE may assume that SS/PBCH blocks transmitted with the same block index on the same center frequency location are quasi co-located with respect to Doppler spread, Doppler shift, average gain, average delay, delay spread, and, when applicable, spatial Rx parameters. The UE shall not assume quasi co-location for any other SS/PBCH block transmissions other than what is specified in [5, TS 38.213].

For cell search on a carrier with a channel bandwidth of 3 MHz, the UE is not expected to receive subcarriers 0 to 47 and 192 to 239 in any of the 4 OFDM symbols of the SS/PBCH block, where the remaining 12 resource blocks form the SS/PBCH block after puncturing.

Table 7.4.3.1-1: Resources within an SS/PBCH block for PSS, SSS, PBCH, and DM-RS for PBCH.

Channel or signal	OFDM symbol number l relative to the start of an SS/PBCH block	Subcarrier number k relative to the start of an SS/PBCH block
PSS	0	56, 57, …, 182
SSS	2	56, 57, …, 182
Set to 0	0	0, 1, …, 55, 183, 184, …, 239
	2	48, 49, …, 55, 183, 184, …, 191
PBCH	1, 3	0, 1, …, 239
	2	0, 1, …, 47, 192, 193, …, 239
DM-RS for PBCH	1, 3	$0+v, 4+v, 8+v, \ldots, 236+v$
	2	$0+v, 4+v, 8+v, \ldots, 44+v$ $192+v, 196+v, \ldots, 236+v$

7.4.3.1.1 Mapping of PSS within an SS/PBCH block

The UE shall assume the sequence of symbols $d_{\mathrm{PSS}}(0),\ldots,d_{\mathrm{PSS}}(126)$ constituting the primary synchronization signal to be scaled by a factor β_{PSS} to conform to the PSS power allocation specified in [5, TS 38.213] and mapped to resource elements $(k,l)_{p,\mu}$ in increasing order of k where k and l are given by Table 7.4.3.1-1 and represent the frequency and time indices, respectively, within one SS/PBCH block.

7.4.3.1.2 Mapping of SSS within an SS/PBCH block

The UE shall assume the sequence of symbols $d_{\mathrm{SSS}}(0),\ldots,d_{\mathrm{SSS}}(126)$ constituting the secondary synchronization signal to be scaled by a factor β_{SSS} and mapped to resource elements $(k,l)_{p,\mu}$ in increasing order of k where k and l are given by Table 7.4.3.1-1 and represent the frequency and time indices, respectively, within one SS/PBCH block.

7.4.3.1.3 Mapping of PBCH and DM-RS within an SS/PBCH block

The UE shall assume the sequence of complex-valued symbols $d_{\text{PBCH}}(0),\ldots,d_{\text{PBCH}}(M_{\text{symb}}-1)$ constituting the physical broadcast channel to be scaled by a factor β_{PBCH} to conform to the PBCH power allocation specified in [5, TS 38.213] and mapped in sequence starting with $d_{\text{PBCH}}(0)$ to resource elements $(k,l)_{p,\mu}$ which meet all the following criteria:

- they are not used for PBCH demodulation reference signals

The mapping to resource elements $(k,l)_{p,\mu}$ not reserved for PBCH DM-RS shall be in increasing order of first the index k and then the index l, where k and l represent the frequency and time indices, respectively, within one SS/PBCH block and are given by Table 7.4.3.1-1.

The UE shall assume the sequence of complex-valued symbols $r(0),\ldots,r(143)$ constituting the demodulation reference signals for the SS/PBCH block to be scaled by a factor of $\beta_{\text{PBCH}}^{\text{DM-RS}}$ to conform to the PBCH power allocation specified in [5, TS 38.213] and to be mapped to resource elements $(k,l)_{p,\mu}$ in increasing order of first k and then l where k and l are given by Table 7.4.3.1-1 and represent the frequency and time indices, respectively, within one SS/PBCH block.

7.4.3.2 Time location of an SS/PBCH block

The locations in the time domain where a UE shall monitor for a possible SS/PBCH block are described in clause 4.1 of [5, TS 38.213].

8 Sidelink

8.1 Overview

8.1.1 Overview of physical channels

A sidelink physical channel corresponds to a set of resource elements carrying information originating from higher layers. The following sidelink physical channels are defined:

- Physical Sidelink Shared Channel, PSSCH
- Physical Sidelink Broadcast Channel, PSBCH
- Physical Sidelink Control Channel, PSCCH
- Physical Sidelink Feedback Channel, PSFCH

8.1.2 Overview of physical signals

A sidelink physical signal corresponds to a set of resource elements used by the physical layer but does not carry information originating from higher layers.

The following sidelink physical signals are defined:

- Demodulation reference signals, DM-RS
- Channel-state information reference signal, CSI-RS
- Phase-tracking reference signals, PT-RS
- Sidelink primary synchronization signal, S-PSS
- Sidelink secondary synchronization signal, S-SSS
- Sidelink positioning reference signal, SL PRS

8.2 Physical resources

8.2.1 General

In a shared SL PRS resource pool, the OFDM symbol immediately preceding the symbols which are configured for use by PSFCH if PSFCH is configured in this slot, and the last symbol configured for sidelink in a slot, serve as guard symbol(s). In a dedicated SL PRS resource pool, the last symbol configured for sidelink in a slot serves as a guard symbol. Otherwise, the OFDM symbol immediately following the last symbol used for PSSCH, PSFCH, or S-SSB serves as a guard symbol.

The first OFDM symbol of a PSSCH and its associated PSCCH is duplicated as described in clauses 8.3.1.5 and 8.3.2.3. The first OFDM symbol of a PSFCH is duplicated as described in clause 8.3.4.2.2.

The OFDM symbol immediately preceding an SL PRS transmission in a dedicated SL PRS resource pool is generated as described in clause 8.4.1.6.3.

8.2.2 Numerologies

Multiple OFDM numerologies are supported as given by Table 8.2.2-1 where μ and the cyclic prefix for a sidelink bandwidth part are obtained from the higher-layer parameter *sl-BWP*.

Table 8.2.2-1: Supported transmission numerologies.

μ	$\Delta f = 2^\mu \cdot 15$ [kHz]	Cyclic prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal

8.2.3 Frame structure

8.2.3.1 Frames and subframes

The frame and subframe structure for sidelink transmission is defined in clause 4.3.1.

8.2.3.2 Slots

The slot structure for sidelink transmission is defined in clause 4.3.2.

8.2.4 Antenna ports

An antenna port is defined in clause 4.4.1.

The following antenna ports are defined for the sidelink:

- Antenna ports starting with 1000 for PSSCH
- Antenna ports starting with 2000 for PSCCH
- Antenna ports starting with 3000 for CSI-RS
- Antenna ports starting with 4000 for S-SS/PSBCH block
- Antenna ports starting with 5000 for PSFCH
- Antenna ports starting with 6000 for SL PRS

For DM-RS associated with a PSBCH, the channel over which a PSBCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within a S-SS/PSBCH block transmitted within the same slot, and with the same block index according to clause 8.4.3.1.

For DM-RS associated with a PSSCH, the channel over which a PSSCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within the same frequency resource as the scheduled PSSCH and in the same slot.

For DM-RS associated with a PSCCH, the channel over which a PSCCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within the same frequency resource as the transmitted PSCCH and in the same slot.

8.2.5 Resource grid

The resource grid for sidelink transmission is defined in clause 4.4.2.

For sidelink, the carrier bandwidth $N_{\text{grid}}^{\text{size},\mu}$ and the starting position $N_{\text{grid}}^{\text{start},\mu}$ for subcarrier spacing configuration μ are obtained from the higher-layer parameter *sl-SCS-SpecificCarrierList*.

For the sidelink, the higher-layer parameter *sl-TxDirectCurrentLocation* indicates the location of the transmitter DC subcarrier in the sidelink for each of the configured bandwidth parts. Values in the range 0 – 3299 represent the number of the DC subcarrier, the value 3300 indicates that the DC subcarrier is located outside the resource grid, and the value 3301 indicates that the position of the DC subcarrier in the sidelink is undetermined. The DC subcarrier location offset relative to the center of the indicated subcarrier is given by $7.5 + 5N$ kHz if *frequencyShift7p5khzSL* is provided and by $5N$ kHz otherwise, where $N \in \{-1,0,1\}$ is given by the higher-layer parameter *valueN*.

8.2.6 Resource elements

Resource elements are defined in clause 4.4.3.

8.2.7 Resource blocks

Resource blocks are defined in clause 4.4.4.

Point A for sidelink transmission/reception is obtained from the higher-layer parameter *sl-AbsoluteFrequencyPointA*.

8.2.8 Bandwidth part

Configuration of the single bandwidth part for sidelink transmission is described in clause 16 of [5, TS 38.213].

8.3 Physical channels

8.3.1 Physical sidelink shared channel

8.3.1.1 Scrambling

For the single codeword $q = 0$, the block of bits $b^{(q)}(0), \ldots, b^{(q)}\left(M_{\text{bit}}^{(q)} - 1\right)$, where $M_{\text{bit}}^{(q)} = M_{\text{bit,SCI2}}^{(q)} + M_{\text{bit,data}}^{(q)}$ is the number of bits in codeword q transmitted on the physical channel as defined in [4, TS 38.212], shall be scrambled prior to modulation.

Scrambling shall be done according to the following pseudo code

```
set $i = 0$
set $j = 0$
while $i < M_{\text{bit}}^{(q)}$
    if $b^{(q)}(i) = x$ // SCI placeholder bits
```

```
            $\tilde{b}^{(q)}(i) = \tilde{b}^{(q)}(i-2)$
            $j = j + 1$
        else
            $\tilde{b}^{(q)}(i) = \left(b^{(q)}(i) + c^{(q)}(i - \widetilde{M}_{i,j}^{(q)})\right) \bmod 2$
        end if
        $i = i + 1$
    end while
```

where the scrambling sequence $c^{(q)}(i)$ is given by clause 5.2.1 and

- for $0 \leq i < M_{\text{bit,SCI2}}^{(q)}$
  - $\widetilde{M}_{i,j}^{(q)} = j$
  - The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = 2^{15} N_{\text{ID}} + 1010$$

  where $N_{\text{ID}} = N_{\text{ID}}^{\text{X}} \bmod 2^{16}$ and the quantity N_{ID}^{X} equals the decimal representation of the CRC on the PSCCH associated with the PSSCH according to $N_{\text{ID}}^{\text{X}} = \sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$ with p and L given by clause 8.3.2 in [4, TS 38.212].

- for $M_{\text{bit,SCI2}}^{(q)} \leq i < M_{\text{bit}}^{(q)}$
  - $\widetilde{M}_{i,j}^{(q)} = M_{\text{bit,SCI2}}^{(q)}$
  - The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = 2^{15} N_{\text{ID}} + 1010$$

  where $N_{\text{ID}} = N_{\text{ID}}^{\text{X}} \bmod 2^{16}$ and the quantity N_{ID}^{X} equals the decimal representation of the CRC on the PSCCH associated with the PSSCH according to $N_{\text{ID}}^{\text{X}} = \sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$ with p and L given by clause 8.3.2 in [4, TS 38.212].

8.3.1.2 Modulation

For the single codeword $q = 0$, the block of scrambled bits shall be modulated, resulting in a block of complex-valued modulation symbols $d^{(q)}(0), \ldots, d^{(q)}\left(M_{\text{symb}}^{(q)} - 1\right)$ where $M_{\text{symb}}^{(q)} = M_{\text{symb},1}^{(q)} + M_{\text{symb},2}^{(q)}$.

Modulation for $0 \leq i < M_{\text{bit,SCI2}}^{(q)}$ shall be done as described in clause 5.1 using QPSK, where $M_{\text{symb},1}^{(q)} = M_{\text{bit,SCI2}}^{(q)}/2$.

Modulation for $M_{\text{bit,SCI2}}^{(q)} \leq i < M_{\text{bit}}^{(q)}$ shall be done as described in clause 5.1 using one of the modulation schemes in Table 8.3.1.2-1 where $M_{\text{symb},2}^{(q)} = M_{\text{bit,data}}^{(q)}/Q_{\text{m}}$.

Table 8.3.1.2-1: Supported modulation schemes.

Modulation scheme	Modulation order Q_m
QPSK	2
16QAM	4
64QAM	6
256QAM	8

8.3.1.3 Layer mapping

Layer mapping shall be done according to clause 7.3.1.3 with the number of layers $\upsilon \in \{1,2\}$, resulting in $x(i) = [x^{(0)}(i) \quad \dots \quad x^{(\upsilon-1)}(i)]^{\mathrm{T}}$, $i = 0,1,\dots,M_{\mathrm{symb}}^{\mathrm{layer}} - 1$.

8.3.1.4 Precoding

The block of vectors $[x^{(0)}(i) \quad \dots \quad x^{(\upsilon-1)}(i)]^{\mathrm{T}}$ shall be precoded according to clasue 6.3.1.5 where the precoding matrix W equals the identity matrix and $M_{\mathrm{symb}}^{\mathrm{ap}} = M_{\mathrm{symb}}^{\mathrm{layer}}$.

8.3.1.5 Mapping to virtual resource blocks

For each of the antenna ports used for transmission of the PSSCH, the block of complex-valued symbols $z^{(p)}(0),\dots,z^{(p)}(M_{\mathrm{symb}}^{\mathrm{ap}} - 1)$ shall be multiplied with the amplitude scaling factor $\beta_{\mathrm{DMRS}}^{\mathrm{PSSCH}}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped to resource elements $(k', l)_{p,\mu}$ in the virtual resource blocks assigned for transmission, where $k' = 0$ is the first subcarrier in the lowest-numbered virtual resource block assigned for transmission.

The mapping operation shall be done in two steps:

- first, the complex-valued symbols corresponding to the bit for the 2nd-stage SCI in increasing order of first the index k' over the assigned virtual resource blocks and then the index l, starting from the first PSSCH symbol carrying an associated DM-RS and meeting all of the following criteria:
    - the corresponding resource elements in the corresponding physical resource blocks are not used for transmission of the associated DM-RS, PT-RS, or PSCCH;
- secondly, the complex-valued modulation symbols not corresponding to the 2nd -stage SCI shall be in increasing order of first the index k' over the assigned virtual resource blocks, and then the index l with the starting position given by [6, TS 38.214] and meeting all of the following criteria:
    - the resource elements are not used for 2nd-stage SCI in the first step;
    - the resource elements are not in the $L_{\text{SL-PRS}}$ symbols used for transmission of the associated SL PRS according to clause 8.2.4.1.1 of [6, TS 38.214];
    - the corresponding resource elements in the corresponding physical resource blocks are not used for transmission of the associated DM-RS, PT-RS, CSI-RS, or PSCCH.

The resource elements used for the PSSCH in the first OFDM symbol in the mapping operation above, including any DM-RS, PT-RS, or CSI-RS occurring in the first OFDM symbol, shall be duplicated in the OFDM symbol immediately preceding the first OFDM symbol in the mapping.

8.3.1.6 Mapping from virtual to physical resource blocks

Virtual resource blocks shall be mapped to physical resource blocks according to non-interleaved mapping.

For non-interleaved VRB-to-PRB mapping, virtual resource block n is mapped to physical resource block n.

8.3.2 Physical sidelink control channel

8.3.2.1 Scrambling

The block of bits $b(0),\dots,b(M_{\mathrm{bit}} - 1)$, where M_{bit} is the number of bits transmitted on the physical channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0),\dots,\tilde{b}(M_{\mathrm{bit}} - 1)$ according to

$$\tilde{b}(i) = (b(i) + c(i)) \bmod 2$$

where the scrambling sequence $c(i)$ is given by clause 5.2.1. The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = 1010$$

8.3.2.2 Modulation

The block of scrambled bits $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$ shall be modulated as described in clause 5.1 using QPSK, resulting in a block of complex-valued modulation symbols $d(0), \dots, d(M_{\text{symb}} - 1)$ where $M_{\text{symb}} = M_{\text{bit}}/2$.

8.3.2.3 Mapping to physical resources

The set of complex-valued modulation symbols $d(0), \dots, d(M_{\text{symb}} - 1)$ shall be multiplied with the amplitude scaling factor $\beta_{\text{DMRS}}^{\text{PSCCH}}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $d(0)$ to resource elements $(k, l)_{p,\mu}$ assigned for transmission according to clause 16.4 of [5, TS 38.213], and not used for the demodulation reference signals associated with PSCCH, in increasing order of first the index k over the assigned physical resources, and then the index l on antenna port $p = 2000$.

The resource elements used for the PSCCH in the first OFDM symbol in the mapping operation above, including any DM-RS, PT-RS, or CSI-RS occurring in the first OFDM symbol, shall be duplicated in the immediately preceding OFDM symbol.

8.3.3 Physical sidelink broadcast channel

8.3.3.1 Scrambling

The block of bits $b(0), \dots, b(M_{\text{bit}} - 1)$, where M_{bit} is the number of bits transmitted on the physical sidelink broadcast channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$ according to

$$\tilde{b}(i) = (b(i) + c(i)) \bmod 2$$

where the scrambling sequence $c(i)$ is given by clause 5.2.1. The scrambling sequence generator shall be initialized with $c_{\text{init}} = N_{\text{ID}}^{\text{SL}}$ at the start of each S-SS/PSBCH block.

8.3.3.2 Modulation

The block of bits $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$ shall be QPSK modulated as described in clause 5.1.3, resulting in a block of complex-valued modulation symbols $d_{\text{PSBCH}}(0), \dots, d_{\text{PSBCH}}(M_{\text{symb}} - 1)$ where $M_{\text{symb}} = M_{\text{bit}}/2$.

8.3.3.3 Mapping to physical resources

Mapping to physical resources is described in clause 8.4.3.

8.3.4 Physical sidelink feedback channel

8.3.4.1 General

8.3.4.2 PSFCH format 0

8.3.4.2.1 Sequence generation

The sequence $x(n)$ shall be generated according to

$$x(n) = r_{u,v}^{\alpha,\delta}(n)$$

$$n = 0,1, \dots, N_{\text{sc}}^{\text{RB}} - 1$$

where $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 6.3.2.2 with the following exceptions:

- m_{cs} is given by clause 16.3 of [5, TS 38.213];
- m_0 is given by clause 16.3 of [5, TS 38.213];
- m_{int} is given by
  - $m_{\mathrm{int}} = 5n_{\mathrm{IRB}}^{\mu}$ if the higher-layer parameter *sl-PSFCH-Type* is configured and set to '*type1*' and where n_{IRB}^{μ} is the resource block number within the interlace;
  - $m_{\mathrm{int}} = 0$ otherwise
- $l = 0$;
- l' is the index of the OFDM symbol in the slot that corresponds to the second OFDM symbol of the PSFCH transmission in the slot given by [5, TS 38.213];
- $u = n_{\mathrm{ID}} \bmod 30$ and $v = 0$ with n_{ID} given by the higher-layer parameter *sl-PSFCH-HopID* if configured; otherwise, $u = 0$.
- $c_{\mathrm{init}} = n_{\mathrm{ID}}$ with n_{ID} given by the higher-layer parameter *sl-PSFCH-HopID* if configured; otherwise, $c_{\mathrm{init}} = 0$.

8.3.4.2.2 Mapping to physical resources

The sequence $x(n)$ shall be multiplied with the amplitude scaling factor β_{PSFCH} in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $x(0)$ to resource elements $(k,l)_{p,\mu}$ assigned for transmission of the second PSFCH symbol according to clause 16.3 of [5, TS 38.213] in increasing order of the index k over the assigned physical resources on antenna port $p = 5000$.

The resource elements used for the PSFCH in the OFDM symbol in the mapping operation above shall be duplicated in the immediately preceding OFDM symbol.

If the higher-layer parameter *sl-PSFCH-Type* is configured and set to ‘*type1*’, the mapping operation shall be repeated for each resource block in the interlace and in the RB set over the assigned physical resource blocks according to clause 16.3 of [5, TS 38.213], with the resource-block dependent sequence generated according to clause 8.3.4.2.1.

If the higher-layer parameter sl-PSFCH-Type is configured and set to ‘*type2*’, the mapping operation shall be repeated for each resource block assigned for transmission of the common interlace and for PSFCH transmission with HARQ-ACK information over the assigned physical resource according to clause 16.3 of [5, TS 38.213], with the resource-block dependent sequence generated according to clause 8.3.4.2.1, where the cyclic shift α on each resource block assigned for transmission of the common interlace is up to UE implementation.

8.4 Physical signals

8.4.1 Reference signals

8.4.1.1 Demodulation reference signals for PSSCH

8.4.1.1.1 Sequence generation

The sequence $r_l(m)$ shall be generated according to

$$r_l(m) = \frac{1}{\sqrt{2}}\big(1 - 2c(2m)\big) + j\frac{1}{\sqrt{2}}\big(1 - 2c(2m+1)\big)$$

where the pseudo-random sequence $c(m)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialized with

$$c_{\mathrm{init}} = \left(2^{17}\left(N_{\mathrm{symb}}^{\mathrm{slot}} n_{\mathrm{s,f}}^{\mu} + l + 1\right)\left(2N_{\mathrm{ID}} + 1\right) + 2N_{\mathrm{ID}}\right) \bmod 2^{31}$$

where l is the OFDM symbol number within the slot, $n_{\mathrm{s,f}}^{\mu}$ is the slot number within a frame, and $N_{\mathrm{ID}} = N_{\mathrm{ID}}^{\mathrm{X}} \bmod 2^{16}$ where the quantity $N_{\mathrm{ID}}^{\mathrm{X}}$ equals the decimal representation of CRC on the PSCCH associated with the PSSCH according to $N_{\mathrm{ID}}^{\mathrm{X}} = \sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$ with p and L given by clause 7.3.2 in [4, TS 38.212].

8.4.1.1.2 Mapping to physical resources

The sequence $r(m)$ shall be mapped to the intermediate quantity $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)}$ according to clause 6.4.1.1.3 using configuration type 1 without transform precoding, and where $w_{\mathrm{f}}(k')$, $w_{\mathrm{t}}(l')$, and Δ are given by Table 8.4.1.1.2-2, and $r(m)$ is specified in clause 8.4.1.1.1.

The patterns used for the PSSCH DM-RS is indicated in the SCI as described in clause 8.3.1.1 of [4, TS 38.212].

The intermediate quantity $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)}$ shall be precoded, multiplied with the amplitude scaling factor $\beta_{\mathrm{DMRS}}^{\mathrm{PSSCH}}$ specified in clause 8.3.1.5, and mapped to physical resources according to

$$\begin{bmatrix} a_{k,l}^{(p_0,\mu)} \\ \vdots \\ a_{k,l}^{(p_{\rho-1},\mu)} \end{bmatrix} = \beta_{\mathrm{DMRS}}^{\mathrm{PSSCH}} W \begin{bmatrix} \tilde{a}_{k,l}^{(\tilde{p}_0,\mu)} \\ \vdots \\ \tilde{a}_{k,l}^{(\tilde{p}_{\upsilon-1},\mu)} \end{bmatrix}$$

where

- the precoding matrix W is given by clause 8.3.1.4,
- the set of antenna ports $\{p_0, \dots, p_{\rho-1}\}$ is given by clause 8.3.1.4, and
- the set of antenna ports $\{\tilde{p}_0, \dots, \tilde{p}_{\upsilon-1}\}$ is given by [6, TS 38.214];

and the following conditions are fulfilled:

- the resource elements $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)}$ are within the common resource blocks allocated for PSSCH transmission.

The quantity k is defined relative to subcarrier 0 in common resource block 0 and the quantity l is defined relative to the start of the scheduled resources for transmission of PSSCH and the associated PSCCH, including the OFDM symbol duplicated as described in clauses 8.3.1.5 and 8.3.2.3.

The position(s) of the DM-RS symbols is given by $\bar{l}$ according to Table 8.4.1.1.2-1 where the number of PSSCH DM-RS is indicated in the SCI, and l_{d} is the duration of the scheduled resources for transmission of PSSCH according to clause 8.1.2.1 of [6, TS 38.214] and the associated PSCCH, including the OFDM symbol duplicated as described in clauses 8.3.1.5 and 8.3.2.3.

Table 8.4.1.1.2-1: PSSCH DM-RS time-domain location.

l_{d} in symbols	**DM-RS position $\bar{l}$**					
	PSCCH duration 2 symbols			**PSCCH duration 3 symbols**		
	Number of PSSCH DM-RS			**Number of PSSCH DM-RS**		
	2	**3**	**4**	**2**	**3**	**4**
6	1, 5			1, 5		
7	1, 5			1, 5		
8	1, 5			1, 5		
9	3, 8	1, 4, 7		4, 8	1, 4, 7	
10	3, 8	1, 4, 7		4, 8	1, 4, 7	
11	3, 10	1, 5, 9	1, 4, 7, 10	4, 10	1, 5, 9	1, 4, 7, 10
12	3, 10	1, 5, 9	1, 4, 7, 10	4, 10	1, 5, 9	1, 4, 7, 10
13	3, 10	1, 6, 11	1, 4, 7, 10	4, 10	1, 6, 11	1, 4, 7, 10

Table 8.4.1.1.2-2: Parameters for PSSCH DM-RS.

p	CDM group λ	Δ	$w_\mathrm{f}(k')$		$w_\mathrm{t}(l')$
			$k'=0$	$k'=1$	$l'=0$
1000	0	0	+1	+1	+1
1001	0	0	+1	-1	+1

8.4.1.2 Phase-tracking reference signals for PSSCH

8.4.1.2.1 Sequence generation

The precoded sidelink phase-tracking reference signal for subcarrier k on layer j is given by

$$r^{(\tilde{p}_j)}(m) = \begin{cases} r(m) & \text{if } j = j' \text{ or } j = j" \\ 0 & \text{otherwise} \end{cases}$$

where

- antenna ports $\tilde{p}_{j'}$ or $\{\tilde{p}_{j'}, \tilde{p}_{j''}\}$ associated with PT-RS transmission are given by clause 8.2.3 of [6, TS 38.214];
- $r(m)$ is given by clause 8.4.1.1.1 at the position of the first PSSCH symbol carrying an associated DM-RS.

8.4.1.2.2 Mapping to physical resources

The UE shall transmit phase-tracking reference signals only in the resource blocks used for the PSSCH, and only if the procedure in [6, TS 38.214] indicates that phase-tracking reference signals are being used.

The PSSCH PT-RS shall be mapped to resource elements according to

$$\begin{bmatrix} a_{k,l}^{(p_o,\mu)} \\ \vdots \\ a_{k,l}^{(p_{\rho-1},\mu)} \end{bmatrix} = \beta_{\mathrm{DMRS}}^{\mathrm{PSSCH}} W \begin{bmatrix} r^{(\tilde{p}_0)}(2n+k') \\ \vdots \\ r^{(\tilde{p}_{\upsilon-1})}(2n+k') \end{bmatrix}$$

$$k = 4n + 2k' + \Delta$$

when all the following conditions are fulfilled

- l is within the OFDM symbols allocated for the PSSCH transmission;
- resource element (k,l) is not used for PSCCH, nor DM-RS associated with PSSCH;
- k' and Δ correspond to $\tilde{p}_0, \ldots, \tilde{p}_{\upsilon-1}$

The precoding matrix W is given by clause 8.3.1.4.

The set of time indices l defined relative to the start of the PSSCH allocation is defined by

1. set $i = 0$ and $l_\mathrm{ref} = 0$
2. if any symbol in the interval $\max(l_\mathrm{ref} + (i-1)L_\text{PT-RS} + 1, l_\mathrm{ref}), \ldots, l_\mathrm{ref} + iL_\text{PT-RS}$ overlaps with a symbol used for DM-RS according to clause 8.4.1.1.2
    - set $i = 1$
    - set l_ref to the symbol index of the DM-RS symbol
    - repeat from step 2 as long as $l_\mathrm{ref} + iL_\text{PT-RS}$ is inside the PSSCH allocation
3. add $l_\mathrm{ref} + iL_\text{PT-RS}$ to the set of time indices for PT-RS
4. increment i by one
5. repeat from step 2 above as long as $l_\mathrm{ref} + iL_\text{PT-RS}$ is inside the PSSCH allocation

where $L_{\text{PT-RS}} \in \{1,2,4\}$ is given by clause 8.4.3 of [6, TS 38.214].

For the purpose of PT-RS mapping, the resource blocks allocated for PSSCH transmission are numbered from 0 to $N_{\text{RB}} - 1$ from the lowest scheduled resource block to the highest. The corresponding subcarriers in this set of resource blocks are numbered in increasing order starting from the lowest frequency from 0 to $N_{\text{sc}}^{\text{RB}} N_{\text{RB}} - 1$. The subcarriers to which the PT-RS shall be mapped are given by

$$k = k_{\text{ref}}^{\text{RE}} + \left(iK_{\text{PT-RS}} + k_{\text{ref}}^{\text{RB}}\right)N_{\text{sc}}^{\text{RB}}$$
$$k_{\text{ref}}^{\text{RB}} = \begin{cases} N_{\text{ID}} \bmod K_{\text{PT-RS}} & \text{if } N_{\text{RB}} \bmod K_{\text{PT-RS}} = 0 \\ N_{\text{ID}} \bmod \left(N_{\text{RB}} \bmod K_{\text{PT-RS}}\right) & \text{otherwise} \end{cases}$$

where

- $i = 0,1,2,\ldots$
- $k_{\text{ref}}^{\text{RE}}$ is given by Table 8.4.1.2.2-1 for the DM-RS port associated with the PT-RS port according to clause 8.2.3 in [6, TS 38.214].
- N_{RB} is the number of resource blocks scheduled;
- $K_{\text{PT-RS}} \in \{2,4\}$ is given by [6, TS 38.214];
- $N_{\text{ID}} = N_{\text{ID}}^{\text{X}} \bmod 2^{16}$ where the quantity N_{ID}^{X} equals the decimal representation of CRC on the PSCCH associated with the PSSCH according to $N_{\text{ID}}^{\text{X}} = \sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$ with p and L given by clause 7.3.2 in [4, TS 38.212].

PSSCH PT-RS shall not be mapped to resource elements containing PSCCH or PSCCH DMRS by puncturing PSSCH PT-RS.

A UE is not expected to receive sidelink CSI-RS and PSSCH PT-RS on the same resource elements.

Table 8.4.1.2.2-1: The parameter $k_{\text{ref}}^{\text{RE}}$.

DM-RS antenna port $\tilde{p}$	$k_{\text{ref}}^{\text{RE}}$ ***resourceElementOffset***			
	offset00	**offset01**	**offset10**	**offset11**
0	0	2	6	8
1	2	4	8	10

8.4.1.3 Demodulation reference signals for PSCCH

8.4.1.3.1 Sequence generation

The sequence $r_l(m)$ shall be generated according to

$$r_l(m) = \frac{1}{\sqrt{2}}\left(1 - 2c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2c(2m+1)\right)$$

where the pseudo-random sequence $c(m)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialized with

$$c_{\text{init}} = \left(2^{17}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)\left(2N_{\text{ID}} + 1\right) + 2N_{\text{ID}}\right) \bmod 2^{31}$$

where

- l is the OFDM symbol number within the slot,
- $n_{\text{s,f}}^{\mu}$ is the slot number within a frame, and
- $N_{ID} \in \{0,1,\ldots,65535\}$ is given by the higher-layer parameter *sl-DMRS-ScrambleID.*

8.4.1.3.2 Mapping to physical resources

The sequence $r_l(m)$ shall be multiplied with the amplitude scaling factor $\beta_{\mathrm{DMRS}}^{\mathrm{PSCCH}}$ in order to conform to the transmit power specified in [5, 38.213] and mapped in sequence starting with $r_l(0)$ to resource elements $(k,l)_{p,\mu}$ in a slot on antenna port $p = 2000$ according to

$$\begin{aligned} a_{k,l}^{(p,\mu)} &= \beta_{\mathrm{DMRS}}^{\mathrm{PSCCH}} w_{\mathrm{f},i}(k') r_l(3n+k') \\ k &= nN_{\mathrm{sc}}^{\mathrm{RB}} + 4k' + 1 \\ k' &= 0,1,2 \\ n &= 0,1,\ldots \end{aligned}$$

where the following conditions are fulfilled

- they are within the resource elements constituting the PSCCH

The quantity $w_{\mathrm{f},i}(k')$ is given by Table 8.4.1.3.2-1 and $i \in \{0,1,2\}$ shall be randomly selected by the UE.

The reference point for k is subcarrier 0 in common resource block 0.

The quantity l is the OFDM symbol number within the slot.

Table 8.4.1.3.2-1: The quantity $w_{\mathrm{f},i}(k')$.

k'	$w_{f,i}(k')$		
	$i = 0$	$i = 1$	$i = 2$
0	1	1	1
1	1	$e^{j2/3\pi}$	$e^{-j2/3\pi}$
2	1	$e^{-j2/3\pi}$	$e^{j2/3\pi}$

8.4.1.4 Demodulation reference signals for PSBCH

8.4.1.4.1 Sequence generation

The reference-signal sequence $r(m)$ for an S-SS/PSBCH block is defined by

$$r(m) = \frac{1}{\sqrt{2}}\big(1 - 2c(2m)\big) + j\frac{1}{\sqrt{2}}\big(1 - 2c(2m+1)\big)$$

where $c(n)$ is given by clause 5.2. The scrambling sequence generator shall be initialized at the start of each S-SS/PSBCH block occasion with

$$c_{\mathrm{init}} = N_{\mathrm{ID}}^{\mathrm{SL}}$$

8.4.1.4.2 Mapping to physical resources

Mapping to physical resources is described in clause 8.4.3.

8.4.1.5 CSI reference signals

8.4.1.5.1 General

8.4.1.5.2 Sequence generation

The sequence $r(m)$ shall be generated according to

$$r(m) = \frac{1}{\sqrt{2}}\big(1 - 2c(2m)\big) + j\frac{1}{\sqrt{2}}\big(1 - 2c(2m+1)\big)$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}} = \left(2^{10}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)(2n_{\text{ID}} + 1) + n_{\text{ID}}\right) \bmod 2^{31}$$

at the start of each OFDM symbol where $n_{\text{s,f}}^{\mu}$ is the slot number within a radio frame, l is the OFDM symbol number within a slot, and $n_{\text{ID}} = N_{\text{ID}}^{\text{X}} \bmod 2^{10}$ where the quantity N_{ID}^{X} equals the decimal representation of CRC for the sidelink control information mapped to the PSCCH associated with the CSI-RS according to $N_{\text{ID}}^{\text{X}} = \sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$ with p and L given by clause 7.3.2 in [4, TS 38.212].

8.4.1.5.3 Mapping to physical resources

Mapping to resource elements shall be done according to clause 7.4.1.5.3 with the following exceptions:

- only 1 and 2 antenna ports are supported, $X \in \{1,2\}$;
- only density $\rho = 1$ is supported;
- zero-power CSI-RS is not supported;
- the quantity β_{CSIRS} is an amplitude scaling factor to conform with the transmit power specified in clause 8.2.1 of [6, TS 38.214].

8.4.1.6 Positioning reference signals

8.4.1.6.1 General

A SL PRS resource refers to a time-frequency resource within a slot, used for SL PRS transmission.

8.4.1.6.2 Sequence generation

The sequence $r(m)$ is defined by

$$r(m) = \frac{1}{\sqrt{2}}\left(1 - 2c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2c(2m+1)\right)$$

where the pseudo-random sequence $c(i)$ is defined in clause 5.2.1. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}} = \left(2^{22}\left\lfloor\frac{n_{\text{ID,seq}}^{\text{SL-PRS}}}{1024}\right\rfloor + 2^{10}\left(N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1\right)\left(2\left(n_{\text{ID,seq}}^{\text{SL-PRS}} \bmod 1024\right) + 1\right) + \left(n_{\text{ID,seq}}^{\text{SL-PRS}} \bmod 1024\right)\right) \bmod 2^{31}$$

where

- $n_{\text{s,f}}^{\mu}$ is the slot number within the radio frame
- l is the OFDM symbol number within the slot to which the sequence is mapped
- $n_{\text{ID,seq}}^{\text{SL-PRS}} \in \{0,1,\ldots,4095\}$ is the sidelink PRS sequence ID, which, if not provided by higher layers, is obtained from the decimal representation of the CRC for the sidelink control information mapped to the PSCCH associated with the SL PRS according to $n_{\text{ID,seq}}^{\text{SL-PRS}} = \left(\sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}\right) \bmod 2^{12}$ with p and L given by clause 7.3.2 in [4, TS 38.212].

8.4.1.6.3 Mapping to physical resources

The sequence shall be multiplied with the amplitude scaling factor $\beta_{\text{SL-PRS}}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped to resources elements $(k,l)_{p,\mu}$ according to

$$a_{k,l}^{(p,\mu)} = \beta_{\text{SL-PRS}}\, r(m)$$
$$m = 0,1,\ldots$$

$$k = mK_{\text{comb}}^{\text{SL-PRS}} + \left(\left(k_{\text{offset}}^{\text{SL-PRS}} + k'\right) \bmod K_{\text{comb}}^{\text{SL-PRS}}\right)$$
$$l = l_{\text{start}}^{\text{SL-PRS}}, l_{\text{start}}^{\text{SL-PRS}} + 1, \ldots, l_{\text{start}}^{\text{SL-PRS}} + L_{\text{SL-PRS}} - 1$$

when the following conditions are fulfilled:

- the resource element $(k, l)_{p,\mu}$ is within the common resource blocks occupied by the SL PRS resource

and where

- the comb size $K_{\text{comb}}^{\text{SL-PRS}}$ is provided by the higher layer parameter *nCombSize*
- the resource-element offset $k_{\text{offset}}^{\text{SL-PRS}} \in \left\{0,1, \ldots, K_{\text{comb}}^{\text{SL-PRS}} - 1\right\}$
- the frequency offset k' is given by Table 8.4.1.6.3-1
- the starting symbol $l_{\text{start}}^{\text{SL-PRS}}$ is provided by the higher-layer parameter *sl-PRS-starting-symbol* for a dedicated SL PRS resource pool, or is determined such that the symbols $\{l_{\text{start}}^{\text{SL-PRS}}, l_{\text{start}}^{\text{SL-PRS}} + 1, \ldots, l_{\text{start}}^{\text{SL-PRS}} + L_{\text{SL-PRS}} - 1\}$ are mapped to the last consecutive $L_{\text{SL-PRS}}$ symbols in the slot that can be used for SL PRS for a shared SL PRS resource pool as described in clause 8.2.4.1.1 in [6, TS38.214]
- the number of symbols $L_{\text{SL-PRS}}$ is provided by the higher-layer parameter *mNumberOfSymbols* and limited to combinations $\left\{L_{\text{SL-PRS}}, K_{\text{comb}}^{\text{SL-PRS}}\right\}$ fulfilling
  - in a dedicated SL PRS resource pool: $\{1, 2\}$, $\{2, 2\}$, $\{2, 4\}$, $\{4, 4\}$, $\{6, 6\}$, and combinations with $K_{\text{comb}}^{\text{SL-PRS}} \in \{2, 4, 6\}$ and $L_{\text{SL-PRS}} \in \{3, 4, \ldots, 9\}$ where $L_{\text{SL-PRS}} > K_{\text{comb}}^{\text{SL-PRS}}$
  - in a shared SL PRS resource pool:$\{1, 1\}$, $\{1, 2\}$, $\{2, 1\}$, $\{2, 2\}$, $\{2, 4\}$, $\{4, 1\}$, $\{4, 2\}$, $\{4, 4\}$
- the antenna port $p = 6000$

The reference point for k is subcarrier 0 in common resource block 0.

For transmission of an SL PRS in a dedicated SL PRS resource pool, the content of the OFDM symbol immediately preceding the SL PRS resource shall be generated based on 8.4.1.6.2 and mapped to resource elements with

- the time-domain index $l = l_{\text{start}}^{\text{SL-PRS}} - 1$
- the set of frequency-domain indices k shall be identical to those of the last OFDM symbol in the SL PRS resource
- the amplitude scaling factor shall be same as the amplitude scaling factor $\beta_{\text{SL-PRS}}$ of the SL PRS resource.

Table 8.4.1.6.3-1: The frequency offset k' as a function of $l - l_{\text{start}}^{\text{SL-PRS}}$.

$K_{\text{comb}}^{\text{SL-PRS}}$	Symbol number within the sidelink PRS resource $l - l_{\text{start}}^{\text{SL-PRS}}$								
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	0	0	0	0	0	0	0	0	0
2	0	1	0	1	0	1	0	1	0
4	0	2	1	3	0	2	1	3	0
6	0	3	1	4	2	5	0	3	1

8.4.2 Synchronization signals

8.4.2.1 Physical-layer sidelink synchronization identities

There are 672 unique physical-layer sidelink synchronization identities given by

$$N_{\text{ID}}^{\text{SL}} = N_{\text{ID},1}^{\text{SL}} + 336 N_{\text{ID},2}^{\text{SL}}$$

where $N_{\text{ID},1}^{\text{SL}} \in \{0,1,\dots,335\}$ and $N_{\text{ID},2}^{\text{SL}} \in \{0,1\}$. The sidelink synchronization identities are divided into two sets, id_net consisting of $N_{\text{ID}}^{\text{SL}} = 0,1,\dots,335$ and id_oon consisting of $N_{\text{ID}}^{\text{SL}} = 336,337,\dots,671$.

8.4.2.2 Sidelink primary synchronization signal

8.4.2.2.1 Sequence generation

The sequence $d_{\text{S-PSS}}(n)$ for the sidelink primary synchronization signal is defined by

$$\begin{aligned} d_{\text{S-PSS}}(n) &= 1 - 2x(m) \\ m &= \left(n + 22 + 43N_{ID,2}^{\text{SL}}\right) \bmod 127 \\ 0 &\le n < 127 \end{aligned}$$

where

$$x(i+7) = \left(x(i+4) + x(i)\right) \bmod 2$$

and

$$[x(6) \quad x(5) \quad x(4) \quad x(3) \quad x(2) \quad x(1) \quad x(0)] = [1 \quad 1 \quad 1 \quad 0 \quad 1 \quad 1 \quad 0]$$

8.4.2.2.2 Mapping to physical resources

Mapping to physical resources is described in clause 8.4.3.

8.4.2.3 Sidelink secondary synchronization signal

8.4.2.3.1 Sequence generation

The sequence $d_{\text{S-SSS}}(n)$ for the sidelink secondary synchronization signal is defined by

$$\begin{aligned} d_{\text{S-SSS}}(n) &= \left[1 - 2x_0\left((n + m_0) \bmod 127\right)\right]\left[1 - 2x_1\left((n + m_1) \bmod 127\right)\right] \\ m_0 &= 15\left\lfloor \frac{N_{\text{ID},1}^{\text{SL}}}{112} \right\rfloor + 5N_{\text{ID},2}^{\text{SL}} \\ m_1 &= N_{\text{ID},1}^{\text{SL}} \bmod 112 \\ 0 &\le n < 127 \end{aligned}$$

where

$$\begin{aligned} x_0(i+7) &= \left(x_0(i+4) + x_0(i)\right) \bmod 2 \\ x_1(i+7) &= \left(x_1(i+1) + x_1(i)\right) \bmod 2 \end{aligned}$$

and

$$\begin{aligned} [x_0(6) \quad x_0(5) \quad x_0(4) \quad x_0(3) \quad x_0(2) \quad x_0(1) \quad x_0(0)] &= [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1] \\ [x_1(6) \quad x_1(5) \quad x_1(4) \quad x_1(3) \quad x_1(2) \quad x_1(1) \quad x_1(0)] &= [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1] \end{aligned}$$

8.4.2.3.2 Mapping to physical resources

Mapping to physical resources is described in clause 8.4.3.

8.4.3 S-SS/PSBCH block

8.4.3.1 Time-frequency structure of an S-SS/PSBCH block

In the time domain, an S-SS/PSBCH block consists of $N_{\text{symb}}^{\text{S-SSB}}$ OFDM symbols, numbered in increasing order from 0 to $N_{\text{symb}}^{\text{S-SSB}} - 1$ within the S-SS/PSBCH block, where S-PSS, S-SSS, and PSBCH with associated DM-RS are mapped to symbols as given by Table 8.4.3.1-1. The number of OFDM symbols in an S-SS/PSBCH block $N_{\text{symb}}^{\text{S-SSB}} = 13$ for normal cyclic prefix and $N_{\text{symb}}^{\text{S-SSB}} = 11$ for extended cyclic prefix. The first OFDM symbol in an S-SS/PSBCH block is the first OFDM symbol in the slot.

In the frequency domain, an S-SS/PSBCH block consists of 132 contiguous subcarriers with the subcarriers numbered in increasing order from 0 to 131 within the sidelink S-SS/PSBCH block. The quantities k and l represent the frequency and time indices, respectively, within one sidelink S-SS/PSBCH block.

For an S-SS/PSBCH block, the UE shall use

- antenna port 4000 for transmission of S-PSS, S-SSS, PSBCH and DM-RS for PSBCH;
- the same cyclic prefix length and subcarrier spacing for the S-PSS, S-SSS, PSBCH and DM-RS for PSBCH,

Table 8.4.3.1-1: Resources within an S-SS/PSBCH block for S-PSS, S-SSS, PSBCH, and DM-RS.

Channel or signal	OFDM symbol number l relative to the start of an S-SS/PSBCH block	Subcarrier number k relative to the start of an S-SS/PSBCH block
S-PSS	1, 2	2, 3, …, 127, 128
S-SSS	3, 4	2, 3, …, 127, 128
Set to zero	1, 2, 3, 4	0, 1, 129, 130, 131
PSBCH	0, 5, 6, …, $N_{\text{symb}}^{\text{S-SSB}} - 1$	0, 1,…, 131
DM-RS for PSBCH	0, 5, 6, …, $N_{\text{symb}}^{\text{S-SSB}} - 1$	0, 4, 8, …., 128

8.4.3.1.1 Mapping of S-PSS within an S-SS/PSBCH block

The sequence of symbols $d_{\text{S-PSS}}(0), \dots, d_{\text{S-PSS}}(126)$ constituting the sidelink primary synchronization signal in one OFDM symbol shall be scaled by a factor $\beta_{\text{S-PSS}}$ to conform to the S-PSS power allocation specified in [5, TS 38.213] and mapped to resource elements $(k, l)_{p,\mu}$ in increasing order of k in each of the symbols l, where k and l are given by Table 8.4.3.1-1 and represent the frequency and time indices, respectively, within one S-SS/PSBCH block.

8.4.3.1.2 Mapping of S-SSS within an S-SS/PSBCH block

The sequence of symbols $d_{\text{S-SSS}}(0), \dots, d_{\text{S-SSS}}(126)$ constituting the sidelink secondary synchronization signal in one OFDM symbol shall be scaled by a factor $\beta_{\text{S-SSS}}$ to conform to the S-SSS power allocation specified in [5, TS 38.213] and mapped to resource elements $(k, l)_{p,\mu}$ in increasing order of k in each of the symbols l, where k and l are given by Table 8.4.3.1-1 and represent the frequency and time indices, respectively, within one S-SS/PSBCH block.

8.4.3.1.3 Mapping of PSBCH and DM-RS within an S-SS/PSBCH block

The sequence of complex-valued symbols $d_{\text{PSBCH}}(0), \dots, d_{\text{PSBCH}}(M_{\text{symb}} - 1)$ constituting the physical sidelink broadcast channel shall be scaled by a factor $\beta_{\text{DMRS}}^{\text{PSBCH}}$ to conform to the PSBCH power allocation specified in [5, TS 38.213] and mapped in sequence starting with $d_{\text{PSBCH}}(0)$ to resource elements $(k, l)_{p,\mu}$ which meet all the following criteria:

- they are not used for PSBCH demodulation reference signals

The mapping to resource elements $(k, l)_{p,\mu}$ not reserved for PSBCH DM-RS shall be in increasing order of first the index k and then the index l, where k and l represent the frequency and time indices, respectively, within one S-SS/PSBCH block and are given by Table 8.4.3.1-1.

The sequence of complex-valued symbols $r(0), \dots, r\left(33\left(N_{\text{symb}}^{\text{S-SSB}} - 4\right) - 1\right)$ constituting the demodulation reference signals for the S-SS/PSBCH block shall be scaled by a factor of $\beta_{\text{DMRS}}^{\text{PSBCH}}$ to conform to the PSBCH power allocation specified in [5, TS 38.213] and mapped to resource elements $(k, l)_{p,\mu}$ in increasing order of first k and then l where k and l are given by Table 8.4.3.1-1 and represent the frequency and time indices, respectively, within one S-SS/PSBCH block.

8.4.3.2 Time location of an S-SS/PSBCH block

The locations in the time domain where a UE shall monitor for a possible S-SS/PSBCH block are described in clause 16.1 of [5, TS 38.213].

8.5 Timing

Transmission of a sidelink radio frame number i from the UE shall start $(N_{\mathrm{TA,SL}} + N_{\mathrm{TA,offset}}) \cdot T_{\mathrm{c}}$ seconds before the start of the corresponding timing reference frame at the UE. The UE is not required to receive sidelink or downlink transmissions earlier than the value of $N_{\mathrm{TA,offset}}$, which is given in [12, TS 38.133], after the end of a sidelink transmission.

For sidelink transmissions:

If the UE has a serving cell fulfilling the S criterion according to clause 8.2 of [13, TS 38.304]

- The timing of reference radio frame i equals that of downlink radio frame i in the cell with the same uplink carrier frequency as the sidelink and
- $N_{\mathrm{TA,offset}}$ is given by clause 4.3.1 of [TS 38.211],

Otherwise

- The timing of reference radio frame i and $N_{\mathrm{TA,offset}}$ value are given by clause 12.2.2, 12.2.3, 12.2.4 or 12.2.5 of [12, TS 38.133].

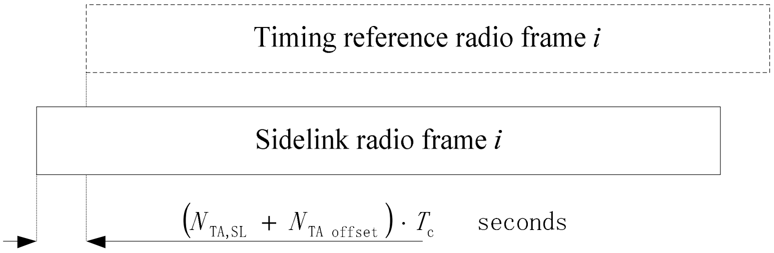

Figure 8.5-1: Sidelink timing relation

The quantity $N_{\mathrm{TA,SL}}$ equals to 0.

Annex A:
Change history

Change history

Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2017-04	RAN1#89	R1-1708219				Draft skeleton	0.0.0
2017-05	AH_1706	R1-1711366				Inclusion of agreements up to and including RAN1#89	0.0.1
2017-06	AH_1706	R1-1711886				Updated editor's version	0.0.2
2017-06	AH_1706	R1-1712004				Clean version further to RAN1's endorsement	0.1.0
2017-07	AH_1706	R1-1712011				Inclusion of agreements up to and including RAN1 NR AdHoc #2	0.1.1
2017-08	AH_1706	R1-1712950				Updated editor's version	0.1.2
2017-08	RAN1#90	R1-1713296				Updated editor's version	0.1.3
2017-08	RAN1#90	R1-1714656				Endorsed by RAN1#90	0.2.0
2017-08	RAN1#90	R1-1715321				Inclusion of agreements from RAN1#90	0.2.1
2017-09	RAN1#90	R1-1715329				Updated editor's version	0.2.2
2017-09	RAN#77	RP-171994				For information to plenary	1.0.0
2017-09	AH_1709	R1-1716927				Inclusion of agreements from AdHoc#3	1.0.1
2017-09	AH_1709	R1-1718318				Updated editor's version	1.0.2
2017-10	RAN1#90b	R1-1719105				Endorsed by RAN1#90bis	1.1.0
2017-10	RAN1#90b	R1-1719224				Inclusion of agreements from RAN1#90bis	1.1.1
2017-11	RAN1#90b	R1-1719685				Updated editor's version	1.1.2
2017-11	RAN1#90b	R1-1720850				Updated editor's version	1.1.3
2017-11	RAN1#90b	R1-1721048				Endorsed by RAN1#90bis	1.2.0
2017-12	RAN1#91	R1-17xxxxx				Inclusion of agreements from RAN1#91	1.2.1
2017-12	RAN1#91	R1-1721341				Endorsed by RAN1#91	1.3.0
2017-12	RAN#78	RP-172284				For approval by plenary	2.0.0
2017-12	RAN#78					Approved by plenary – Rel-15 spec under change control	15.0.0
2018-03	RAN#79	RP-180200	0001	-	F	CR capturing the Jan18 ad-hoc and RAN1#92 meeting agreements	15.1.0
2018-06	RAN#80	RP-181172	0002	1	F	CR to 38.211 capturing the RAN1#92bis and RAN1#93 meeting agreements	15.2.0
2018-09	RAN#81	RP-181789	0003	-	F	Corrections according to agreements from RAN1#94	15.3.0
2018-12	RAN#82	RP-182523	0004	1	F	Combined CR of all essential corrections to 38.211 from RAN1#94bis and RAN1#95	15.4.0
2019-03	RAN#83	RP-190447	0005	-	F	CR for PUCCH Format 1	15.5.0
2019-03	RAN#83	RP-190447	0006	-	F	CR on PDSCH mapping to virtual resource blocks	15.5.0
2019-03	RAN#83	RP-190447	0007	2	F	Alignment of terminology across specifications	15.5.0
2019-03	RAN#83	RP-190447	0008	-	F	Correction on physical resource mapping for PUSCH with configured grant	15.5.0
2019-03	RAN#83	RP-190773	0009	1	F	Correction to frequency-domain starting position for SRS resource mapping	15.5.0
2019-06	RAN#84	RP-191281	0010	-	F	CR on PUCCH format 1	15.6.0
2019-06	RAN#84	RP-191281	0011	-	F	Correction on reference name of UE capability of additional DMRS for co-existence with LTE CRS	15.6.0
2019-06	RAN#84	RP-191281	0012	-	F	Correction on mapping from virtual to physical resource blocks	15.6.0
2019-06	RAN#84	RP-191281	0014	2	F	Corrections to 38.211 including alignment of terminology across specifications	15.6.0
2019-06	RAN#84	RP-191281	0015	-	F	Clarification regarding non-full-duplex UE communication	15.6.0
2019-06	RAN#84	RP-191281	0016	-	F	Corrections on PUSCH scheduled by RAR UL grant and Msg3 PUSCH retransmission	15.6.0
2019-09	RAN#85	RP-191940	0017	-	F	Correction on PUSCH scrambling	15.7.0
2019-09	RAN#85	RP-191940	0018	-	F	Correction on PDSCH resource allocation scheduled by PDCCH in Type 0 common search space	15.7.0
2019-09	RAN#85	RP-191940	0019	-	F	Corrections to 38.211 including alignment of terminology across specifications in RAN1#98	15.7.0
2019-12	RAN#86	RP-192624	0022	-	F	Corrections to 38.211 including alignment of terminology across specifications in RAN1#98bis and RAN1#99	15.8.0
2019-12	RAN#86	RP-192634	0020	1	B	Introduction of remote interference management	16.0.0
2019-12	RAN#86	RP-192635	0023	-	B	Introduction of two-step RACH	16.0.0
2019-12	RAN#86	RP-192636	0024	-	B	Introduction of NR-based access to unlicensed spectrum	16.0.0
2019-12	RAN#86	RP-192637	0025	-	B	Introduction of integrated access and backhaul for NR	16.0.0
2019-12	RAN#86	RP-192638	0026	-	B	Introduction of V2X	16.0.0
2019-12	RAN#86	RP-192639	0027	-	B	Introduction of eURLLC support	16.0.0
2019-12	RAN#86	RP-192641	0028	-	B	Introduction of MIMO enhancements	16.0.0
2019-12	RAN#86	RP-192643	0029	-	B	Introduction of NR positioning support	16.0.0
2019-12	RAN#86	RP-192646	0030	-	B	Introduction of enhanced support for dynamic spectrum sharing	16.0.0

2019-12	RAN#86	RP-192646	0031	-	B	Introduction of additional RACH configurations for TDD FR1	16.0.0
2019-12	RAN#86	RP-192645	0032	-	B	Introduction of cross-carrier scheduling with different numerologies	16.0.0
2020-03	RAN#87-e	RP-200186	0033	-	F	Corrections to integrated access and backhaul for NR	16.1.0
2020-03	RAN#87-e	RP-200192	0034	-	F	Corrections to NR positioning support	16.1.0
2020-03	RAN#87-e	RP-200184	0035	-	F	Corrections to two-step RACH	16.1.0
2020-03	RAN#87-e	RP-200194	0036	-	F	Corrections to cross-carrier scheduling with different numerologies	16.1.0
2020-03	RAN#87-e	RP-200185	0037	-	F	Corrections to NR-based access to unlicensed spectrum	16.1.0
2020-03	RAN#87-e	RP-200187	0038	-	F	Corrections to V2X	16.1.0
2020-03	RAN#87-e	RP-200190	0039	-	F	Corrections to MIMO enhancements	16.1.0
2020-06	RAN#88-e	RP-200687	0040	1	F	Corrections to NR-based access to unlicensed spectrum	16.2.0
2020-06	RAN#88-e	RP-200694	0041	1	F	Corrections to NR positioning support	16.2.0
2020-06	RAN#88-e	RP-200692	0042	1	F	Corrections to MIMO enhancements	16.2.0
2020-06	RAN#88-e	RP-200686	0043	1	F	Corrections to two-step RACH	16.2.0
2020-06	RAN#88-e	RP-200696	0044	1	F	Corrections to carrier aggregation with unaligned frame boundaries	16.2.0
2020-06	RAN#88-e	RP-200689	0045	1	F	Corrections to V2X	16.2.0
2020-06	RAN#88-e	RP-200688	0046	1	F	Corrections to integrated access and backhaul for NR	16.2.0
2020-09	RAN#89-e	RP-201804	0047	-	F	CR on 2-step RACH for 38.211	16.3.0
2020-09	RAN#89-e	RP-201812	0048	-	F	CR on correction half duplex operation during DAPS HO	16.3.0
2020-09	RAN#89-e	RP-201807	0049	-	F	Corrections to V2X	16.3.0
2020-09	RAN#89-e	RP-201809	0050	-	F	Corrections to MIMO enhancements	16.3.0
2020-09	RAN#89-e	RP-201811	0051	-	F	Corrections to NR positioning support	16.3.0
2020-09	RAN#89-e	RP-201805	0052	-	F	Corrections to NR-based access to unlicensed spectrum	16.3.0
2020-12	RAN#90-e	RP-202380	0053	-	F	CR on the determination of DMRS sequences in 38.211	16.4.0
2020-12	RAN#90-e	RP-202383	0054	-	F	Correction on sidelink timing definition	16.4.0
2020-12	RAN#90-e	RP-202381	0055	-	F	Correction to UE assumption on RB set configuration for PRACH	16.4.0
2020-12	RAN#90-e	RP-202381	0057	-	F	CR to 38.211 on NR-U PRACH RO configuration	16.4.0
2020-12	RAN#90-e	RP-202383	0058	-	F	Corrections on sidelink for PHY layer structure	16.4.0
2020-12	RAN#90-e	RP-202383	0059	-	F	Correction on SL PT-RS sequence generation	16.4.0
2020-12	RAN#90-e	RP-202383	0060	-	F	Correction on PSFCH mapping	16.4.0
2020-12	RAN#90-e	RP-202387	0062	-	F	Corrections to 38.211 for NR positioning	16.4.0
2020-12	RAN#90-e	RP-202381	0063	-	F	CR to 38.211 to correct CP extension for SRS	16.4.0
2020-12	RAN#90-e	RP-202398	0064	-	F	Alignment CR for TS 38.211	16.4.0
2021-03	RAN#91-e	RP-210049	0065	-	F	Correction on DM-RS presence with PDSCH mapping type B	16.5.0
2021-03	RAN#91-e	RP-210049	0066	-	F	Correction on usage of subCarrierSpacingCommon for unlicensed	16.5.0
2021-03	RAN#91-e	RP-210050	0067	-	F	Clarification on Sidelink SSID	16.5.0

2021-03	RAN#91-e	RP-210059	0068	-	F	Alignment of notation	16.5.0
2021-06	RAN#92-e	RP-211248	0069	-	F	Correction on RIM RS resource and set ID mapping	16.6.0
2021-06	RAN#92-e	RP-211236	0070	-	F	Correction on channel inference assumption for PUSCH repetition Type B	16.6.0
2021-06	RAN#92-e	RP-211243	0071	1	F	Alignment of notation	16.6.0
2021-06	RAN#92-e	RP-211235	0072	-	F	Correction on OFDM signal generation and PSSCH DM-RS time-domain OCC in TS 38.211	16.6.0
2021-06	RAN#92-e	RP-211233	0074	-	A	Correction on channel properties assumption of UL transmission	16.6.0
2021-09	RAN#93-e	RP-211850	0076	-	F	Alignment of notation	16.7.0
2021-12	RAN#94-e	RP-212958	0078	-	A	Correction to CCE-to-REG mapping and CSI-RS mapping	16.8.0
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History

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