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# Foreword

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# 1 Scope

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

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# 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"

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# 3 Definitions, symbols and abbreviations

## 3.1 Definitions

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 $\mu$ ; see clause 4.4.3
$a_{k,l}^{(p,\mu)}$	Value of resource element $(k,l)$ for antenna port $p$ and subcarrier spacing configuration $\mu$ ; see clause 4.4.3
$\beta$	Amplitude scaling for a physical channel/signal
$c(n)$	PN sequence; see clause 5.2.1
$\Delta f$	Subcarrier spacing

$\Delta f_{\text{RA}}$	Subcarrier spacing for random-access preambles
$\kappa$	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
$\mu$	Subcarrier spacing configuration, $\Delta f = 2^\mu \cdot 15$ [kHz]
$M_{\text{bit}}^{(q)}$	Number of coded bits to transmit on a physical channel [for codeword $q$ ]
$M_{\text{symb}}^{(q)}$	Number of modulation symbols to transmit on a physical channel [for codeword $q$ ]
$M_{\text{symb}}^{\text{layer}}$	Number of modulation symbols to transmit per layer for a physical channel
$M_{\text{sc}}^{\text{PUSCH}}$	Scheduled bandwidth for uplink transmission, expressed as a number of subcarriers
$M_{\text{RB}}^{\text{PUSCH}}$	Scheduled bandwidth for uplink transmission, expressed as a number of resource blocks
$M_{\text{symb}}^{\text{ap}}$	Number of modulation symbols to transmit per antenna port for a physical channel
$\nu$	Number of transmission layers
$N_{\text{BWP},i}^{\text{size}}$	Size of bandwidth part $i$ ; see clause 4.4.4.4
$N_{\text{BWP},i}^{\text{start}}$	Start of bandwidth part $i$ ; see clause 4.4.4.4
$N_{\text{CP},i}^\mu$	Cyclic prefix length; see clause 5.3.1
$N_{\text{grid},x}^{\text{size},\mu}$	The size of the resource grid; see clauses 4.4.2 and 5.3
$N_{\text{grid},x}^{\text{start},\mu}$	The start of the resource grid; see clause 4.4.2
$N_{\text{group}}^{\text{PT-RS}}$	The number of PT-RS groups; see clause 6.3.1.4
$N_{\text{ID}}^{\text{cell}}$	Physical layer cell identity; see clause 7.4.2.1
$N_{\text{ID}}^{\text{SL}}$	Physical-layer sidelink identity; see clause 8.4.2.1
$N_{\text{RB}}^{\text{CORESET}}$	Frequency-domain size of a control resource set; see clause 7.3.2.2
$N_{\text{REG}}^{\text{CORESET}}$	Number of resource-element groups in a CORESET; see clause 7.3.2.2
$N_{\text{samp}}^{\text{group}}$	Number of samples per PT-RS group; see clause 6.3.1.4
$N_{\text{sc}}^{\text{RB}}$	Number of subcarriers per resource block, see clause 4.4.4.1
$N_{\text{slot}}^{\text{subframe},\mu}$	Number of slots per subframe for subcarrier spacing configuration $\mu$ , see clause 4.3.2
$N_{\text{slot}}^{\text{frame},\mu}$	Number of slots per frame for subcarrier spacing configuration $\mu$ , see clause 4.3.2
$N_{\text{symb}}^{\text{CORESET}}$	Time duration of a control resource set; see clause 7.3.2.2
$N_{\text{symb}}^{\text{PUCCH}}$	Length of the PUCCH transmission in OFDM symbols; see clause 6.3.2.1
$N_{\text{symb}}^{\text{subframe},\mu}$	Number of OFDM symbols per subframe for subcarrier spacing configuration $\mu$ ; see clause 4.3.1
$N_{\text{symb}}^{\text{slot}}$	Number of symbols per slot
$N_{\text{TA}}$	Timing advance between downlink and uplink; see clause 4.3.1
$N_{\text{TA,offset}}^{\text{common}}$	A fixed offset used to calculate the timing advance; see clause 4.3.1
$N_{\text{TA,adj}}^{\text{UE}}$	Network-controlled timing correction; see clause 4.3.1
$N_{\text{TA,adj}}^{\text{UE}}$	UE-derived timing correction; see clause 4.3.1
$N_{\text{Rx-Tx}}$	Minimum time from reception to transmission for a half-duplex UE; see clause 4.3.2
$n_f$	System frame number (SFN)
$n_{\text{CRB}}^\mu$	Common resource block number for subcarrier spacing configuration $\mu$ , see clause 4.4.4.3
$n_{\text{PRB}}$	Physical resource block number; see clause 4.4.4.4
$n_{\text{RNTI}}$	Radio network temporary identifier
$n_s^\mu$	Slot number within a subframe for subcarrier spacing configuration $\mu$ ; see clause 4.3.2
$n_{s,f}^\mu$	Slot number within a frame for subcarrier spacing configuration $\mu$ ; see clause 4.3.2
$p$	Antenna port number
$Q_m$	Modulation order
$\rho$	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 $\mu$ 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
$T_{\text{sf}}$	Subframe duration; see clause 4.3.1

$T_{\text{slot}}$	Slot duration; see clause 4.3.2
$T_{\text{TA}}$	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 [8, TS 38.104]
FR2	Frequency range 2 as defined in [8, TS 38.104]
IAB	Integrated access and backhaul
IAB-MT	IAB mobile termination
IE	Information element
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
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  $T_c = 1/(\Delta f_{\text{max}} \cdot N_f)$  where  $\Delta f_{\text{max}} = 480 \cdot 10^3$  Hz and  $N_f = 4096$ . The constant  $\kappa = T_s/T_c = 64$  where  $T_s = 1/(\Delta f_{\text{ref}} \cdot N_{f,\text{ref}})$ ,  $\Delta f_{\text{ref}} = 15 \cdot 10^3$  Hz and  $N_{f,\text{ref}} = 2048$ .

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.

### 4.2 Numerologies

Multiple OFDM numerologies are supported as given by Table 4.2-1 where  $\mu$  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.**

$\mu$	$\Delta f = 2^\mu \cdot 15$ [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

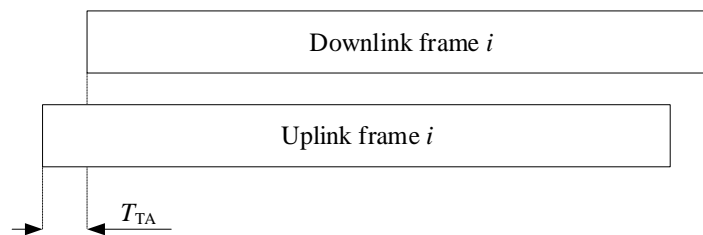
### 4.3.1 Frames and subframes

Downlink, uplink, and sidelink transmissions are organized into frames with  $T_f = (\Delta f_{\max} N_f / 100) \cdot T_c = 10$  ms duration, each consisting of ten subframes of  $T_{sf} = (\Delta f_{\max} N_f / 1000) \cdot T_c = 1$  ms duration. The number of consecutive OFDM symbols per subframe is  $N_{\text{sym}}^{\text{subframe},\mu} = N_{\text{slot}}^{\text{subframe},\mu}$ . 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  $T_{TA} = (N_{TA} + N_{TA,\text{offset}} + N_{TA,\text{adj}}^{\text{common}} + N_{TA,\text{adj}}^{\text{UE}}) T_c$  before the start of the corresponding downlink frame at the UE where

- $N_{TA}$  and  $N_{TA,\text{offset}}$  are given by clause 4.2 of [5, TS 38.213], except for msgA transmission on PUSCH where  $N_{TA} = 0$  shall be used;
- $N_{TA,\text{adj}}^{\text{common}}$  given by clause 4.2 of [5, TS 38.213] is derived from the higher-layer parameters  $TACommon$ ,  $TACommonDrift$ , and  $TACommonDriftVariation$  if configured, otherwise  $N_{TA,\text{adj}}^{\text{common}} = 0$ ;
- $N_{TA,\text{adj}}^{\text{UE}}$  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  $N_{TA,\text{adj}}^{\text{UE}} = 0$ .

**Figure 4.3.1-1: Uplink-downlink timing relation.**

### 4.3.2 Slots

For subcarrier spacing configuration  $\mu$ , slots are numbered  $n_s^\mu \in \{0, \dots, N_{\text{slot}}^{\text{subframe},\mu} - 1\}$  in increasing order within a subframe and  $n_{s,f}^\mu \in \{0, \dots, N_{\text{slot}}^{\text{frame},\mu} - 1\}$  in increasing order within a frame. There are  $N_{\text{sym}}^{\text{slot}}$  consecutive OFDM symbols in a slot where  $N_{\text{sym}}^{\text{slot}}$  depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2. The start of slot  $n_s^\mu$  in a subframe is aligned in time with the start of OFDM symbol  $n_s^\mu N_{\text{sym}}^{\text{slot}}$  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  $N_{\text{Rx-Tx}}T_c$  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  $N_{\text{Tx-Rx}}T_c$  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  $N_{\text{Rx-Tx}}T_c$  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  $N_{\text{Tx-Rx}}T_c$  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  $N_{\text{Rx-Tx}}T_c$  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  $N_{\text{Tx-Rx}}T_c$  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.**

$\mu$	$N_{\text{ymb}}^{\text{slot}}$	$N_{\text{slot}}^{\text{frame},\mu}$	$N_{\text{slot}}^{\text{subframe},\mu}$
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.**

$\mu$	$N_{\text{ymb}}^{\text{slot}}$	$N_{\text{slot}}^{\text{frame},\mu}$	$N_{\text{slot}}^{\text{subframe},\mu}$
2	12	40	4

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

Transition time	FR1	FR2
$N_{\text{Tx-Rx}}$	25600	13792
$N_{\text{Rx-Tx}}$	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  $N_{\text{grid},x}^{\text{size},\mu} N_{\text{sc}}^{\text{RB}}$  subcarriers and  $N_{\text{ymb}}^{\text{subframe},\mu}$  OFDM symbols is defined, starting at common resource block  $N_{\text{grid}}^{\text{start},\mu}$  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  $\mu$ , and transmission direction (downlink, uplink, or sidelink).

For uplink and downlink, the carrier bandwidth  $N_{\text{grid}}^{\text{size},\mu}$  for subcarrier spacing configuration  $\mu$  is given by the higher-layer parameter *carrierBandwidth* in the *SCS-SpecificCarrier* IE. The starting position  $N_{\text{grid}}^{\text{start},\mu}$  for subcarrier spacing configuration  $\mu$  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  $\mu$  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  $\mu$  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  $N_{\text{sc}}^{\text{RB}} = 12$  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 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  $\mu$ . The center of subcarrier 0 of common resource block 0 for subcarrier spacing configuration  $\mu$  coincides with 'point A'.

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

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

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

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

where  $N_{\text{BWP},i}^{\text{start},\mu}$  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  $\mu$  may be dropped.

#### 4.4.4.5 Virtual resource blocks

Virtual resource blocks are defined within a bandwidth part and numbered from 0 to  $N_{\text{BWP},i}^{\text{size}} - 1$  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  $n_{\text{IRB},m}^{\mu} \in \{0, 1, \dots\}$  in bandwidth part  $i$  and interlace  $m$  and the common resource block  $n_{\text{CRB}}^{\mu}$  is given by

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

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

$\mu$	$M$
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  $\mu_i$  in bandwidth part  $i$  on a given carrier. The starting position  $N_{\text{BWP},i}^{\text{start},\mu}$  and the number of resource blocks  $N_{\text{BWP},i}^{\text{size},\mu}$  in a bandwidth part shall fulfil  $N_{\text{grid},x}^{\text{start},\mu} \leq N_{\text{BWP},i}^{\text{start},\mu} < N_{\text{grid},x}^{\text{start},\mu} + N_{\text{BWP},i}^{\text{size},\mu}$  and  $N_{\text{grid},x}^{\text{start},\mu} < N_{\text{BWP},i}^{\text{start},\mu} + N_{\text{BWP},i}^{\text{size},\mu} \leq N_{\text{grid},x}^{\text{start},\mu} + N_{\text{grid},x}^{\text{size},\mu}$ , 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  $\mu$  may be dropped from  $N_{\text{BWP},i}^{\text{start},\mu}$ ,  $N_{\text{BWP},i}^{\text{size},\mu}$ ,  $N_{\text{grid},x}^{\text{start},\mu}$ , and  $N_{\text{grid},x}^{\text{size},\mu}$ .

#### 4.4.6 Common MBS frequency resource

A common MBS frequency resource is a contiguous subset of common resource blocks within a bandwidth part. The starting position  $N_{\text{MBS},i}^{\text{start},\mu}$  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  $N_{\text{MBS},i}^{\text{size},\mu}$ . Resource blocks in a common MBS frequency resource are numbered in the same way as resource blocks in clause 4.4.4.4 with  $N_{\text{BWP},i}^{\text{start},\mu}$  and  $N_{\text{BWP},i}^{\text{size},\mu}$  replaced by  $N_{\text{MBS},i}^{\text{start},\mu}$  and  $N_{\text{MBS},i}^{\text{size},\mu}$ , respectively.

A UE is not expected to receive PDSCH or PDCCH associated with MBS transmissions scheduled with G-RNTI, G-CS-RNTI or 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  $N_{\text{slot,offset}}^{\text{CA}}$  between a PCell/PSCell and an SCell is determined by higher-layer parameter *ca-SlotOffset* for the SCell. The quantity  $\mu_{\text{offset}}$  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  $N_{\text{slot,offset}}^{\text{CA}}$  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 subcarrier 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 $\pi/2$ -BPSK

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

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

#### 5.1.2 BPSK

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

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

#### 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

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

#### 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

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

#### 5.1.5 64QAM

In case of 64QAM modulation, hexuplets 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

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

## 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

$$d(i) = \frac{1}{\sqrt{170}} \left\{ (1-2b(8i)) \left[ 8 - (1-2b(8i+2)) \left[ 4 - (1-2b(8i+4)) \left[ 2 - (1-2b(8i+6)) \right] \right] \right] \right. \\ \left. + j(1-2b(8i+1)) \left[ 8 - (1-2b(8i+3)) \left[ 4 - (1-2b(8i+5)) \left[ 2 - (1-2b(8i+7)) \right] \right] \right] \right\}$$

## 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

$$d(i) = \\ \frac{1}{\sqrt{682}} (1-2b(10i+0)) \left[ 16 - (1-2b(10i+2)) \left[ 8 - (1-2b(10i+4)) \left[ 4 - (1-2b(10i+6)) \left[ 2 - (1-2b(10i+8)) \right] \right] \right] \right] \\ + j \frac{1}{\sqrt{682}} (1-2b(10i+1)) \left[ 16 - (1-2b(10i+3)) \left[ 8 - (1-2b(10i+5)) \left[ 4 - (1-2b(10i+7)) \left[ 2 - (1-2b(10i+9)) \right] \right] \right] \right]$$

## 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  $M_{\text{PN}}$ , where  $n = 0, 1, \dots, M_{\text{PN}} - 1$ , is defined by

$$c(n) = (x_1(n + N_C) + x_2(n + N_C)) \bmod 2 \\ x_1(n + 31) = (x_1(n + 3) + x_1(n)) \bmod 2 \\ x_2(n + 31) = (x_2(n + 3) + x_2(n + 2) + x_2(n + 1) + x_2(n)) \bmod 2$$

where  $N_C = 1600$  and the first m-sequence  $x_1(n)$  shall be initialized with  $x_1(0) = 1, x_1(n) = 0, n = 1, 2, \dots, 30$ . 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  $\alpha$  of a base sequence  $\bar{r}_{u,v}(n)$  according to

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

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  $\alpha$  and  $\delta$ .

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 each length  $M_{\text{ZC}} = mN_{\text{sc}}^{\text{RB}}/2^\delta$ ,  $1/2 \leq m/2^\delta \leq 5$  and two base sequences ( $v = 0, 1$ ) of each length  $M_{\text{ZC}} = mN_{\text{sc}}^{\text{RB}}/2^\delta$ ,  $6 \leq m/2^\delta$ . The definition of the base sequence  $\bar{r}_{u,v}(0), \dots, \bar{r}_{u,v}(M_{\text{ZC}} - 1)$  depends on the sequence length  $M_{\text{ZC}}$ .

### 5.2.2.1 Base sequences of length 36 or larger

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

$$\bar{r}_{u,v}(n) = x_q(n \bmod N_{\text{ZC}})$$

$$x_q(m) = e^{-j \frac{\pi q m(m+1)}{N_{\text{ZC}}}}$$

where

$$q = \lfloor \bar{q} + 1/2 \rfloor + v \cdot (-1)^{\lfloor 2\bar{q} \rfloor}$$

$$\bar{q} = N_{\text{ZC}} \cdot (u+1) / 31$$

The length  $N_{\text{ZC}}$  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

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

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  $\bar{r}_{u,v}(0), \dots, \bar{r}_{u,v}(M_{\text{ZC}} - 1)$  is given by

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

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

$u$	$\varphi(0), \dots, \varphi(5)$					
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  $M_{ZC} = 12$ .

$u$	$\varphi(0), \dots, \varphi(11)$											
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  $M_{ZC} = 18$**

$u$	$\varphi(0), \dots, \varphi(17)$																	
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  $M_{ZC} = 24$**

$u$	$\varphi(0), \dots, \varphi(23)$																							
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

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

where  $M = mN_{sc}^{RB}/2^\delta$  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  $M = mN_{sc}^{RB}/2^\delta$ ,  $1/2 \leq m/2^\delta$ . The sequence  $\bar{r}_{u,v}(0), \dots, \bar{r}_{u,v}(M - 1)$  is defined by

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

$$n = 0, \dots, M - 1$$

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  $M \geq 30$ , 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  $\varphi(i)$  for  $M = 6$ .**

$u$	$\varphi(0), \dots, \varphi(5)$					
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  $M = 12$ .

$u$	$b(0), \dots, b(11)$											
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  $M = 18$ .**

$u$	$b(0), \dots, b(17)$																	
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  $M = 24$

$u$	$b(0), \dots, b(23)$																							
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	1	0	0	1	0	0	1	0	0	1	1	1	1	1	0	1	1
3	0	0	0	0	0	0	0	1	1	0	1	1	0	0	1	0	1	0	1	1	0	1	1	1
4	1	0	0	1	1	1	1	0	1	1	0	1	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	1	0	0	1	0	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	1	0	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	0	0	1	0	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	0	0	1	0	0	1	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  $\mu$  for OFDM symbol  $l \in \{0, 1, \dots, N_{\text{slot}}^{\text{subframe}, \mu} N_{\text{ymb}}^{\text{slot}} - 1\}$  in a subframe for any physical channel or signal except PRACH is defined by

$$s_l^{(p,\mu)}(t) = \begin{cases} \bar{s}_l^{(p,\mu)}(t) & t_{\text{start},l}^\mu \leq t < t_{\text{start},l}^\mu + T_{\text{ymb},l}^\mu \\ 0 & \text{otherwise} \end{cases}$$

$$\bar{s}_l^{(p,\mu)}(t) = \sum_{k=0}^{N_{\text{grid},x}^{\text{size},\mu} N_{\text{sc}}^{\text{RB}} - 1} a_{k,l}^{(p,\mu)} e^{j2\pi \left( k + k_0^\mu - N_{\text{grid},x}^{\text{size},\mu} N_{\text{sc}}^{\text{RB}} / 2 \right) \Delta f \left( t - N_{\text{CP},l}^\mu T_c - t_{\text{start},l}^\mu \right)}$$

$$k_0^\mu = \left( N_{\text{grid},x}^{\text{start},\mu} + N_{\text{grid},x}^{\text{size},\mu} / 2 \right) N_{\text{sc}}^{\text{RB}} - \left( N_{\text{grid},x}^{\text{start},\mu_0} + N_{\text{grid},x}^{\text{size},\mu_0} / 2 \right) N_{\text{sc}}^{\text{RB}} 2^{\mu_0 - \mu}$$

$$T_{\text{ymb},l}^\mu = \left( N_u^\mu + N_{\text{CP},l}^\mu \right) T_c$$

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

$$N_u^\mu = 2048\kappa \cdot 2^{-\mu}$$

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

and

- $\Delta f$  is given by clause 4.2;
- $\mu$  is the subcarrier spacing configuration;
- $\mu_0$  is the largest  $\mu$  value among the subcarrier spacing configurations by *scs-SpecificCarrierList* for each of uplink and downlink and by *sl-SCS-SpecificCarrierList* for sidelink.

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

$$s_{\text{ext}}^{(p,\mu)}(t) = \bar{s}_l^{(p,\mu)}(t)$$

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

- for dynamically scheduled PUSCH, SRS, and PUCCH transmissions

$$T_{\text{ext}} = \min \left( \max(T'_{\text{ext}}, 0), T_{\text{symb},(l-1)\bmod 7 \cdot 2^{\mu}}^{\mu} \right)$$

$$T'_{\text{ext}} = \sum_{k=1}^{C_i} T_{\text{symb},(l-k)\bmod 7 \cdot 2^{\mu}}^{\mu} - \Delta_i$$

where  $\Delta_i$  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  $T_{\text{TA}}$  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  $T_{\text{ext}} < T_{\text{symb},(l-1)\bmod 7 \cdot 2^{\mu}}^{\mu}$  for each of the values of  $i \in \{2,3\}$ .  $T_{\text{ext}}$  is applied to the first UL transmission scheduled by the scheduling DCI.

- for a PUSCH transmission using configured grant

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

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

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

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

**Table 5.3.1-1: The variables  $C_i$  and  $\Delta_i$  for cyclic prefix extension**

$T_{\text{ext}}$ index $i$	$C_i$	$\Delta_i$
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  $\Delta_i$  for cyclic prefix extension with configured grants.

index $i$	$\Delta_i$
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	$\sum_{k=1}^{2^\mu} T_{\text{symb},(l-k) \bmod 7 \cdot 2^\mu}^\mu$

### 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

$$s_l^{(p,\mu)}(t) = \sum_{k=0}^{L_{\text{RA}}-1} a_k^{(p,\text{RA})} e^{j2\pi(k+Kk_1+k)\Delta f_{\text{RA}}(t-N_{\text{CP},i}^{\text{RA}}T_c-t_{\text{start}}^{\text{RA}})}$$

$$K = \Delta f / \Delta f_{\text{RA}}$$

$$k_1 = k_0^\mu + \left( N_{\text{BWP},i}^{\text{start}} - N_{\text{grid}}^{\text{start},\mu} \right) N_{\text{sc}}^{\text{RB}} - N_{\text{grid}}^{\text{size},\mu} N_{\text{sc}}^{\text{RB}} / 2 + n_{\text{RA}}^{\text{start}} N_{\text{sc}}^{\text{RB}}$$

$$+ \begin{cases} n_{\text{RA}} N_{\text{RB}}^{\text{RA}} N_{\text{sc}}^{\text{RB}} & \text{if } L_{\text{RA}} \in \{139, 839\} \\ n_{\text{RA}} N_{\text{RB}}^{\text{RA}} N_{\text{sc}}^{\text{RB}} & \text{if } L_{\text{RA}} \in \{571, 1151\} \text{ in FR2-2} \\ \left( N_{\text{RB,UL},n_0+n_{\text{RA}}}^{\text{start},\mu} - N_{\text{RB,UL},n_0}^{\text{start},\mu} \right) N_{\text{sc}}^{\text{RB}} & \text{if } L_{\text{RA}} \in \{571, 1151\} \text{ in FR1} \end{cases}$$

$$k_0^\mu = \left( N_{\text{grid}}^{\text{start},\mu} + N_{\text{grid}}^{\text{size},\mu} / 2 \right) N_{\text{sc}}^{\text{RB}} - \left( N_{\text{grid}}^{\text{start},\mu_0} + N_{\text{grid}}^{\text{size},\mu_0} / 2 \right) N_{\text{sc}}^{\text{RB}} 2^{\mu_0 - \mu}$$

where  $t_{\text{start}}^{\text{RA}} \leq t < t_{\text{start}}^{\text{RA}} + (N_u + N_{\text{CP},i}^{\text{RA}}) T_c$  and

- $\bar{k}$  is given by clause 6.3.3;
- $\Delta f$  is the subcarrier spacing of the initial uplink bandwidth part during initial access. Otherwise,  $\Delta f$  is the subcarrier spacing of the active uplink bandwidth part;
- $\mu_0$  is the largest  $\mu$  value among the subcarrier spacing configurations by the higher-layer parameter *scs-SpecificCarrierList*;
- $N_{\text{BWP},i}^{\text{start}}$  is the lowest numbered resource block of the initial uplink bandwidth part and is derived by the higher-layer parameter *initialUplinkBWP* during initial access. Otherwise,  $N_{\text{BWP},i}^{\text{start}}$  is the lowest numbered resource block of the active uplink bandwidth part and is derived by the higher-layer parameter *BWP-Uplink*;
- $n_{\text{RA}}^{\text{start}}$  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  $n_{\text{RA}}^{\text{start}}$  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];
- $n_{\text{RA}}$  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;
- $N_{\text{RB}}^{\text{RA}}$  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.
- $N_{\text{RB,UL},n}^{\text{start},\mu}$  is the start CRB index of uplink RB set  $n$  corresponding to the quantity  $RB_{n,\text{UL}}^{\text{start},\mu}$ . 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  $n_{RA}^{start}$ . The UE may assume that  $n_{RA}^{start}$  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
- $N_{CP,l}^{RA} = N_{CP}^{RA} + n \cdot 16\kappa$  where
  - for  $\Delta f_{RA} \in \{1.25, 5\}$  kHz,  $n = 0$
  - for  $\Delta f_{RA} \in \{15, 30, 60, 120, 480, 960\}$  kHz,  $n$  is the number of times the interval  $[t_{start}^{RA}, t_{start}^{RA} + (N_u^{RA} + N_{CP}^{RA})T_c]$  overlaps with either time instance 0 or time instance  $(\Delta f_{max} N_f / 2000) \cdot T_c = 0.5$  ms in a subframe

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

$$t_{start}^{RA} = t_{start,l}^{\mu}$$

$$t_{start,l}^{\mu} = \begin{cases} 0 & l = 0 \\ t_{start,l-1}^{\mu} + (N_u^{\mu} + N_{CP,l-1}^{\mu}) \cdot T_c & \text{otherwise} \end{cases}$$

where

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

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

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  $N_t^{RA,slot} - 1$  within a RACH slot where  $N_t^{RA,slot}$  is given Tables 6.3.3.2-2 to 6.3.3.2-4 for  $L_{RA} \in \{139, 571, 1151\}$  and fixed to 1 for  $L_{RA} = 839$ ;
- $N_{dur}^{RA}$  is given by Tables 6.3.3.2-2 to 6.3.3.2-4;
- $n_{slot}^{RA}$  is given by
  - if  $\Delta f_{RA} \in \{1.25, 5, 15, 60\}$  kHz, then  $n_{slot}^{RA} = 0$
  - if  $\Delta f_{RA} \in \{30, 120\}$  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  $n_{slot}^{RA} = 1$ , otherwise  $n_{slot}^{RA} \in \{0, 1\}$
  - if  $\Delta f_{RA} \in \{480, 960\}$  kHz and
    - the "Number of PRACH slots within a 60 kHz slot" in Table 6.3.3.2-4 is equal to 1, then  $n_{slot}^{RA} = 7$  for  $\Delta f_{RA} = 480$  kHz and  $n_{slot}^{RA} = 15$  for  $\Delta f_{RA} = 960$  kHz, or
    - the "Number of PRACH slots within a 60 kHz slot" in Table 6.3.3.2-4 is equal to 2, then  $n_{slot}^{RA} \in \{3, 7\}$  for  $\Delta f_{RA} = 480$  kHz and  $n_{slot}^{RA} \in \{7, 15\}$  for  $\Delta f_{RA} = 960$  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

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

where

$$t_{\text{start},l_0}^{\text{RIM}} \leq t < t_{\text{start},l_0}^{\text{RIM}} + (N_u^{\text{RIM}} + N_{\text{CP}}^{\text{RIM}})T_c$$

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

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

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

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;
- $t_{\text{start},l_0}^{\text{RIM}} = t_{\text{start},l}^{\mu}$  is given by clause 5.3.1 with  $l = l_0$ ;
- $N_{\text{CP},l_0}^{\text{RIM}} = N_{\text{CP},l}^{\mu}$  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  $\mu$ , and OFDM symbol  $l$  in a subframe assumed to start at  $t=0$  is given by

- for PRACH

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

- for RIM-RS

$$\text{Re}\left\{s_l^{(p,\mu)}(t)e^{j2\pi f_0^{\text{RIM}}(t - t_{\text{start},l_0}^{\mu} - N_{\text{CP}}^{\text{RIM}}T_c)}\right\}$$

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

- for all other channels and signals

$$\text{Re}\left\{s_l^{(p,\mu)}(t) \cdot e^{j2\pi f_0(t - t_{\text{start},l}^{\mu} - N_{\text{CP},l}^{\mu}T_c)}\right\}$$



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.

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## 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

For the single codeword  $q=0$ , 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, shall be 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 the following pseudo code

Set  $i = 0$

while  $i < M_{\text{bit}}^{(q)}$

if  $b^{(q)}(i) = x$  // UCI placeholder bits

$\tilde{b}^{(q)}(i) = 1$

else

if  $b^{(q)}(i) = y$  // UCI placeholder bits

$\tilde{b}^{(q)}(i) = \tilde{b}^{(q)}(i-1)$

else

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

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

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

where

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

- $n_{\text{RAPID}}$  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  $n_{\text{RNTI}}$  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 the single codeword  $q=0$ , the block of scrambled bits  $\tilde{b}^{(q)}(0), \dots, \tilde{b}^{(q)}(M_{\text{bit}}^{(q)} - 1)$  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  $d^{(q)}(0), \dots, d^{(q)}(M_{\text{symb}}^{(q)} - 1)$ .

**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 $Q_m$
		$\pi/2$ -BPSK	1
QPSK	2	QPSK	2
16QAM	4	16QAM	4
64QAM	6	64QAM	6
256QAM	8	256QAM	8

### 6.3.1.3 Layer mapping

For the single codeword  $q=0$ , the complex-valued modulation symbols for the codeword to be transmitted shall be mapped onto up to four layers according to Table 7.3.1.3-1. Complex-valued modulation symbols  $d^{(q)}(0), \dots, d^{(q)}(M_{\text{symb}}^{(q)} - 1)$  for codeword  $q$  shall be mapped onto the layers  $x(i) = [x^{(0)}(i) \dots x^{(v-1)}(i)]^T$ ,  $i = 0, 1, \dots, M_{\text{symb}}^{\text{layer}} - 1$  where  $v$  is the number of layers and  $M_{\text{symb}}^{\text{layer}}$  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  $\lambda = 0, 1, \dots, v-1$ .

If transform precoding is enabled according to 6.1.3 of [6, TS38.214],  $v = 1$  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  $x^{(0)}(0), \dots, x^{(0)}(M_{\text{symb}}^{\text{layer}} - 1)$  for the single layer  $\lambda = 0$  shall be divided into  $M_{\text{symb}}^{\text{layer}}/M_{\text{sc}}^{\text{PUSCH}}$  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  $x^{(0)}(0), \dots, x^{(0)}(M_{\text{symb}}^{\text{layer}} - 1)$  shall be divided into sets, each set corresponding to one OFDM symbol, and where set  $l$  contains  $M_{\text{sc}}^{\text{PUSCH}} - \varepsilon_l N_{\text{samp}}^{\text{group}} N_{\text{group}}^{\text{PTRS}}$  symbols and is mapped to the complex-valued symbols  $\tilde{x}^{(0)}(lM_{\text{sc}}^{\text{PUSCH}} + i')$  corresponding to OFDM symbol  $l$  prior to transform precoding, with  $i' \in \{0, 1, \dots, M_{\text{sc}}^{\text{PUSCH}} - 1\}$  and  $i' \neq m$ . The index  $m$  of PT-RS samples in set  $l$ , the number of samples per PT-RS group  $N_{\text{samp}}^{\text{group}}$ , and the number of PT-RS groups  $N_{\text{group}}^{\text{PT-RS}}$  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

$$y^{(0)}(l \cdot M_{\text{sc}}^{\text{PUSCH}} + k) = \frac{1}{\sqrt{M_{\text{sc}}^{\text{PUSCH}}}} \sum_{i=0}^{M_{\text{sc}}^{\text{PUSCH}} - 1} \tilde{x}^{(0)}(l \cdot M_{\text{sc}}^{\text{PUSCH}} + i) e^{-j \frac{2\pi i k}{M_{\text{sc}}^{\text{PUSCH}}}}$$

$$k = 0, \dots, M_{\text{sc}}^{\text{PUSCH}} - 1$$

$$l = 0, \dots, M_{\text{symb}}^{\text{layer}} / M_{\text{sc}}^{\text{PUSCH}} - 1$$

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

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

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

### 6.3.1.5 Precoding

The block of vectors  $[y^{(0)}(i) \ \dots \ y^{(v-1)}(i)]^T$ ,  $i = 0, 1, \dots, M_{\text{symb}}^{\text{layer}} - 1$  shall be precoded according to

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

where  $i = 0, 1, \dots, M_{\text{symb}}^{\text{ap}} - 1$ ,  $M_{\text{symb}}^{\text{ap}} = M_{\text{symb}}^{\text{layer}}$ . The set of antenna ports  $\{p_0, \dots, p_{\rho-1}\}$  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  $W$  is given by  $W = 1$  for single-layer transmission on a single antenna port, otherwise by Tables 6.3.1.5-1 to 6.3.1.5-7 with the TPMI index 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	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ -1 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ j \\ 0 \end{bmatrix}$
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	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ 1 \\ j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ 1 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ -1 \\ -j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ -j \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ 1 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ j \\ -j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ -1 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ -j \\ j \end{bmatrix}$
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	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ -1 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ j \\ 0 \end{bmatrix}$
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	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ 1 \\ j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ 1 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ -1 \\ -j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ -j \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ 1 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ j \\ -j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ -1 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ -j \\ j \end{bmatrix}$
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	$\frac{1}{2} \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix}$
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	$\frac{1}{2} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$
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	$\frac{1}{2} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}} \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \end{bmatrix}$	$\frac{1}{2\sqrt{2}} \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ j & -j & 0 & 0 \\ 0 & 0 & j & -j \end{bmatrix}$
4	$\frac{1}{4} \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ j & j & -j & -j \\ j & -j & -j & j \end{bmatrix}$	-	-	-

### 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  $z^{(p)}(0), \dots, z^{(p)}(M_{\text{symb}}^{\text{ap}} - 1)$  shall be multiplied with the amplitude scaling factor  $\beta_{\text{PUSCH}}$  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  $\lfloor N_{\text{symb}}^{\text{PUCCH}}/2 \rfloor$  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	$\leq 2$
1	4 – 14	$\leq 2$
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  $\alpha$  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  $u = (f_{\text{gh}} + f_{\text{ss}}) \bmod 30$  and the sequence number  $v$  within the group depends on the higher-layer parameter *pucch-GroupHopping*:

- if *pucch-GroupHopping* equals 'neither'

$$\begin{aligned} f_{\text{gh}} &= 0 \\ f_{\text{ss}} &= n_{\text{ID}} \bmod 30 \\ v &= 0 \end{aligned}$$

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

- if *pucch-GroupHopping* equals 'enable'

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

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  $c_{\text{init}} = \lfloor n_{\text{ID}}/30 \rfloor$  where  $n_{\text{ID}}$  is given by the higher-layer parameter *hoppingId* if configured, otherwise  $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ .

- if *pucch-GroupHopping* equals 'disable'



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

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  $c_{\text{init}} = 2^5 \lfloor n_{\text{ID}}/30 \rfloor + (n_{\text{ID}} \bmod 30)$  where  $n_{\text{ID}}$  is given by the higher-layer parameter *hoppingId* if configured, otherwise  $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ .

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

### 6.3.2.2.2 Cyclic shift hopping

The cyclic shift  $\alpha$  varies as a function of the symbol and slot number according to

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

where

- $n_{\text{s,f}}^{\mu}$  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
- $m_{\text{cs}} = 0$  except for PUCCH format 0 when it depends on the information to be transmitted according to clause 9.2 of [5, TS 38.213].
- $m_{\text{int}}$  is given by
  - $m_{\text{int}} = 5n_{\text{RB}}^{\mu}$  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  $n_{\text{RB}}^{\mu}$  is the resource block number within the interlace;
  - $m_{\text{int}} = 0$  otherwise

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

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

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  $n_{\text{ID}}$  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

$$x(lM_{\text{RB}}^{\text{PUCCH},0} N_{\text{sc}}^{\text{RB}} + n) = r_{u,v}^{(\alpha,\delta)}(n)$$

$$n = 0, 1, \dots, M_{\text{RB}}^{\text{PUCCH},0} N_{\text{sc}}^{\text{RB}} - 1$$

$$l = \begin{cases} 0 & \text{for single-symbol PUCCH transmission} \\ 0, 1 & \text{for double-symbol PUCCH transmission} \end{cases}$$

where  $r_{u,v}^{(\alpha,\delta)}(n)$  is given by clause 6.3.2.2 with  $m_{\text{cs}}$  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

$$y(n) = d(0)r_{u,v}^{(\alpha,\delta)}(n)$$

$$n = 0, 1, \dots, M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} - 1$$

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

$$z(m' M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} N_{\text{SF},0}^{\text{PUCCH},1} + m M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} + n) = w_i(m)y(n)$$

$$n = 0, 1, \dots, M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} - 1$$

$$m = 0, 1, \dots, N_{\text{SF},m'}^{\text{PUCCH},1} - 1$$

$$m' = \begin{cases} 0 & \text{no intra-slot frequency hopping} \\ 0, 1 & \text{intra-slot frequency hopping} \end{cases}$$

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  $N_{SF,m'}^{PUCCH,1}$ .**

PUCCH length, $N_{\text{sym}}^{PUCCH,1}$	$N_{SF,m'}^{PUCCH,1}$		
	No intra-slot hopping $m' = 0$	Intra-slot hopping	
		$m' = 0$	$m' = 1$
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  $w_i(m) = e^{j2\pi\phi(m)/N_{SF,m'}^{PUCCH,1}}$  for PUCCH format 1.**

$N_{SF,m'}^{PUCCH,1}$	$\phi$						
	$i=0$	$i=1$	$i=2$	$i=3$	$i=4$	$i=5$	$i=6$
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  $\beta_{PUCCH,1}$  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  $b(0), \dots, b(M_{\text{bit}} - 1)$ , where  $M_{\text{bit}}$  is the number of bits transmitted on the physical channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits  $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$  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

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

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

### 6.3.2.5.2 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  $M_{\text{symb}} = M_{\text{bit}}/2$ .

#### 6.3.2.5.2A Spreading

Spreading shall be applied according to

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

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

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  $n_{\text{IRB}}$  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 +1]
1	[+1 -1]

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

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

### 6.3.2.5.3 Mapping to physical resources

The block of complex-valued symbols  $z(0), \dots, z(N_{SF}^{PUCCH,2} M_{\text{symb}} - 1)$  shall be multiplied with the amplitude scaling factor  $\beta_{PUCCH,2}$  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  $b(0), \dots, b(M_{\text{bit}} - 1)$ , where  $M_{\text{bit}}$  is the number of bits transmitted on the physical channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits  $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$  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

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

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

### 6.3.2.6.2 Modulation

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

### 6.3.2.6.3 Block-wise spreading

For both PUCCH format 3 and 4,  $M_{\text{sc}}^{\text{PUCCH},s} = M_{\text{RB}}^{\text{PUCCH},s} N_{\text{sc}}^{\text{RB}}$  with  $M_{\text{RB}}^{\text{PUCCH},s}$  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

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

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

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

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

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

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

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

where

- for PUCCH format 3 with interlaced mapping,  $N_{\text{SF}}^{\text{PUCCH},3} \in \{1, 2, 4\}$  if a single interlace is configured and  $N_{\text{SF}}^{\text{PUCCH},3} = 1$ ,  $w_n = 1$  if two interlaces are configured;
- for PUCCH format 4,  $M_{\text{RB}}^{\text{PUCCH},4}$  is given by clause 9.2.1 of [5, TS 38.213] and  $N_{\text{SF}}^{\text{PUCCH},4} \in \{2, 4\}$  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  $N_{\text{SF}}^{\text{PUCCH},s} > 1$  where  $n$  is the index of the orthogonal sequence to use according to clause 9.2.1 of [5, TS 38.213]. The quantity  $N_{\text{SF}}^{\text{PUCCH},3} \in \{2, 4\}$  is given by the higher-layer parameter *occ-Length* if provided, otherwise  $N_{\text{SF}}^{\text{PUCCH},3} = 1$ .

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

$n$	$w_n$
0	[+1 +1]
1	[+1 -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  $N_{SF}^{PUCCH,s} = 4$ .**

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

#### 6.3.2.6.4 Transform precoding

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

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

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

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

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

#### 6.3.2.6.5 Mapping to physical resources

The block of modulation symbols  $z(0), \dots, z(N_{SF}^{PUCCH,s} M_{\text{symb}} - 1)$  shall be multiplied with the amplitude scaling factor  $\beta_{PUCCH,s}$  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],  $\lfloor N_{\text{symb}}^{PUCCH,s} / 2 \rfloor$  OFDM symbols shall be transmitted in the first hop and  $N_{\text{symb}}^{PUCCH,s} - \lfloor N_{\text{symb}}^{PUCCH,s} / 2 \rfloor$  symbols in the second hop where  $N_{\text{symb}}^{PUCCH,s}$  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

$$x_{u,v}(n) = x_u((n + C_v) \bmod L_{RA})$$

$$x_u(i) = e^{-j \frac{\pi i(i+1)}{L_{RA}}}, i = 0, 1, \dots, L_{RA} - 1$$

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

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

where  $L_{RA} = 839$ ,  $L_{RA} = 139$ ,  $L_{RA} = 1151$ , or  $L_{RA} = 571$  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  $L_{RA} - 2$ . 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

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

$$w = n_{\text{shift}}^{\text{RA}} n_{\text{group}}^{\text{RA}} + \overline{\overline{n}}_{\text{shift}}^{\text{RA}}$$

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

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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





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

<i>i</i>	Sequence number <i>u</i> in increasing order of <i>i</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  $\Delta f_{RA} = 1.25$  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  $\Delta f_{RA} = 5$  kHz.**

<b>zeroCorrelationZoneConfig, msgA-ZeroCorrelationZoneConfig</b>	<b><math>N_{CS}</math> value</b>		
	<b>Unrestricted set</b>	<b>Restricted set type A</b>	<b>Restricted set type B</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  $L_{RA} \in \{139, 571, 1151\}$ .**

<b>zeroCorrelationZoneConfig, msgA-ZeroCorrelationZoneConfig</b>	<b><math>N_{CS}</math> value</b>		
	<b><math>L_{RA} = 139</math></b>	<b><math>L_{RA} = 571</math></b>	<b><math>L_{RA} = 1151</math></b>
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

$$a_k^{(p,RA)} = \beta_{PRACH} y_{u,v}(k)$$

$$k = 0, 1, \dots, L_{RA} - 1$$

where  $\beta_{PRACH}$  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  $n_f \bmod x = y$  of Tables 6.3.3.2-2 to 6.3.3.2-4 shall be replaced by  $x_{\text{IAB}}$ , where  $x_{\text{IAB}} = \delta x$  and  $\delta$  is given by the higher-layer parameter *prach-ConfigurationPeriodScaling-IAB* and the IAB-node does not expect  $x_{\text{IAB}}$  to be larger than 64;
- if the higher-layer parameter *prach-ConfigurationFrameOffset-IAB* is configured, the variable  $y$  used in  $n_f \bmod x = y$  of Tables 6.3.3.2-2 to 6.3.3.2-4 shall be replaced by  $y_{\text{IAB}} = (y + \Delta y) \bmod x$  where  $\Delta y$  is given by the higher-layer parameter *prach-ConfigurationFrameOffset-IAB*, and  $x$  is the value used in  $n_f \bmod x = y$ ;
- 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  $(s_n + \Delta s) \bmod L$  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  $n_{\text{RA}} \in \{0, 1, \dots, M - 1\}$ , 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,  $n_{\text{RA}}$  are numbered in increasing order within the active uplink bandwidth part, starting from the lowest frequency.

For operation with shared spectrum channel access, for  $L_{\text{RA}} = 139$ , 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  $L_{\text{RA}} = 571$  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  $L_{\text{max}} = 4$ , 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  $153600T_s$  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  $L_{\text{max}} = 8$ , 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  $76800T_s$ .

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

$L_{RA}$	$\Delta f_{RA}$ for PRACH	$\Delta f$ for PUSCH	$N_{RB}^{RA}$ , 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	$n_t \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$ , number of time-domain PRACH occasions within a PRACH slot	$N_{dur}^{RA}$ , 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	$n_t \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$ , number of time-domain PRACH occasions within a PRACH slot	$N_{dur}^{RA}$ , 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	$n_f \bmod x = y$		Slot number	Starting symbol	Number of PRACH slots within a 60 kHz slot	$N_t^{RA,slot}$ , number of time-domain PRACH occasions within a PRACH slot	$N_{dur}^{RA}$ , 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

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

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

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

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

- $N_{\text{ID}}^0, N_{\text{ID}}^1 \in \{0, 1, \dots, 65535\}$  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 or 0\_2, or by a PUSCH transmission with a configured grant;
- $N_{\text{ID}}^0 \in \{0, 1, \dots, 65535\}$  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;
- $N_{\text{ID}}^0, N_{\text{ID}}^1 \in \{0, 1, \dots, 65535\}$  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];
- $N_{\text{ID}}^{\bar{\lambda}} = N_{\text{ID}}^{\text{cell}}$  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  $\lambda$  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  $n_{\text{SCID}} \in \{0,1\}$  is

- indicated by the DM-RS initialization field, if present, either in the DCI associated with the PUSCH transmission if DCI format 0\_1 or 0\_2, 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  $n_{\text{SCID}} = 0$ .

#### 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

$$r(n) = r_{u,v}^{(\alpha,\delta)}(n)$$

$$n = 0, 1, \dots, M_{\text{sc}}^{\text{PUSCH}} / 2^\delta - 1$$

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

- if the higher-layer parameter *dmrs-UplinkTransformPrecoding* is configured,  $\pi/2$ -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  $c_{\text{init}}$  given by

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

where  $n_{\text{SCID}} = 0$  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 higher-layer parameter *antennaPort* for a PUSCH transmission scheduled by a type-1 configured grant; and

- $N_{\text{ID}}^0, N_{\text{ID}}^1 \in \{0,1, \dots, 65535\}$  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 a PUSCH transmission with a configured grant;
- $N_{\text{ID}}^0 \in \{0,1, \dots, 65535\}$  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;
- $N_{\text{ID}}^{\text{SCID}} = N_{\text{ID}}^{\text{cell}}$  otherwise;
- otherwise,  $r_{u,v}^{(\alpha,\delta)}(n)$  is given by clause 5.2.2 with  $\alpha = 0$ .

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

- $n_{\text{ID}}^{\text{RS}} = n_{\text{ID}}^{\text{PUSCH}}$  if  $n_{\text{ID}}^{\text{PUSCH}}$  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  $\pi/2$ -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];

- $n_{\text{ID}}^{\text{RS}} = N_{\text{ID}}^{\text{rSCID}}$  if the higher-layer parameter *dmrs-UplinkTransformPrecoding* is configured,  $\pi/2$ -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;
- $n_{\text{ID}}^{\text{RS}} = N_{\text{ID}}^{\text{cell}}$  otherwise

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

- if neither group, nor sequence hopping is enabled

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

- if group hopping is enabled and sequence hopping is disabled

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

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

- if sequence hopping is enabled and group hopping is disabled

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

where the pseudo-random sequence  $c(i)$  is defined by clause 5.2.1 and shall be initialized with  $c_{\text{init}} = n_{\text{ID}}^{\text{RS}}$  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,

$$\begin{aligned}\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)} &= w_f(k') w_t(l') r(2n+k') \\ k &= \begin{cases} 4n+2k'+\Delta & \text{Configuration type 1} \\ 6n+k'+\Delta & \text{Configuration type 2} \end{cases} \\ k' &= 0,1 \\ l &= \bar{l} + l' \\ n &= 0,1,\dots \\ j &= 0,1,\dots,\nu-1\end{aligned}$$

- if transform precoding is enabled

$$\begin{aligned}\tilde{a}_{k,l}^{(\tilde{p}_0,\mu)} &= w_f(k') w_t(l') r(2n+k') \\ k &= 4n+2k'+\Delta \\ k' &= 0,1 \\ l &= \bar{l} + l' \\ n &= 0,1,\dots\end{aligned}$$

where  $w_f(k')$ ,  $w_t(l')$ , and  $\Delta$  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  $\Delta$  correspond to  $\tilde{p}_0, \dots, \tilde{p}_{\nu-1}$ . The intermediate quantity  $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)} = 0$  if  $\Delta$  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  $\beta_{\text{PUSCH}}^{\text{DMRS}}$  in order to conform to the transmit power specified in [6, TS 38.214], and mapped to physical resources according to

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

where

- the precoding matrix  $W$  is given by clause 6.3.1.5,
- the set of antenna ports  $\{p_0, \dots, p_{\rho-1}\}$  is given by clause 6.3.1.5, and
- the set of antenna ports  $\{\tilde{p}_0, \dots, \tilde{p}_{\nu-1}\}$  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';
- $l_d = 4$  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.

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.

The time-domain index  $l'$  and the supported antenna ports  $\bar{p}_j$  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 $\lambda$	$\Delta$	$w_f(k')$		$w_t(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
0	0	0	+1	+1	+1	+1
1	0	0	+1	-1	+1	+1
2	1	1	+1	+1	+1	+1
3	1	1	+1	-1	+1	+1
4	0	0	+1	+1	+1	-1
5	0	0	+1	-1	+1	-1
6	1	1	+1	+1	+1	-1
7	1	1	+1	-1	+1	-1

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

$\tilde{p}$	CDM group $\lambda$	$\Delta$	$w_f(k')$		$w_t(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
0	0	0	+1	+1	+1	+1
1	0	0	+1	-1	+1	+1
2	1	2	+1	+1	+1	+1
3	1	2	+1	-1	+1	+1
4	2	4	+1	+1	+1	+1
5	2	4	+1	-1	+1	+1
6	0	0	+1	+1	+1	-1
7	0	0	+1	-1	+1	-1
8	1	2	+1	+1	+1	-1
9	1	2	+1	-1	+1	-1
10	2	4	+1	+1	+1	-1
11	2	4	+1	-1	+1	-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 <i>dmrs-AdditionalPosition</i>				PUSCH mapping type B <i>dmrs-AdditionalPosition</i>			
	<i>pos0</i>	<i>pos1</i>	<i>pos2</i>	<i>pos3</i>	<i>pos0</i>	<i>pos1</i>	<i>pos2</i>	<i>pos3</i>
<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 duration	$l'$	Supported antenna ports $\tilde{p}$	
		Configuration type 1	Configuration type 2
single-symbol DM-RS	0	0 – 3	0 – 5
double-symbol DM-RS	0, 1	0 – 7	0 – 11

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			
1 <sup>st</sup> hop	2 <sup>nd</sup> hop	1 <sup>st</sup> hop	2 <sup>nd</sup> hop	1 <sup>st</sup> hop	2 <sup>nd</sup> hop	1 <sup>st</sup> hop	2 <sup>nd</sup> hop	1 <sup>st</sup> hop	2 <sup>nd</sup> hop	1 <sup>st</sup> hop	2 <sup>nd</sup> hop		
≤3	-	-	-	-	-	-	-	-	-	0	0	0	0
4	2	0	2	0	3	0	3	0	0	0	0	0	0
5, 6	2	0	2	0, 4	3	0	3	0, 4	0	0	0, 4	0, 4	0, 4
7	2	0	2, 6	0, 4	3	0	3	0, 4	0	0	0, 4	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  $M_{\text{sc}}^{\text{PUSCH}}$  according to Table 6.4.1.2.2.2-1, shall be generated according to

$$r_m(m') = w(k') \frac{e^{j\frac{\pi}{2}(m \bmod 2)}}{\sqrt{2}} \left[ (1 - 2c(m')) + j(1 - 2c(m')) \right]$$

$$m' = N_{\text{samp}}^{\text{group}} s' + k'$$

$$s' = 0, 1, \dots, N_{\text{group}}^{\text{PT-RS}} - 1$$

$$k' = 0, 1, N_{\text{samp}}^{\text{group}} - 1$$

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

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

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

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

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

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

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

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  $\Delta$  correspond to  $\tilde{p}_0, \dots, \tilde{p}_{v-1}$

The quantities  $k'$  and  $\Delta$  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  $\beta_{\text{PTRS}}$  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  $l_{\text{ref}} = 0$
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 6.4.1.1.3
  - set  $i = 1$
  - set  $l_{\text{ref}}$  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

$$k = k_{\text{ref}}^{\text{RE}} + (iK_{\text{PT-RS}} + k_{\text{ref}}^{\text{RB}})N_{\text{sc}}^{\text{RB}}$$

$$k_{\text{ref}}^{\text{RB}} = \begin{cases} n_{\text{RNTI}} \bmod K_{\text{PT-RS}} & \text{if } N_{\text{RB}} \bmod K_{\text{PT-RS}} = 0 \\ n_{\text{RNTI}} \bmod (N_{\text{RB}} \bmod K_{\text{PT-RS}}) & \text{otherwise} \end{cases}$$

where

- $i = 0, 1, 2, \dots$
- $k_{\text{ref}}^{\text{RE}}$  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.
- $n_{\text{RNTI}}$  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
- $N_{\text{RB}}$  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 $\tilde{p}$	$k_{\text{ref}}^{\text{RE}}$							
	DM-RS Configuration type 1				DM-RS Configuration type 2			
	resourceElementOffset				resourceElementOffset			
	offset00	offset01	offset10	offset11	offset00	offset01	offset10	offset11
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

#### 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  $\beta'$  and mapped to  $N_{\text{samp}}^{\text{group}} N_{\text{group}}^{\text{PT-RS}}$  complex valued symbols in  $\tilde{x}^{(l)}(m)$  where

- $\tilde{x}^{(l)}(m)$  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
- $\beta'$  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  $\max(l_{\text{ref}} + (i - 1)L_{\text{PT-RS}} + 1, l_{\text{ref}}), \dots, l_{\text{ref}} + iL_{\text{PT-RS}}$  overlaps with a symbol used for DM-RS according to clause 6.4.1.1.3
  - set  $i = 1$
  - set  $l_{\text{ref}}$  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 6.4.1.2.2-1: 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	$s M_{\text{sc}}^{\text{PUSCH}} + k$ where $\begin{cases} s = 0 & \text{and } k = 0,1,2,3 \\ s = 1 & \text{and } k = -4, -3, -2, -1 \end{cases}$
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	$s M_{\text{sc}}^{\text{PUSCH}}/4 + n + k$ where $\begin{cases} s = 0 & \text{and } k = 0,1,2,3 & n = 0 \\ s = 1,2 & \text{and } k = -2, -1, 0, 1 & n = \lfloor M_{\text{sc}}^{\text{PUSCH}}/8 \rfloor \\ s = 4 & \text{and } k = -4, -3, -2, -1 & n = 0 \end{cases}$
8	4	$\lfloor s M_{\text{sc}}^{\text{PUSCH}}/8 \rfloor + n + k$ where $\begin{cases} s = 0 & \text{and } k = 0,1,2,3 & n = 0 \\ s = 1,2,3,4,5,6 & \text{and } k = -2, -1, 0, 1 & n = \lfloor M_{\text{sc}}^{\text{PUSCH}}/16 \rfloor \\ s = 8 & \text{and } k = -4, -3, -2, -1 & n = 0 \end{cases}$

### 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

$$z(m' N_{\text{SF},0}^{\text{PUCCH},1} M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} + m M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} + n) = w_i(m) r_{u,v}^{(\alpha,\delta)}(n)$$

$$n = 0, 1, \dots, M_{\text{RB}}^{\text{PUCCH},1} N_{\text{sc}}^{\text{RB}} - 1$$

$$m = 0, 1, \dots, N_{\text{SF},m'}^{\text{PUCCH},1} - 1$$

$$m' = \begin{cases} 0 & \text{no intra-slot frequency hopping} \\ 0, 1 & \text{intra-slot frequency hopping} \end{cases}$$

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  $N_{SF,m'}^{PUCCH,1}$ .

PUCCH length, $N_{\text{symb}}^{PUCCH,1}$	$N_{SF,m'}^{PUCCH,1}$		
	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  $\beta_{PUCCH,1}$  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

$$a_{k,l}^{(p,\mu)} = \beta_{PUCCH,1} z(m)$$

$$l = 0, 2, 4, \dots$$

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

$$z_l(mN_{SF}^{PUCCH,2} + i) = w_n(i)r_l(m)$$

$$r_l(m) = \frac{1}{\sqrt{2}}(1 - 2c(2m)) + j\frac{1}{\sqrt{2}}(1 - 2c(2m + 1))$$

$$i = 0, 1, \dots, N_{SF}^{PUCCH,2} - 1$$

$$m = 0, 1, \dots$$

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

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

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

The quantity  $N_{\text{ID}}^0 \in \{0, 1, \dots, 65535\}$  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

$$r_l(m) = r_{u,v}^{(\alpha,\delta)}(m)$$

$$m = 0, 1, \dots, M_{\text{sc}}^{\text{PUCCH},s} - 1$$

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  $c_{\text{init}}$  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  $\alpha$  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

$$a_{k,l}^{(p,\mu)} = \beta_{\text{PUCCH},s} \cdot r_l(m)$$

$$m = 0, 1, \dots, M_{\text{sc}}^{\text{PUCCH},s} - 1$$

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

- $N_{\text{ap}}^{\text{SRS}} \in \{1, 2, 4\}$  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* 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'
- $N_{\text{symb}}^{\text{SRS}} \in \{1, 2, 4, 8, 10, 12, 14\}$  consecutive OFDM symbols given by the field *nrofSymbols* contained in the higher layer parameter *resourceMapping*
- $l_0$ , the starting position in the time domain given by  $l_0 = N_{\text{symb}}^{\text{slot}} - 1 - l_{\text{offset}}$  where the offset  $l_{\text{offset}} \in \{0, 1, \dots, 13\}$  counts symbols backwards from the end of the slot and is given by the field *startPosition* contained in the higher layer parameter *resourceMapping* and  $l_{\text{offset}} \geq N_{\text{symb}}^{\text{SRS}} - 1$
- $k_0$ , 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 shall be generated according to

$$r^{(p_i)}(n, l') = r_{u,v}^{(\alpha_i, \delta)}(n)$$

$$0 \leq n \leq M_{\text{sc},b}^{\text{SRS}} - 1$$

$$l' \in \{0, 1, \dots, N_{\text{symb}}^{\text{SRS}} - 1\}$$

where  $M_{sc,b}^{SRS}$  is given by clause 6.4.1.4.3,  $r_{u,v}^{(\alpha,\delta)}(n)$  is given by clause 5.2.2 with  $\delta = \log_2(K_{TC})$  and the transmission comb number  $K_{TC} \in \{2,4,8\}$  is contained in the higher-layer parameter *transmissionComb*. The cyclic shift  $\alpha_i$  for antenna port  $p_i$  is given as

$$\alpha_i = 2\pi \frac{n_{SRS}^{cs,i}}{n_{SRS}^{cs,max}}$$

$$n_{SRS}^{cs,i} = \begin{cases} \left( n_{SRS}^{cs} + \frac{n_{SRS}^{cs,max} \lfloor (p_i - 1000) / 2 \rfloor}{N_{ap}^{SRS} / 2} \right) \bmod n_{SRS}^{cs,max} & \text{if } N_{ap}^{SRS} = 4 \text{ and } n_{SRS}^{cs,max} = 6 \\ \left( n_{SRS}^{cs} + \frac{n_{SRS}^{cs,max} (p_i - 1000)}{N_{ap}^{SRS}} \right) \bmod n_{SRS}^{cs,max} & \text{otherwise} \end{cases},$$

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

The sequence group  $u = (f_{gh}(n_{s,f}^\mu, l') + n_{ID}^{SRS}) \bmod 30$  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  $n_{ID}^{SRS}$  is given by the higher layer parameter *sequenceId* in the *SRS-Resource* IE, in which case  $n_{ID}^{SRS} \in \{0, 1, \dots, 1023\}$ , or the *SRS-PosResource-r16* IE, in which case  $n_{ID}^{SRS} \in \{0, 1, \dots, 65535\}$ . The quantity  $l' \in \{0, 1, \dots, N_{symb}^{SRS} - 1\}$  is the OFDM symbol number within the SRS resource.

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

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

$$v = 0$$

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

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

$$v = 0$$

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

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

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

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

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

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

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

#### 6.4.1.4.3 Mapping to physical resources

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  $\beta_{SRS}$  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



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

The length of the sounding reference signal sequence is given by

$$M_{sc,b}^{SRS} = m_{SRS,b} N_{sc}^{RB} / (K_{TC} P_F)$$

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

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

where

$$\begin{aligned} \bar{k}_0^{(p_i)} &= n_{shift} N_{sc}^{RB} + (k_{TC}^{(p_i)} + k_{offset}^{l'}) \bmod K_{TC} \\ k_{TC}^{(p_i)} &= \begin{cases} (\bar{k}_{TC} + K_{TC}/2) \bmod K_{TC} & \text{if } N_{ap}^{SRS} = 4, p_i \in \{1001, 1003\}, \text{ and } n_{SRS}^{cs,max} = 6 \\ (\bar{k}_{TC} + K_{TC}/2) \bmod K_{TC} & \text{if } N_{ap}^{SRS} = 4, p_i \in \{1001, 1003\}, \text{ and } n_{SRS}^{cs} \in \{n_{SRS}^{cs,max}/2, \dots, n_{SRS}^{cs,max} - 1\} \\ \bar{k}_{TC} & \text{otherwise} \end{cases} \\ n_{offset}^{FH} &= \sum_{b=0}^{B_{SRS}} m_{SRS,b} N_{sc}^{RB} n_b \\ n_{offset}^{RPFS} &= N_{sc}^{RB} m_{SRS,B_{SRS}} ((k_F + k_{hop}) \bmod P_F) / P_F \end{aligned}$$

and

- $k_F \in \{0, 1, \dots, P_F - 1\}$  is given by the higher-layer parameter *StartRBIndex* if configured, otherwise  $k_F = 0$ ;
- $k_{hop}$  is given by Table 6.4.1.4.3-3 with

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

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

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

If  $N_{BWP}^{start} \leq n_{shift}$  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  $k_{offset}^{l'}$  is given by Table 6.4.1.4.3-2, otherwise  $k_{offset}^{l'} = 0$ .

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  $k_{TC} \in \{0, 1, \dots, K_{TC} - 1\}$  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  $b_{hop} \in \{0, 1, 2, 3\}$ , given by the field  $b$ -hop contained in the higher-layer parameter *freqHopping* if configured, otherwise  $b_{hop} = 0$ .

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

$$n_b = \lfloor 4n_{\text{RRC}}/m_{\text{SRS},b} \rfloor \bmod N_b$$

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

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

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

where  $N_b$  is given by Table 6.4.1.4.3-1,

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

and where  $N_{b_{\text{hop}}} = 1$  regardless of the value of  $N_b$ . The quantity  $n_{\text{SRS}}$  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  $n_{\text{SRS}} = \lfloor l'/R \rfloor$  within the slot in which the  $N_{\text{sy mb}}^{\text{SRS}}$  symbol SRS resource is transmitted. The quantity  $R \leq N_{\text{sy mb}}^{\text{SRS}}$  is the repetition factor given by the field *repetitionFactor* if configured, otherwise  $R = N_{\text{sy mb}}^{\text{SRS}}$ .

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

$$n_{\text{SRS}} = \left( \frac{N_{\text{slot}}^{\text{frame},\mu} n_f + n_{\text{s,f}}^\mu - T_{\text{offset}}}{T_{\text{SRS}}} \right) \cdot \left( \frac{N_{\text{sy mb}}^{\text{SRS}}}{R} \right) + \left\lfloor \frac{l'}{R} \right\rfloor$$

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

**Table 6.4.1.4.3-1: SRS bandwidth configuration.**

$C_{SRS}$	$B_{SRS} = 0$		$B_{SRS} = 1$		$B_{SRS} = 2$		$B_{SRS} = 3$	
	$m_{SRS,0}$	$N_0$	$m_{SRS,1}$	$N_1$	$m_{SRS,2}$	$N_2$	$m_{SRS,3}$	$N_3$
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
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**Table 6.4.1.4.3-2: The offset  $k'_{\text{offset}}$  for SRS as a function of  $K_{\text{TC}}$  and  $l'$ .**

$K_{\text{TC}}$	$k'_{\text{offset}}, \dots, k'_{\text{offset}}^{N_{\text{SRS}}^{\text{Symb}}-1}$				
	$N_{\text{SRS}}^{\text{Symb}} = 1$	$N_{\text{SRS}}^{\text{Symb}} = 2$	$N_{\text{SRS}}^{\text{Symb}} = 4$	$N_{\text{SRS}}^{\text{Symb}} = 8$	$N_{\text{SRS}}^{\text{Symb}} = 12$
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  $k_{\text{hop}}$  as a function of  $\bar{k}_{\text{hop}}$ .**

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

#### 6.4.1.4.4 Sounding reference signal slot configuration

For an SRS resource configured as periodic or semi-persistent by the higher-layer parameter *resourceType*, a periodicity  $T_{\text{SRS}}$  (in slots) and slot offset  $T_{\text{offset}}$  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

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

SRS is transmitted as described in clause 11.1 of [5, TS 38.213].

## 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

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

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, or 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  $n_{\text{RNTI}}$  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  $d^{(q)}(0), \dots, d^{(q)}(M_{\text{symp}}^{(q)} - 1)$ .

**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  $d^{(q)}(0), \dots, d^{(q)}(M_{\text{symp}}^{(q)} - 1)$  for codeword  $q$  shall be mapped onto the layers  $x(i) = [x^{(0)}(i) \ \dots \ x^{(v-1)}(i)]^T$ ,  $i = 0, 1, \dots, M_{\text{symp}}^{\text{layer}} - 1$  where  $v$  is the number of layers and  $M_{\text{symp}}^{\text{layer}}$  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 $i = 0, 1, \dots, M_{\text{symp}}^{\text{layer}} - 1$
1	1	$x^{(0)}(i) = d^{(0)}(i)$ $M_{\text{symp}}^{\text{layer}} = M_{\text{symp}}^{(0)}$
2	1	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$ $M_{\text{symp}}^{\text{layer}} = M_{\text{symp}}^{(0)} / 2$
3	1	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $M_{\text{symp}}^{\text{layer}} = M_{\text{symp}}^{(0)} / 3$
4	1	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$ $M_{\text{symp}}^{\text{layer}} = M_{\text{symp}}^{(0)} / 4$
5	2	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$ $x^{(2)}(i) = d^{(1)}(3i)$ $x^{(3)}(i) = d^{(1)}(3i+1)$ $x^{(4)}(i) = d^{(1)}(3i+2)$ $M_{\text{symp}}^{\text{layer}} = M_{\text{symp}}^{(0)} / 2 = M_{\text{symp}}^{(1)} / 3$
6	2	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $x^{(3)}(i) = d^{(1)}(3i)$ $x^{(4)}(i) = d^{(1)}(3i+1)$ $x^{(5)}(i) = d^{(1)}(3i+2)$ $M_{\text{symp}}^{\text{layer}} = M_{\text{symp}}^{(0)} / 3 = M_{\text{symp}}^{(1)} / 3$
7	2	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $x^{(3)}(i) = d^{(1)}(4i)$ $x^{(4)}(i) = d^{(1)}(4i+1)$ $x^{(5)}(i) = d^{(1)}(4i+2)$ $x^{(6)}(i) = d^{(1)}(4i+3)$ $M_{\text{symp}}^{\text{layer}} = M_{\text{symp}}^{(0)} / 3 = M_{\text{symp}}^{(1)} / 4$
8	2	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$ $x^{(4)}(i) = d^{(1)}(4i)$ $x^{(5)}(i) = d^{(1)}(4i+1)$ $x^{(6)}(i) = d^{(1)}(4i+2)$ $x^{(7)}(i) = d^{(1)}(4i+3)$ $M_{\text{symp}}^{\text{layer}} = M_{\text{symp}}^{(0)} / 4 = M_{\text{symp}}^{(1)} / 4$

#### 7.3.1.4 Antenna port mapping

The block of vectors  $[x^{(0)}(i) \dots x^{(v-1)}(i)]^T$ ,  $i = 0, 1, \dots, M_{\text{symp}}^{\text{layer}} - 1$  shall be mapped to antenna ports according to



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

where  $i = 0, 1, \dots, M_{\text{symb}}^{\text{ap}} - 1$ ,  $M_{\text{symb}}^{\text{ap}} = M_{\text{symb}}^{\text{layer}}$ . The set of antenna ports  $\{p_0, \dots, p_{v-1}\}$  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  $y^{(p)}(0), \dots, y^{(p)}(M_{\text{symb}}^{\text{ap}} - 1)$  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  $N_{\text{bundle}}$  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  $N_{\text{bundle}}$  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  $L - ((N_{\text{BWP},i}^{\text{start}} + N_{\text{start}}^{\text{CORESET}}) \bmod L)$  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  $N_{\text{bundle}} = \lceil (N_{\text{BWP},i}^{\text{size}} + (N_{\text{BWP},i}^{\text{start}} \bmod L_i)) / L_i \rceil$  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 and 1\_1 in a UE-specific search space, or *vrb-ToPRB-InterleaverDCI-1-2* for DCI format 1\_2, and
  - resource block bundle 0 consists of  $L_i - (N_{\text{BWP},i}^{\text{start}} \bmod L_i)$  resource blocks,
  - resource block bundle  $N_{\text{bundle}} - 1$  consists of  $(N_{\text{BWP},i}^{\text{start}} + N_{\text{BWP},i}^{\text{size}}) \bmod L_i$  resource blocks if  $(N_{\text{BWP},i}^{\text{start}} + N_{\text{BWP},i}^{\text{size}}) \bmod L_i > 0$  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

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

- 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-Config-Multicast*.

For PDSCH transmissions scheduled by DCI format 4\_0, and using G-RNTI or 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  $\{iL, iL+1, \dots, iL+L-1\}$  where  $L$  is the REG bundle size,  $i = 0, 1, \dots, N_{\text{REG}}^{\text{CORESET}} / L - 1$ , 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  $\{f(6j/L), f(6j/L+1), \dots, f(6j/L+6/L-1)\}$  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

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

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, the UE may assume
  - the same precoding being used within a REG bundle if the higher-layer parameter *precoderGranularity* equals *sameAsREG-bundle*;
  - the same precoding being used across the all resource-element groups within the set of contiguous resource blocks in the CORESET, and that no resource elements in the CORESET overlap with an SSB or LTE cell-specific reference signals as indicated by the higher-layer parameter *lte-CRS-ToMatchAround*, *lte-CRS-PatternList1*, or *lte-CRS-PatternList2*, if the higher-layer parameter *precoderGranularity* equals *allContiguousRBs*.

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.

### 7.3.2.3 Scrambling

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

$$c_{\text{init}} = (n_{\text{RNTI}} \cdot 2^{16} + n_{\text{ID}}) \bmod 2^{31}$$

where

- for a UE-specific search space as defined in clause 10 of [5, TS 38.213],  $n_{\text{ID}} \in \{0,1,\dots,65535\}$  equals the higher-layer parameter *pdccch-DMRS-ScramblingID* if configured;
- for a PDCCH with the CRC scrambled by G-RNTI, G-CS-RNTI, or MCCH-RNTI in a common search space as defined in clause 10 of [5, TS 38.213],  $n_{\text{ID}} \in \{0,1, \dots, 65535\}$  equals the higher-layer parameter *pdccch-DMRS-ScramblingID* if configured in a common MBS frequency resource;
- $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$  otherwise

and where

- $n_{\text{RNTI}}$  is given by the C-RNTI for a PDCCH in a UE-specific search space if the higher-layer parameter *pdccch-DMRS-ScramblingID* is configured, and
- $n_{\text{RNTI}} = 0$  otherwise.

### 7.3.2.4 PDCCH modulation

The UE shall assume the block of bits  $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$  to be QPSK modulated as described in clause 5.1.3, resulting in a block of complex-valued modulation symbols  $d(0), \dots, d(M_{\text{sy mb}} - 1)$ .

### 7.3.2.5 Mapping to physical resources

The UE shall assume the block of complex-valued symbols  $d(0), \dots, d(M_{\text{sy mb}} - 1)$  to be scaled by a factor  $\beta_{\text{PDCCH}}$  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  $b(0), \dots, b(M_{\text{bit}} - 1)$ , where  $M_{\text{bit}}$  is the number of bits transmitted on the physical broadcast channel, are scrambled prior to modulation, resulting in a block of scrambled bits  $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$  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  $\bar{L}_{\text{max}} = 4$ ,  $v$  is the two least significant bits of the candidate SS/PBCH block index
- for  $\bar{L}_{\text{max}} > 4$ ,  $v$  is the three least significant bits of the candidate SS/PBCH block index

with  $\bar{L}_{\text{max}}$  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  $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$  are QPSK modulated as described in clause 5.1.3, resulting in a block of complex-valued modulation symbols  $d_{\text{PBCH}}(0), \dots, d_{\text{PBCH}}(M_{\text{symb}} - 1)$ .

### 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

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

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

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

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

- $N_{\text{ID}}^0, N_{\text{ID}}^1 \in \{0, 1, \dots, 65535\}$  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 or 1\_2 with the CRC scrambled by C-RNTI, MCS-C-RNTI, or CS-RNTI;
- $N_{\text{ID}}^0 \in \{0, 1, \dots, 65535\}$  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;
- $N_{\text{ID}}^0, N_{\text{ID}}^1 \in \{0, 1, \dots, 65535\}$  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;
- $N_{\text{ID}}^0 \in \{0, 1, \dots, 65535\}$  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, or MCCH-RNTI;
- $N_{\text{ID}}^{\bar{\lambda}} = N_{\text{ID}}^{\text{cell}}$  otherwise;
- $\bar{n}_{\text{SCID}}^{\bar{\lambda}}$  and  $\bar{\lambda}$  are given by
  - if the higher-layer parameter *dmrs-Downlink* in the *DMRS-DownlinkConfig* 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  $\lambda$  is the CDM group defined in clause 7.4.1.1.2.

- otherwise by

$$\begin{aligned}\bar{n}_{\text{SCID}} &= n_{\text{SCID}} \\ \bar{\lambda} &= 0\end{aligned}$$

The quantity  $n_{\text{SCID}} \in \{0, 1\}$  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, or 4\_2 in [4, TS 38.212] is used, otherwise  $n_{\text{SCID}} = 0$ .

#### 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  $\beta_{\text{PDSCH}}^{\text{DMRS}}$  to conform with the transmission power specified in [6, TS 38.214] and mapped to resource elements  $(k, l)_{p,\mu}$  according to

$$\begin{aligned}a_{k,l}^{(p,\mu)} &= \beta_{\text{PDSCH}}^{\text{DMRS}} w_f(k') w_t(l') r(2n+k') \\ k &= \begin{cases} 4n+2k'+\Delta & \text{Configuration type 1} \\ 6n+k'+\Delta & \text{Configuration type 2} \end{cases} \\ k' &= 0,1 \\ l &= \bar{l} + l' \\ n &= 0,1,\dots\end{aligned}$$

where  $w_f(k')$ ,  $w_t(l')$ , and  $\Delta$  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';

- $l_d = 3$  and  $l_d = 4$  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*, or *lte-CRS-PatternList2* 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  $l_d \in \{2,3,4,5,6,7,8,9,10,11,12,13\}$  OFDM symbols for normal cyclic prefix or  $l_d \in \{2,4,6\}$  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  $l_d \in \{5,6,7,8,9,10,11,12,13\}$  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  $(l_d - 1)$ :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*, or *lte-CRS-PatternList2* is configured, the PDSCH duration  $l_d = 10$  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*, or *lte-CRS-PatternList2*, 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'.

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 $\lambda$	$\Delta$	$w_f(k')$		$w_t(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
1000	0	0	+1	+1	+1	+1
1001	0	0	+1	-1	+1	+1
1002	1	1	+1	+1	+1	+1
1003	1	1	+1	-1	+1	+1
1004	0	0	+1	+1	+1	-1
1005	0	0	+1	-1	+1	-1
1006	1	1	+1	+1	+1	-1
1007	1	1	+1	-1	+1	-1

**Table 7.4.1.1.2-2: Parameters for PDSCH DM-RS configuration type 2.**

$p$	CDM group $\lambda$	$\Delta$	$w_f(k')$		$w_t(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
1000	0	0	+1	+1	+1	+1
1001	0	0	+1	-1	+1	+1
1002	1	2	+1	+1	+1	+1
1003	1	2	+1	-1	+1	+1
1004	2	4	+1	+1	+1	+1
1005	2	4	+1	-1	+1	+1
1006	0	0	+1	+1	+1	-1
1007	0	0	+1	-1	+1	-1
1008	1	2	+1	+1	+1	-1
1009	1	2	+1	-1	+1	-1
1010	2	4	+1	+1	+1	-1
1011	2	4	+1	-1	+1	-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			
	<i>dmrs-AdditionalPosition</i>				<i>dmrs-AdditionalPosition</i>			
	<i>pos0</i>	<i>pos1</i>	<i>pos2</i>	<i>pos3</i>	<i>pos0</i>	<i>pos1</i>	<i>pos2</i>	<i>pos3</i>
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		
	<i>dmrs-AdditionalPosition</i> <i>pos0</i>	<i>pos1</i>	<i>pos2</i>	<i>dmrs-AdditionalPosition</i> <i>pos0</i>	<i>pos1</i>	<i>pos2</i>
<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  $p$ .

Single or double symbol DM-RS	$l'$	Supported antenna ports $p$	
		Configuration type 1	Configuration type 2
single	0	1000 – 1003	1000 – 1005
double	0, 1	1000 – 1007	1000 – 1011

## 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

$$r_k = r(2m + k')$$

where  $r(2m + k')$  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  $l_{\text{ref}}$  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

$$k = k_{\text{ref}}^{\text{RE}} + (iK_{\text{PT-RS}} + k_{\text{ref}}^{\text{RB}})N_{\text{sc}}^{\text{RB}}$$

$$k_{\text{ref}}^{\text{RB}} = \begin{cases} n_{\text{RNTI}} \bmod K_{\text{PT-RS}} & \text{if } N_{\text{RB}} \bmod K_{\text{PT-RS}} = 0 \\ n_{\text{RNTI}} \bmod (N_{\text{RB}} \bmod K_{\text{PT-RS}}) & \text{otherwise} \end{cases}$$

where

- $i = 0,1,2, \dots$
- $k_{\text{ref}}^{\text{RE}}$  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.
- $n_{\text{RNTI}}$  is the RNTI associated with the DCI scheduling the transmission
- $N_{\text{RB}}$  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			
	<i>resourceElementOffset</i>				<i>resourceElementOffset</i>			
	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

### 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

$$r_l(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m+1)),$$

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

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

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

- $N_{\text{ID}} \in \{0, 1, \dots, 65535\}$  is given by the higher-layer parameter *pdccch-DMRS-ScramblingID* if provided;
- $N_{\text{ID}} \in \{0, 1, \dots, 65535\}$  is given by the higher-layer parameter *pdccch-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

$$\begin{aligned} a_{k,l}^{(p,\mu)} &= \beta_{\text{DMRS}}^{\text{PDCCH}} \cdot r_l(3n + k') \\ k &= nN_{\text{sc}}^{\text{RB}} + 4k' + 1 \\ k' &= 0, 1, 2 \\ n &= 0, 1, \dots \end{aligned}$$

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

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m+1))$$

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

$$c_{\text{init}} = 2^{11} (\bar{i}_{\text{SSB}} + 1) \left( \left\lfloor \frac{N_{\text{ID}}^{\text{cell}}}{4} \right\rfloor + 1 \right) + 2^6 (\bar{i}_{\text{SSB}} + 1) + (N_{\text{ID}}^{\text{cell}} \bmod 4)$$

where

- for  $\bar{L}_{\text{max}} = 4$ ,  $\bar{i}_{\text{SSB}} = i_{\text{SSB}} + 4n_{\text{hf}}$  where  $n_{\text{hf}}$  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  $i_{\text{SSB}}$  is the two least significant bits of the candidate SS/PBCH block index as defined in [5, TS 38.213]
- for  $\bar{L}_{\text{max}} > 4$ ,  $\bar{i}_{\text{SSB}} = i_{\text{SSB}}$  where  $i_{\text{SSB}}$  is the three least significant bits of the candidate SS/PBCH block index as defined in [5, TS 38.213]

with  $\bar{L}_{\text{max}}$  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

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m+1))$$

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

$$c_{\text{init}} = (2^{10} (N_{\text{symb}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1) (2n_{\text{ID}} + 1) + n_{\text{ID}}) \bmod 2^{31}$$

at the start of each OFDM symbol where  $n_{s,f}^{\mu}$  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 *scramblingID* 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

$$a_{k,l}^{(p,\mu)} = \beta_{\text{CSIRS}} w_f(k') \cdot w_t(l') \cdot r_{l,n_{s,f}}(m')$$

$$m' = \lfloor n\alpha \rfloor + k' + \left\lfloor \frac{\bar{k}\rho}{N_{\text{sc}}^{\text{RB}}} \right\rfloor$$

$$k = nN_{\text{sc}}^{\text{RB}} + \bar{k} + k'$$

$$l = \bar{l} + l'$$

$$\alpha = \begin{cases} \rho & \text{for } X = 1 \\ 2\rho & \text{for } X > 1 \end{cases}$$

$$n = 0, 1, \dots$$

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  $\rho$  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  $\beta_{\text{CSIRS}} > 0$  for a non-zero-power CSI-RS where  $\beta_{\text{CSIRS}}$  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  $k'$ ,  $l'$ ,  $w_f(k')$ , and  $w_t(l')$  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  $l_0 \in \{0, 1, \dots, 13\}$  and  $l_1 \in \{2, 3, \dots, 12\}$  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  $l_0 \in \{0, 1, \dots, 13\}$  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  $i^{\text{th}}$  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  $startPRB$  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

$$\begin{aligned} p &= 3000 + s + jL; \\ j &= 0, 1, \dots, N/L - 1 \\ s &= 0, 1, \dots, L - 1; \end{aligned}$$

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

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

where the periodicity  $T_{\text{CSI-RS}}$  (in slots) and slot offset  $T_{\text{offset}}$  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 $\rho$	<i>cdm-Type</i>	$(\bar{k}, \bar{l})$	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  $w_f(k')$  and  $w_t(l')$  for *cdm-Type* equal to 'noCDM'.**

Index	$w_f(0)$	$w_t(0)$
0	1	1

**Table 7.4.1.5.3-3: The sequences  $w_f(k')$  and  $w_t(l')$  for *cdm-Type* equal to 'fd-CDM2'.**

Index	$[w_f(0) \ w_t(1)]$	$w_t(0)$
0	$[+1 \ +1]$	1
1	$[+1 \ -1]$	1

**Table 7.4.1.5.3-4: The sequences  $w_f(k')$  and  $w_t(l')$  for *cdm-Type* equal to 'cdm4-FD2-TD2'.**

Index	$[w_f(0) \ w_f(1)]$	$[w_t(0) \ w_t(1)]$
0	[+1 +1]	[+1 +1]
1	[+1 -1]	[+1 +1]
2	[+1 +1]	[+1 -1]
3	[+1 -1]	[+1 -1]

**Table 7.4.1.5.3-5: The sequences  $w_f(k')$  and  $w_t(l')$  for *cdm-Type* equal to 'cdm8-FD2-TD4'.**

Index	$[w_f(0) \ w_f(1)]$	$[w_t(0) \ w_t(1) \ w_t(2) \ w_t(3)]$
0	[+1 +1]	[+1 +1 +1 +1]
1	[+1 -1]	[+1 +1 +1 +1]
2	[+1 +1]	[+1 -1 +1 -1]
3	[+1 -1]	[+1 -1 +1 -1]
4	[+1 +1]	[+1 +1 -1 -1]
5	[+1 -1]	[+1 +1 -1 -1]
6	[+1 +1]	[+1 -1 -1 +1]
7	[+1 -1]	[+1 -1 -1 +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

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2c(2m + 1))$$

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

$$c_{\text{init}} = (2^{10} f(n_t^{\text{RIM}}) + n_{\text{SCID}}) \bmod 2^{31}$$

where

- $n_{\text{SCID}} \in \{0, 1, \dots, 2^{10} - 1\}$  is given by clause 7.4.1.6.4.4;
- $f(n_t^{\text{RIM}}) = \sum_{i=0}^{20} 2^i \bar{c}(i)$  where the pseudo-random sequence  $\bar{c}(i)$  is given by clause 5.2.1, initialized with  $\bar{c}_{\text{init}}(i) = (\gamma n_t^{\text{RIM}} + \delta) \bmod 2^{31}$  where the multiplier factor  $\gamma \in \{0, 1, \dots, 2^{31} - 1\}$  and the offset  $\delta \in \{0, 1, \dots, 2^{31} - 1\}$ ;
- $n_t^{\text{RIM}} = \lfloor (t_{\text{RS}}^{\text{RIM}} - t_{\text{ref}}^{\text{RIM}}) / T_{\text{per}}^{\text{RIM}} \rfloor$  is the number of RIM-RS transmission periods since  $t_{\text{ref}}^{\text{RIM}}$  where
  - $t_{\text{RS}}^{\text{RIM}} - t_{\text{ref}}^{\text{RIM}}$  is the time in seconds relative to  $t_{\text{ref}}^{\text{RIM}}$  of 00:00:00 on 1 January 1900, calculated as continuous time without leap second and traceable to a common time reference, and

- $T_{\text{per}}^{\text{RIM}} = N_{\text{slot}}^{P_t} / (1000 \cdot 2^\mu)$  is the RIM-RS transmission periodicity in seconds assuming that the first RIM-RS transmission period starts at  $t_{\text{ref}}^{\text{RIM}}$ , and where  $N_{\text{slot}}^{P_t}$  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

$$a_k^{(p,\text{RIM})} = \beta_{\text{RIM}} r(k)$$

$$k = 0, 1, \dots, L_{\text{RIM}} - 1$$

where  $\beta_{\text{RIM}}$  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  $n_{s,f}^\mu$  in a frame is given by

$$l_0 = T_{\text{offset}}^{\text{UD,RIM}} \bmod N_{\text{symp}}^{\text{slot}}$$

in slots satisfying

$$\left( 1024 N_{\text{slot}}^{\text{frame},\mu} \bar{n}_f^{\text{RIM}} + N_{\text{slot}}^{\text{frame},\mu} n_f^{\text{RIM}} + n_{s,f}^\mu - (\bar{T}_{\text{offset}} + \lfloor T_{\text{offset}}^{\text{UD,RIM}} / N_{\text{symp}}^{\text{slot}} \rfloor) \right) \bmod N_{\text{slot}}^{P_t} = 0$$

where

- $\bar{n}_f^{\text{RIM}} \in \{0, 1, \dots, N_{\text{slot}}^{P_t} / (1024 N_{\text{slot}}^{\text{frame},\mu}) - 1\}$  counts the number of times the SFN periods within the RIM-RS transmission period;
- $T_{\text{offset}}^{\text{UD,RIM}} = N_{\text{ref}}^{\text{UD,RIM}} - N_{\text{symp,ref}}^{\text{RIM},i}$  where  $N_{\text{ref}}^{\text{UD,RIM}} \in \{2, 3, \dots, 20 \cdot 2 \cdot 14 - 1\}$  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  $N_{\text{symp,ref}}^{\text{RIM},i}$  is obtained as described in clause 7.4.1.6.4.2;
- $N_{\text{slot}}^{P_t}$  is the total number of slots in a RIM-RS transmission period as defined in clause 7.4.1.6.4.2;
- $\bar{T}_{\text{offset}}$  is the slot offset of the uplink-downlink switching period with index  $i_t^{\text{RIM}}$  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  $i_t^{\text{RIM}} \in \{0, 1, \dots, P_t - 1\}$ ,  $i_f^{\text{RIM}} \in \{0, 1, \dots, N_f^{\text{RIM}} - 1\}$ , and  $i_s^{\text{RIM}} \in \{0, 1, \dots, N_s^{\text{RIM},i} - 1\}$  used as indices into configured lists of time, frequency, and sequence parameters, respectively.

All RIM-RS resources occupy the same number of resource blocks,  $N_{\text{RB}}^{\text{RIM}}$ . 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

$$P_t = \left\lceil \frac{2^\mu \bar{P}_t T_{\text{per},1}^{\text{RIM}}}{1024 N_{\text{slot}}^{\text{frame},\mu}} \right\rceil \frac{1024 N_{\text{slot}}^{\text{frame},\mu}}{2^\mu T_{\text{per},1}^{\text{RIM}}}$$

where  $T_{\text{per},1}^{\text{RIM}} \in \{0.5, 0.625, 1, 1.25, 2, 2.5, 4, 5, 10, 20\}$  ms;

- $N_{\text{slot}}^{P_t} = 2^\mu P_t T_{\text{per},1}^{\text{RIM}}$  is the total number of slots in a RIM-RS transmission period;
- $\bar{T}_{\text{offset}} = 2^\mu i_t^{\text{RIM}} T_{\text{per},1}^{\text{RIM}}$  is the slot offset of the uplink-downlink switching period with index  $i_t^{\text{RIM}}$  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  $P_t/2$  pairs of uplink-downlink switching periods and is given by

$$P_t = \left\lceil \frac{2^\mu \bar{P}_t (T_{\text{per},1}^{\text{RIM}} + T_{\text{per},2}^{\text{RIM}})/2}{1024 N_{\text{slot}}^{\text{frame},\mu}} \right\rceil \frac{1024 N_{\text{slot}}^{\text{frame},\mu}}{2^\mu (T_{\text{per},1}^{\text{RIM}} + T_{\text{per},2}^{\text{RIM}})/2}$$

where each pair consists of a first period of  $T_{\text{per},1}^{\text{RIM}} \in \{0.5, 0.625, 1, 1.25, 2, 2.5, 3, 4, 5, 10, 20\}$  ms and a second period of  $T_{\text{per},2}^{\text{RIM}} \in \{0.5, 0.625, 1, 1.25, 2, 2.5, 3, 4, 5, 10\}$  ms and where  $T_{\text{per},1}^{\text{RIM}} + T_{\text{per},2}^{\text{RIM}}$  divides 20 ms;

- $N_{\text{slot}}^{P_t} = 2^\mu P_t (T_{\text{per},1}^{\text{RIM}} + T_{\text{per},2}^{\text{RIM}})/2$  is the total number of slots in a RIM-RS transmission period;
- $\bar{T}_{\text{offset}} = 2^\mu \lfloor i_t^{\text{RIM}}/2 \rfloor (T_{\text{per},1}^{\text{RIM}} + T_{\text{per},2}^{\text{RIM}}) + 2^\mu (i_t^{\text{RIM}} \bmod 2) T_{\text{per},1}^{\text{RIM}}$  is the slot offset of the uplink-downlink switching period with index  $i_t^{\text{RIM}}$  with respect to the starting boundary of the RIM-RS transmission period

The intermediate quantity  $\bar{P}_t$  is given by

$$\bar{P}_t = \begin{cases} \left\lceil \frac{N_{\text{setID}}^{\text{RIM},1}}{N_f^{\text{RIM}} N_s^{\text{RIM},1}} \right\rceil R_1 + \left\lceil \frac{N_{\text{setID}}^{\text{RIM},2}}{N_f^{\text{RIM}} N_s^{\text{RIM},2}} \right\rceil R_2 & \text{if } \textit{EnoughIndication} \text{ is disabled} \\ \left\lceil \frac{2 N_{\text{setID}}^{\text{RIM},1}}{N_f^{\text{RIM}} N_s^{\text{RIM},1}} \right\rceil R_1 + \left\lceil \frac{N_{\text{setID}}^{\text{RIM},2}}{N_f^{\text{RIM}} N_s^{\text{RIM},2}} \right\rceil R_2 & \text{if } \textit{EnoughIndication} \text{ is enabled} \end{cases}$$

where

- $N_{\text{setID}}^{\text{RIM},1}$  and  $N_{\text{setID}}^{\text{RIM},2}$  are the total number of setIDs for RIM-RS type 1 and RIM-RS type 2, respectively;
- $N_f^{\text{RIM}} \in \{1, 2, 4\}$  is the number of candidate frequency resources configured in the network;
- $N_s^{\text{RIM},i} \in \{1, 2, \dots, 8\}$  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  $N_{\text{symp,ref}}^{\text{RIM},i}$  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  $i_f^{\text{RIM}}$  in a list of configured frequency offsets expressed in units of resource blocks.

The number of candidate frequency resources configured in the network,  $N_f^{\text{RIM}}$ , shall fulfil

$$N_f^{\text{RIM}} \leq \left\lceil \frac{N_{\text{grid}}^{\text{size},\mu} N_{\text{RB}}^{\text{sc}} \cdot 2^\mu \cdot 15}{40 \cdot 10^3} \right\rceil + \left\lceil \frac{N_{\text{grid}}^{\text{size},\mu} N_{\text{RB}}^{\text{sc}} \cdot 2^\mu \cdot 15}{80 \cdot 10^3} \right\rceil + 1$$

If  $N_f^{\text{RIM}} > 1$ , the frequency difference between any pair of configured frequency offsets in the list is not smaller than  $N_{\text{RB}}^{\text{RIM}}$ .

The number of resource blocks for RIM-RS is given by

$$N_{\text{RB}}^{\text{RIM}} = \min(96, N_{\text{grid,DL}}^{\text{size},\mu}) \quad \text{for } \mu = 0$$

$$N_{\text{RB}}^{\text{RIM}} \in \left\{ \min(48, N_{\text{grid,DL}}^{\text{size},\mu}), \min(96, N_{\text{grid,DL}}^{\text{size},\mu}) \right\} \quad \text{for } \mu = 1$$

#### 7.4.1.6.4.4 Sequence parameters and mapping from $i_s$ to sequence parameters

The scrambling identity  $n_{\text{SCID}}$  clause 7.4.1.6.2 is obtained from entry  $i_s^{\text{RIM}}$  in a list of configured scrambling identities.

#### 7.4.1.6.4.5 Mapping between resource triplet and set ID

The resource indices  $i_t^{\text{RIM}}$ ,  $i_f^{\text{RIM}}$ , and  $i_s^{\text{RIM}}$  are determined from the index  $\bar{r}$  in the set ID  $n_{\text{setID}}$  according to

$$i_t^{\text{RIM}} = T_{\text{start}} + \left( \left\lfloor \frac{n_{\text{setID}}}{N_s^{\text{RIM}}} \right\rfloor \bmod N_t^{\text{RIM}} \right) R_i + \bar{r}$$

$$i_f^{\text{RIM}} = \left( \left\lfloor \frac{n_{\text{setID}}}{N_t^{\text{RIM}} N_s^{\text{RIM}}} \right\rfloor \bmod N_f^{\text{RIM}} \right)$$

$$i_s^{\text{RIM}} = S_{\text{start}} + (n_{\text{setID}} \bmod N_s^{\text{RIM}})$$

where

- $N_t^{\text{RIM}}$  is given by

$$N_t^{\text{RIM}} = \begin{cases} \left\lfloor \frac{N_{\text{setID}}^{\text{RIM},1}}{N_f^{\text{RIM}} N_s^{\text{RIM},1}} \right\rfloor & \text{for RIM-RS type 1 and if } \textit{EnoughIndication} \text{ is disabled} \\ \left\lfloor \frac{2N_{\text{setID}}^{\text{RIM},1}}{N_f^{\text{RIM}} N_s^{\text{RIM},1}} \right\rfloor & \text{for RIM-RS type 1 and if } \textit{EnoughIndication} \text{ is enabled} \\ \left\lfloor \frac{N_{\text{setID}}^{\text{RIM},2}}{N_f^{\text{RIM}} N_s^{\text{RIM},2}} \right\rfloor & \text{for RIM-RS type 2} \end{cases}$$

- $N_f^{\text{RIM}} \in \{1, 2, 4\}$  is the number of candidate frequency resources configured in the network;
- $N_s^{\text{RIM}}$  is the number of sequence candidates for the current RIM-RS resource given by

$$N_s^{\text{RIM}} = \begin{cases} N_s^{\text{RIM},1} & \text{for RIM-RS type 1 and if } \textit{EnoughIndication} \text{ is disabled} \\ N_s^{\text{RIM},1}/2 & \text{for RIM-RS type 1 and if } \textit{EnoughIndication} \text{ is enabled} \\ N_s^{\text{RIM},2} & \text{for RIM-RS type 2} \end{cases}$$

- $T_{\text{start}}$  is the starting time offset given by

$$T_{\text{start}} = \begin{cases} 0 & \text{for RIM-RS type 1} \\ \left\lfloor \frac{N_{\text{setID}}^{\text{RIM},1}}{N_f^{\text{RIM}} N_s^{\text{RIM},1}} \right\rfloor R_1 & \text{for RIM-RS type 2 and if } \textit{EnoughIndication} \text{ is disabled} \\ \left\lfloor \frac{2N_{\text{setID}}^{\text{RIM},1}}{N_f^{\text{RIM}} N_s^{\text{RIM},1}} \right\rfloor R_1 & \text{for RIM-RS type 2 and if } \textit{EnoughIndication} \text{ is enabled} \end{cases}$$

- $S_{\text{start}}$  is given by

$$S_{\text{start}} = \begin{cases} N_s^{\text{RIM},1}/2 & \text{if } \textit{EnoughIndication} \text{ is enabled and 'enough mitigation' is to be indicated} \\ 0 & \text{otherwise} \end{cases}$$

where  $N_s^{\text{RIM},1}$  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

$$n_{\text{setID}} = (i_s^{\text{RIM}} - S_{\text{start}}) + N_s^{\text{RIM}} \left\lfloor \frac{i_t^{\text{RIM}} - T_{\text{start}}}{R_i} \right\rfloor + N_t^{\text{RIM}} N_s^{\text{RIM}} i_f^{\text{RIM}}$$

### 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

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2c(2m + 1))$$

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

$$c_{\text{init}} = \left( 2^{22} \left\lfloor \frac{n_{\text{ID,seq}}^{\text{PRS}}}{1024} \right\rfloor + 2^{10} (N_{\text{slot}}^{\text{slot}} n_{s,f}^{\mu} + l + 1) (2(n_{\text{ID,seq}}^{\text{PRS}} \bmod 1024) + 1) + (n_{\text{ID,seq}}^{\text{PRS}} \bmod 1024) \right) \bmod 2^{31}$$

where  $n_{s,f}^{\mu}$  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  $\beta_{\text{PRS}}$  and mapped to resources elements  $(k, l)_{p,\mu}$  according to

$$\begin{aligned} a_{k,l}^{(p,\mu)} &= \beta_{\text{PRS}} r(m) \\ m &= 0, 1, \dots \\ k &= mK_{\text{comb}}^{\text{PRS}} + \left( (k_{\text{offset}}^{\text{PRS}} + k') \bmod K_{\text{comb}}^{\text{PRS}} \right) \\ l &= l_{\text{start}}^{\text{PRS}}, l_{\text{start}}^{\text{PRS}} + 1, \dots, l_{\text{start}}^{\text{PRS}} + L_{\text{PRS}} - 1 \end{aligned}$$

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  $L_{\text{PRS}} \in \{2, 4, 6, 12\}$  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  $dl\text{-PRS}\text{-CombSize}N$  such that the combination  $\{L_{\text{PRS}}, K_{\text{comb}}^{\text{PRS}}\}$  is one of  $\{2, 2\}, \{4, 2\}, \{6, 2\}, \{12, 2\}, \{4, 4\}, \{12, 4\}, \{6, 6\}, \{12, 6\}$  and  $\{12, 12\}$ ;

- the resource-element offset  $k_{\text{offset}}^{\text{PRS}} \in \{0, 1, \dots, K_{\text{comb}}^{\text{PRS}} - 1\}$  is obtained from the higher-layer parameter  $dl\text{-PRS}\text{-CombSize}N\text{-AndReOffset}$ ;
- 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  $dl\text{-PRS}\text{-PointA}$ .

**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

$$\left( N_{\text{slot}}^{\text{frame}, \mu} n_f + n_{s,f}^{\mu} - T_{\text{offset}}^{\text{PRS}} - T_{\text{offset, res}}^{\text{PRS}} \right) \bmod T_{\text{per}}^{\text{PRS}} \in \left\{ i T_{\text{gap}}^{\text{PRS}} \right\}_{i=0}^{T_{\text{rep}}^{\text{PRS}} - 1}$$

and one of the following conditions are fulfilled:

- the higher-layer parameters  $dl\text{-PRS}\text{-MutingOption}1$  and  $dl\text{-PRS}\text{-MutingOption}2$  are not provided;
- the higher-layer parameter  $dl\text{-PRS}\text{-MutingOption}1$  is provided with bitmap  $\{b^1\}$  but  $dl\text{-PRS}\text{-MutingOption}2$  with bitmap  $\{b^2\}$  is not provided, and bit  $b_i^1$  is set;
- the higher-layer parameter  $dl\text{-PRS}\text{-MutingOption}2$  is provided with bitmap  $\{b^2\}$  but  $dl\text{-PRS}\text{-MutingOption}1$  with bitmap  $\{b^1\}$  is not provided, and bit  $b_i^2$  is set;
- the higher-layer parameters  $dl\text{-PRS}\text{-MutingOption}1$  with bitmap  $\{b^1\}$  and  $dl\text{-PRS}\text{-MutingOption}2$  with  $\{b^2\}$  are both provided, and both bit  $b_i^1$  and  $b_i^2$  are set.

where

- $b_i^1$  is bit  $i = \left\lfloor \left( N_{\text{slot}}^{\text{frame}, \mu} n_f + n_{s,f}^{\mu} - T_{\text{offset}}^{\text{PRS}} - T_{\text{offset, res}}^{\text{PRS}} \right) / \left( T_{\text{muting}}^{\text{PRS}} T_{\text{per}}^{\text{PRS}} \right) \right\rfloor \bmod L$  in the bitmap given by the higher-layer parameter  $dl\text{-PRS}\text{-MutingOption}1$  where  $L \in \{2, 4, 6, 8, 16, 32\}$  is the size of the bitmap;
- $b_i^2$  is bit  $i = \left\lfloor \left( \left( N_{\text{slot}}^{\text{frame}, \mu} n_f + n_{s,f}^{\mu} - T_{\text{offset}}^{\text{PRS}} - T_{\text{offset, res}}^{\text{PRS}} \right) \bmod T_{\text{per}}^{\text{PRS}} \right) / T_{\text{gap}}^{\text{PRS}} \right\rfloor \bmod T_{\text{rep}}^{\text{PRS}}$  in the bitmap given by the higher-layer parameter  $dl\text{-PRS}\text{-MutingOption}2$ ;
- the periodicity  $T_{\text{per}}^{\text{PRS}} \in 2^{\mu} \{4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 160, 320, 640, 1280, 2560, 5120, 10240\}$  and the slot offset  $T_{\text{offset}}^{\text{PRS}} \in \{0, 1, \dots, T_{\text{per}}^{\text{PRS}} - 1\}$  are given by the higher-layer parameter  $dl\text{-PRS}\text{-Periodicity}\text{-and}\text{-ResourceSetSlotOffset}$ ;
- the downlink PRS resource slot offset  $T_{\text{offset, res}}^{\text{PRS}}$  is given by the higher-layer parameter  $dl\text{-PRS}\text{-ResourceSlotOffset}$ ;
- the repetition factor  $T_{\text{rep}}^{\text{PRS}} \in \{1, 2, 4, 6, 8, 16, 32\}$  is given by the higher-layer parameter  $dl\text{-PRS}\text{-ResourceRepetitionFactor}$ ;
- the muting repetition factor  $T_{\text{muting}}^{\text{PRS}}$  is given by the higher-layer parameter  $dl\text{-PRS}\text{-MutingBitRepetitionFactor}$ ;

- the time gap  $T_{\text{gap}}^{\text{PRS}} \in \{1,2,4,8,16,32\}$  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

$$N_{\text{ID}}^{\text{cell}} = 3N_{\text{ID}}^{(1)} + N_{\text{ID}}^{(2)}$$

where  $N_{\text{ID}}^{(1)} \in \{0,1, \dots, 335\}$  and  $N_{\text{ID}}^{(2)} \in \{0,1,2\}$ .

### 7.4.2.2 Primary synchronization signal

#### 7.4.2.2.1 Sequence generation

The sequence  $d_{\text{PSS}}(n)$  for the primary synchronization signal is defined by

$$\begin{aligned} d_{\text{PSS}}(n) &= 1 - 2x(m) \\ m &= (n + 43N_{\text{ID}}^{(2)}) \bmod 127 \\ 0 &\leq n < 127 \end{aligned}$$

where

$$x(i+7) = (x(i+4) + x(i)) \bmod 2$$

and

$$[x(6) \ x(5) \ x(4) \ x(3) \ x(2) \ x(1) \ x(0)] = [1 \ 1 \ 1 \ 0 \ 1 \ 1 \ 0]$$

#### 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  $d_{\text{SSS}}(n)$  for the secondary synchronization signal is defined by

$$\begin{aligned} d_{\text{SSS}}(n) &= [1 - 2x_0((n + m_0) \bmod 127)][1 - 2x_1((n + m_1) \bmod 127)] \\ m_0 &= 15 \left\lfloor \frac{N_{\text{ID}}^{(1)}}{112} \right\rfloor + 5N_{\text{ID}}^{(2)} \\ m_1 &= N_{\text{ID}}^{(1)} \bmod 112 \\ 0 &\leq n < 127 \end{aligned}$$

where

$$\begin{aligned} x_0(i+7) &= (x_0(i+4) + x_0(i)) \bmod 2 \\ x_1(i+7) &= (x_1(i+1) + x_1(i)) \bmod 2 \end{aligned}$$



and

$$\begin{bmatrix} x_0(6) & x_0(5) & x_0(4) & x_0(3) & x_0(2) & x_0(1) & x_0(0) \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} x_1(6) & x_1(5) & x_1(4) & x_1(3) & x_1(2) & x_1(1) & x_1(0) \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

#### 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  $v = N_{\text{ID}}^{\text{cell}} \bmod 4$ . The quantity  $k_{\text{SSB}}$  is the subcarrier offset from subcarrier 0 in common resource block  $N_{\text{CRB}}^{\text{SSB}}$  to subcarrier 0 of the SS/PBCH block, where  $N_{\text{CRB}}^{\text{SSB}}$  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  $k_{\text{SSB}}$  are given by the higher-layer parameter *ssb-SubcarrierOffset* and for FR1 the most significant bit of  $k_{\text{SSB}}$  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  $\bar{k}_{\text{SSB}}$  are given by the higher-layer parameter *ssb-SubcarrierOffset* and the most significant bit of  $\bar{k}_{\text{SSB}}$  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  $\bar{k}_{\text{SSB}} \geq 24$ ,  $k_{\text{SSB}} = \bar{k}_{\text{SSB}}$ ; otherwise,  $k_{\text{SSB}} = 2 \lfloor \bar{k}_{\text{SSB}} / 2 \rfloor$ .

If *ssb-SubcarrierOffset* is not provided,  $k_{\text{SSB}}$  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 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  $k_{\text{SSB}} \in \{0, 1, 2, \dots, 23\}$  with the quantities  $k_{\text{SSB}}$ , and  $N_{\text{CRB}}^{\text{SSB}}$  expressed in terms of 15 kHz subcarrier spacing, and
- for SS/PBCH block type B in FR2-1,  $\mu \in \{3, 4\}$  and  $k_{\text{SSB}} \in \{0, 1, 2, \dots, 11\}$  with the quantity  $k_{\text{SSB}}$  expressed in terms of the subcarrier spacing provided by the higher-layer parameter *subCarrierSpacingCommon* and  $N_{\text{CRB}}^{\text{SSB}}$  expressed in terms of 60 kHz subcarrier spacing;
- for SS/PBCH block type B in FR2-2,  $\mu \in \{3, 5, 6\}$  and  $k_{\text{SSB}} \in \{0, 1, 2, \dots, 11\}$  with the quantity  $k_{\text{SSB}}$  expressed in terms of the SS/PBCH block subcarrier spacing and  $N_{\text{CRB}}^{\text{SSB}}$  expressed in terms of 60 kHz subcarrier spacing;
- the centre of subcarrier 0 of resource block  $N_{\text{CRB}}^{\text{SSB}}$  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 first resource block of the SS/PBCH block.

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].

**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	$0 + v, 4 + v, 8 + v, \dots, 236 + v$
	2	$0 + v, 4 + v, 8 + v, \dots, 44 + v$ $192 + v, 196 + v, \dots, 236 + v$

#### 7.4.3.1.1 Mapping of PSS within an SS/PBCH block

The UE shall assume the sequence of symbols  $d_{\text{PSS}}(0), \dots, d_{\text{PSS}}(126)$  constituting the primary synchronization signal to be scaled by a factor  $\beta_{\text{PSS}}$  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  $d_{\text{SSS}}(0), \dots, d_{\text{SSS}}(126)$  constituting the secondary synchronization signal to be scaled by a factor  $\beta_{\text{SSS}}$  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  $d_{\text{PBCH}}(0), \dots, d_{\text{PBCH}}(M_{\text{sy mb}} - 1)$  constituting the physical broadcast channel to be scaled by a factor  $\beta_{\text{PBCH}}$  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  $r(0), \dots, r(143)$  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

## 8.2 Physical resources

### 8.2.1 General

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

### 8.2.2 Numerologies

Multiple OFDM numerologies are supported as given by Table 8.2.2-1 where  $\mu$  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.**

$\mu$	$\Delta f = 2^\mu \cdot 15$ [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
- Antenna ports starting with 5000 for PSFCH

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  $\mu$  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  $b^{(q)}(0), \dots, b^{(q)}(M_{\text{bit}}^{(q)} - 1)$ , 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
     $\tilde{b}^{(q)}(i) = (b^{(q)}(i) + c^{(q)}(i - \tilde{M}_{i,j}^{(q)})) \bmod 2$ 
  end if
   $i = i + 1$ 
end while

```

where the scrambling sequence  $c^{(q)}(i)$  is given by clause 5.2.1 and

- for  $0 \leq i < M_{\text{bit,SCI2}}^{(q)}$
- $\tilde{M}_{i,j}^{(q)} = j$
- The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = 2^{15} N_{\text{ID}} + 1010$$

where  $N_{ID} = N_{ID}^X \bmod 2^{16}$  and the quantity  $N_{ID}^X$  equals the decimal representation of the CRC on the PSSCH associated with the PSSCH according to  $N_{ID}^X = \sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$  with  $p$  and  $L$  given by clause 8.3.2 in [4, TS 38.212].

- for  $M_{\text{bit,SCI2}}^{(q)} \leq i < M_{\text{bit}}^{(q)}$
- $\tilde{M}_{i,j}^{(q)} = M_{\text{bit,SCI2}}^{(q)}$
- The scrambling sequence generator shall be initialized with

$$c_{\text{init}} = 2^{15} N_{ID} + 1010$$

where  $N_{ID} = N_{ID}^X \bmod 2^{16}$  and the quantity  $N_{ID}^X$  equals the decimal representation of the CRC on the PSSCH associated with the PSSCH according to  $N_{ID}^X = \sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$  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  $d^{(q)}(0), \dots, d^{(q)}(M_{\text{sy mb}}^{(q)} - 1)$  where  $M_{\text{sy mb}}^{(q)} = M_{\text{sy mb},1}^{(q)} + M_{\text{sy mb},2}^{(q)}$ .

Modulation for  $0 \leq i < M_{\text{bit,SCI2}}^{(q)}$  shall be done as described in clause 5.1 using QPSK, where  $M_{\text{sy mb},1}^{(q)} = M_{\text{bit,SCI2}}^{(q)} / 2$ .

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  $M_{\text{sy mb},2}^{(q)} = M_{\text{bit,data}}^{(q)} / Q_m$ .

**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  $v \in \{1,2\}$ , resulting in  $x(i) = [x^{(0)}(i) \dots x^{(v-1)}(i)]^T$ ,  $i = 0, 1, \dots, M_{\text{sy mb}}^{\text{layer}} - 1$ .

### 8.3.1.4 Precoding

The block of vectors  $[x^{(0)}(i) \dots x^{(v-1)}(i)]^T$  shall be precoded according to clause 6.3.1.5 where the precoding matrix  $W$  equals the identity matrix and  $M_{\text{sy mb}}^{\text{ap}} = M_{\text{sy mb}}^{\text{layer}}$ .

### 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  $z^{(p)}(0), \dots, z^{(p)}(M_{\text{sy mb}}^{\text{ap}} - 1)$  shall be multiplied with the amplitude scaling factor  $\beta_{\text{DMRS}}^{\text{PSSCH}}$  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 2<sup>nd</sup>-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 2<sup>nd</sup>-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 2<sup>nd</sup>-stage SCI in the first step;
  - 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  $b(0), \dots, b(M_{\text{bit}} - 1)$ , where  $M_{\text{bit}}$  is the number of bits transmitted on the physical channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits  $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$  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

$$c_{\text{init}} = 1010$$

### 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  $d(0), \dots, d(M_{\text{sy mb}} - 1)$  where  $M_{\text{sy mb}} = M_{\text{bit}}/2$ .

### 8.3.2.3 Mapping to physical resources

The set of complex-valued modulation symbols  $d(0), \dots, d(M_{\text{sy mb}} - 1)$  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  $M_{\text{bit}}$  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:

- $m_{\text{cs}}$  is given by clause 16.3 of [5, TS 38.213];
- $m_0$  is given by clause 16.3 of [5, TS 38.213];
- $l = 0$ ;
- $l'$  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];
- $u = n_{\text{ID}} \bmod 30$  and  $v = 0$  with  $n_{\text{ID}}$  given by the higher-layer parameter *sl-PSFCH-HopID* if configured; otherwise,  $u = 0$ .
- $c_{\text{init}} = n_{\text{ID}}$  with  $n_{\text{ID}}$  given by the higher-layer parameter *sl-PSFCH-HopID* if configured; otherwise,  $c_{\text{init}} = 0$ .

#### 8.3.4.2.2 Mapping to physical resources

The sequence  $x(n)$  shall be multiplied with the amplitude scaling factor  $\beta_{\text{PSFCH}}$  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.



## 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

$$r_l(m) = \frac{1}{\sqrt{2}}(1 - 2c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2c(2m + 1))$$

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

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

where  $l$  is the OFDM symbol number within the slot,  $n_{s,f}^{\mu}$  is the slot number within a frame, and  $N_{\text{ID}} = N_{\text{ID}}^{\text{X}} \bmod 2^{16}$  where the quantity  $N_{\text{ID}}^{\text{X}}$  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].

##### 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  $w_f(k')$ ,  $w_t(l')$ , and  $\Delta$  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  $\beta_{\text{DMRS}}^{\text{PSSCH}}$  specified in clause 8.3.1.5, and mapped to physical resources according to

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

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  $\{\tilde{p}_0, \dots, \tilde{p}_{v-1}\}$  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 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 $\bar{l}$					
	PSSCH duration 2 symbols			PSSCH 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 $\lambda$	$\Delta$	$w_t(k')$		$w_t(l')$
			$k' = 0$	$k' = 1$	$l' = 0$
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

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

$$k = 4n + 2k' + \Delta$$

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 PSSCH, nor DM-RS associated with PSSCH;
- $k'$  and  $\Delta$  correspond to  $\tilde{p}_0, \dots, \tilde{p}_{v-1}$

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  $l_{\text{ref}} = 0$
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 8.4.1.1.2
  - set  $i = 1$
  - set  $l_{\text{ref}}$  to the symbol index of the DM-RS symbol
  - repeat from step 2 as long as  $l_{\text{ref}} + iL_{\text{PT-RS}}$  is inside the PSSCH 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 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

$$k = k_{\text{ref}}^{\text{RE}} + (iK_{\text{PT-RS}} + k_{\text{ref}}^{\text{RB}})N_{\text{sc}}^{\text{RB}}$$

$$k_{\text{ref}}^{\text{RB}} = \begin{cases} N_{\text{ID}} \bmod K_{\text{PT-RS}} & \text{if } N_{\text{RB}} \bmod K_{\text{PT-RS}} = 0 \\ N_{\text{ID}} \bmod (N_{\text{RB}} \bmod K_{\text{PT-RS}}) & \text{otherwise} \end{cases}$$

where

- $i = 0,1,2, \dots$
- $k_{\text{ref}}^{\text{RE}}$  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].
- $N_{\text{RB}}$  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  $N_{\text{ID}}^{\text{X}}$  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 $\tilde{p}$	$k_{\text{ref}}^{\text{RE}}$ <i>resourceElementOffset</i>			
	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  $r_i(m)$  shall be generated according to

$$r_l(m) = \frac{1}{\sqrt{2}}(1 - 2c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2c(2m + 1))$$

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

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

where

- $l$  is the OFDM symbol number within the slot,
- $n_{\text{s,f}}^{\mu}$  is the slot number within a frame, and
- $N_{\text{ID}} \in \{0,1, \dots, 65535\}$  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  $\beta_{\text{DMRS}}^{\text{PSCCH}}$  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

$$\begin{aligned} a_{k,l}^{(p,\mu)} &= \beta_{\text{DMRS}}^{\text{PSCCH}} w_{f,i}(k') r_l(3n + k') \\ k &= nN_{\text{sc}}^{\text{RB}} + 4k' + 1 \\ k' &= 0,1,2 \\ n &= 0,1, \dots \end{aligned}$$

where the following conditions are fulfilled

- they are within the resource elements constituting the PSCCH

The quantity  $w_{f,i}(k')$  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  $w_{f,i}(k')$ .**

$k'$	$w_{f,i}(k')$		
	$i = 0$	$i = 1$	$i = 2$
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

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2c(2m + 1))$$

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

$$c_{\text{init}} = N_{\text{ID}}^{\text{SL}}$$

#### 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

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2c(2m)) + j \frac{1}{\sqrt{2}}(1 - 2c(2m + 1))$$

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

$$c_{\text{init}} = (2^{10}(N_{\text{slot}}^{\text{slot}} n_{\text{s,f}}^{\mu} + l + 1)(2n_{\text{ID}} + 1) + n_{\text{ID}}) \bmod 2^{31}$$

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  $N_{\text{ID}}^{\text{X}}$  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  $\beta_{\text{CSI-RS}}$  is an amplitude scaling factor to conform with the transmit power specified in clause 8.2.1 of [6, TS 38.214].

## 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

$$N_{\text{ID}}^{\text{SL}} = N_{\text{ID},1}^{\text{SL}} + 336N_{\text{ID},2}^{\text{SL}}$$

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,  $\text{id\_net}$  consisting of  $N_{\text{ID}}^{\text{SL}} = 0,1, \dots, 335$  and  $\text{id\_oon}$  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

$$\begin{aligned} d_{\text{S-PSS}}(n) &= 1 - 2x(m) \\ m &= (n + 22 + 43N_{\text{ID},2}^{\text{SL}}) \bmod 127 \\ 0 &\leq n < 127 \end{aligned}$$

where

$$x(i + 7) = (x(i + 4) + x(i)) \bmod 2$$

and

$$[x(6) \ x(5) \ x(4) \ x(3) \ x(2) \ x(1) \ x(0)] = [1 \ 1 \ 1 \ 0 \ 1 \ 1 \ 0]$$

#### 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  $d_{S\_SSS}(n)$  for the sidelink secondary synchronization signal is defined by

$$\begin{aligned} d_{S\_SSS}(n) &= [1 - 2x_0((n + m_0) \bmod 127)][1 - 2x_1((n + m_1) \bmod 127)] \\ m_0 &= 15 \left\lfloor \frac{N_{ID,1}^{SL}}{112} \right\rfloor + 5N_{ID,2}^{SL} \\ m_1 &= N_{ID,1}^{SL} \bmod 112 \\ 0 &\leq n < 127 \end{aligned}$$

where

$$\begin{aligned} x_0(i + 7) &= (x_0(i + 4) + x_0(i)) \bmod 2 \\ x_1(i + 7) &= (x_1(i + 1) + x_1(i)) \bmod 2 \end{aligned}$$

and

$$\begin{aligned} [x_0(6) \ x_0(5) \ x_0(4) \ x_0(3) \ x_0(2) \ x_0(1) \ x_0(0)] &= [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 1] \\ [x_1(6) \ x_1(5) \ x_1(4) \ x_1(3) \ x_1(2) \ x_1(1) \ x_1(0)] &= [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 1] \end{aligned}$$

#### 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  $N_{\text{sy mb}}^{S\text{-SSB}}$  OFDM symbols, numbered in increasing order from 0 to  $N_{\text{sy mb}}^{S\text{-SSB}} - 1$  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  $N_{\text{sy mb}}^{S\text{-SSB}} = 13$  for normal cyclic prefix and  $N_{\text{sy mb}}^{S\text{-SSB}} = 11$  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  $r(0), \dots, r(33(N_{\text{symb}}^{\text{S-SSB}} - 4) - 1)$  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  $(N_{\text{TA,SL}} + N_{\text{TA,offset}}) \cdot T_c$  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  $N_{\text{TA,offset}}$ , which is given in [12, TS 38.133], after the end of a sidelink transmission.

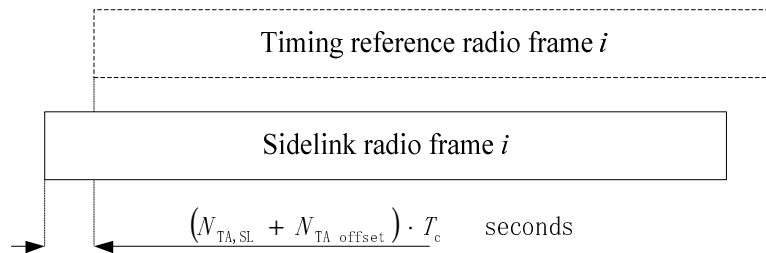
For sidelink transmissions:

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
- $N_{TA,offset}$  is given by clause 4.3.1 of [TS 38.211],

Otherwise

- The timing of reference radio frame  $i$  is given by clause 12.2.2, 12.2.3, 12.2.4 or 12.2.5 of [12, TS 38.133] and
- $N_{TA,offset} = 0$ .



**Figure 8.5-1: Sidelink timing relation**

The quantity  $N_{TA,SL}$  equals to 0.



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## Annex <A> (informative): 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
2021-12	RAN#94-e	RP-212960	0079	-	F	Correction to VRB-to-PRB mapping for DCI format 1_2	16.8.0
2021-12	RAN#94-e	RP-212966	0080	-	B	Introduction of MIMO enhancements	17.0.0
2021-12	RAN#94-e	RP-212967	0081	-	B	Introduction of extensions to 71 GHz	17.0.0
2021-12	RAN#94-e	RP-212969	0082	-	B	Introduction of Non-Terrestrial Networks (NTN)	17.0.0
2021-12	RAN#94-e	RP-212973	0083	-	B	Introduction of coverage enhancements	17.0.0
2021-12	RAN#94-e	RP-212979	0084	-	B	Introduction of Multicast and Broadcast Services (MBS) support	17.0.0
2021-12	RAN#94-e	RP-212982	0085	-	B	Introduction of DL 1024QAM for NR FR1	17.0.0
2022-03	RAN#95-e	RP-220920	0086	2	C	Pi/2-BPSK specification updates for the merger of 5Gi into 3GPP	17.1.0
2022-03	RAN#95-e	RP-220245	0088	-	A	CR on corrections on SL timing	17.1.0
2022-03	RAN#95-e	RP-220251	0089	-	F	Corrections to NR in the 52.6 – 71 GHz range	17.1.0
2022-03	RAN#95-e	RP-220263	0090	-	F	Corrections to NR support of multicast and broadcast services	17.1.0
2022-03	RAN#95-e	RP-220250	0091	-	F	Corrections to MIMO enhancements	17.1.0
2022-03	RAN#95-e	RP-220252	0092	-	F	Corrections to IIoT and URLLC enhancements	17.1.0
2022-03	RAN#95-e	RP-220253	0093	-	F	Corrections to NR NTN support	17.1.0
2022-03	RAN#95-e	RP-220270	0094	-	F	Corrections to small data transmissions in RRC_INACTIVE state	17.1.0
2022-06	RAN#96	RP-221606	0095	-	F	Corrections on NR UE Power Saving Enhancements	17.2.0
2022-06	RAN#96	RP-221600	0096	-	F	Corrections to MIMO enhancements	17.2.0
2022-06	RAN#96	RP-221603	0097	-	F	Corrections to timing advance for NTN	17.2.0
2022-06	RAN#96	RP-221620	0099	-	A	Clarification of PUSCH DM-RS generation	17.2.0
2022-09	RAN#97-e	RP-222401	0100	-	F	Correction on the subcarrier offset, kssb	17.3.0
2022-09	RAN#97-e	RP-222406	0101	-	F	Corrections on UE Power Saving Enhancements for NR in TS 38.211	17.3.0
2022-09	RAN#97-e	RP-222412	0102	-	F	Corrections to NR support of multicast and broadcast services	17.3.0

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# History

<b>Document history</b>		
V17.1.0	April 2022	Publication
V17.2.0	July 2022	Publication
V17.3.0	September 2022	Publication