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Contents

Foreword.....	6
1 Scope	7
2 References	7
3 Definitions, symbols and abbreviations	7
3.1 Definitions	7
3.2 Symbols	7
3.3 Abbreviations.....	8
4 Frame structure and physical resources.....	9
4.1 General.....	9
4.2 Numerologies.....	9
4.3 Frame structure	9
4.3.1 Frames and subframes.....	9
4.3.2 Slots.....	10
4.4 Physical resources.....	11
4.4.1 Antenna ports	11
4.4.2 Resource grid	11
4.4.3 Resource elements.....	12
4.4.4 Resource blocks	12
4.4.4.1 General	12
4.4.4.2 Point A.....	12
4.4.4.3 Common resource blocks	12
4.4.4.4 Physical resource blocks.....	12
4.4.4.5 Virtual resource blocks.....	12
4.4.5 Bandwidth part.....	13
4.5 Carrier aggregation	13
5 Generic functions	13
5.1 Modulation mapper.....	13
5.1.1 π/2-BPSK	13
5.1.2 BPSK.....	13
5.1.3 QPSK	13
5.1.4 16QAM	14
5.1.5 64QAM	14
5.1.6 256QAM	14
5.2 Sequence generation	14
5.2.1 Pseudo-random sequence generation	14
5.2.2 Low-PAPR sequence generation.....	14
5.2.2.1 Base sequences of length 36 or larger	15
5.2.2.2 Base sequences of length less than 36	15
5.3 OFDM baseband signal generation.....	19
5.3.1 OFDM baseband signal generation for all channels except PRACH	19
5.3.2 OFDM baseband signal generation for PRACH	20
5.4 Modulation and upconversion.....	21
6 Uplink.....	22
6.1 Overview	22
6.1.1 Overview of physical channels.....	22
6.1.2 Overview of physical signals	22
6.2 Physical resources.....	22
6.3 Physical channels	23
6.3.1 Physical uplink shared channel	23
6.3.1.1 Scrambling.....	23
6.3.1.2 Modulation	23
6.3.1.3 Layer mapping.....	24
6.3.1.4 Transform precoding	24
6.3.1.5 Precoding.....	25
6.3.1.6 Mapping to virtual resource blocks	28

6.3.1.7	Mapping from virtual to physical resource blocks	28
6.3.2	Physical uplink control channel	28
6.3.2.1	General	28
6.3.2.2	Sequence and cyclic shift hopping	29
6.3.2.2.1	Group and sequence hopping	29
6.3.2.2.2	Cyclic shift hopping	29
6.3.2.3	PUCCH format 0	30
6.3.2.3.1	Sequence generation	30
6.3.2.3.2	Mapping to physical resources	30
6.3.2.4	PUCCH format 1	30
6.3.2.4.1	Sequence modulation	30
6.3.2.4.2	Mapping to physical resources	32
6.3.2.5	PUCCH format 2	32
6.3.2.5.1	Scrambling	32
6.3.2.5.2	Modulation	32
6.3.2.5.3	Mapping to physical resources	32
6.3.2.6	PUCCH formats 3 and 4	32
6.3.2.6.1	Scrambling	32
6.3.2.6.2	Modulation	33
6.3.2.6.3	Block-wise spreading	33
6.3.2.6.4	Transform precoding	34
6.3.2.6.5	Mapping to physical resources	34
6.3.3	Physical random-access channel	34
6.3.3.1	Sequence generation	34
6.3.3.2	Mapping to physical resources	40
6.4	Physical signals	59
6.4.1	Reference signals	59
6.4.1.1	Demodulation reference signal for PUSCH	59
6.4.1.1.1	Sequence generation	59
6.4.1.1.2	(void)	60
6.4.1.1.3	Precoding and mapping to physical resources	60
6.4.1.2	Phase-tracking reference signals for PUSCH	64
6.4.1.2.1	Sequence generation	64
6.4.1.2.1.1	Sequence generation if transform precoding is not enabled	64
6.4.1.2.1.2	Sequence generation if transform precoding is enabled	65
6.4.1.2.2	Mapping to physical resources	65
6.4.1.2.2.1	Precoding and mapping to physical resources if transform precoding is not enabled	65
6.4.1.2.2.2	Mapping to physical resources if transform precoding is enabled	67
6.4.1.3	Demodulation reference signal for PUCCH	68
6.4.1.3.1	Demodulation reference signal for PUCCH format 1	68
6.4.1.3.1.1	Sequence generation	68
6.4.1.3.1.2	Mapping to physical resources	69
6.4.1.3.2	Demodulation reference signal for PUCCH format 2	69
6.4.1.3.2.1	Sequence generation	69
6.4.1.3.2.2	Mapping to physical resources	69
6.4.1.3.3	Demodulation reference signal for PUCCH formats 3 and 4	70
6.4.1.3.3.1	Sequence generation	70
6.4.1.3.3.2	Mapping to physical resources	70
6.4.1.4	Sounding reference signal	71
6.4.1.4.1	SRS resource	71
6.4.1.4.2	Sequence generation	71
6.4.1.4.3	Mapping to physical resources	72
6.4.1.4.4	Sounding reference signal slot configuration	76
7	Downlink	76
7.1	Overview	76
7.1.1	Overview of physical channels	76
7.1.2	Overview of physical signals	76
7.2	Physical resources	76
7.3	Physical channels	77
7.3.1	Physical downlink shared channel	77
7.3.1.1	Scrambling	77

7.3.1.2	Modulation	77
7.3.1.3	Layer mapping	77
7.3.1.4	Antenna port mapping	78
7.3.1.5	Mapping to virtual resource blocks	79
7.3.1.6	Mapping from virtual to physical resource blocks	79
7.3.2	Physical downlink control channel (PDCCH)	81
7.3.2.1	Control-channel element (CCE)	81
7.3.2.2	Control-resource set (CORESET)	81
7.3.2.3	Scrambling	82
7.3.2.4	PDCCH modulation	82
7.3.2.5	Mapping to physical resources	83
7.3.3	Physical broadcast channel	83
7.3.3.1	Scrambling	83
7.3.3.2	Modulation	83
7.3.3.3	Mapping to physical resources	83
7.4	Physical signals	83
7.4.1	Reference signals	83
7.4.1.1	Demodulation reference signals for PDSCH	83
7.4.1.1.1	Sequence generation	83
7.4.1.1.2	Mapping to physical resources	84
7.4.1.2	Phase-tracking reference signals for PDSCH	87
7.4.1.2.1	Sequence generation	87
7.4.1.2.2	Mapping to physical resources	87
7.4.1.3	Demodulation reference signals for PDCCH	88
7.4.1.3.1	Sequence generation	88
7.4.1.3.2	Mapping to physical resources	89
7.4.1.4	Demodulation reference signals for PBCH	89
7.4.1.4.1	Sequence generation	89
7.4.1.4.2	Mapping to physical resources	90
7.4.1.5	CSI reference signals	90
7.4.1.5.1	General	90
7.4.1.5.2	Sequence generation	90
7.4.1.5.3	Mapping to physical resources	90
7.4.2	Synchronization signals	93
7.4.2.1	Physical-layer cell identities	93
7.4.2.2	Primary synchronization signal	93
7.4.2.2.1	Sequence generation	93
7.4.2.2.2	Mapping to physical resources	94
7.4.2.3	Secondary synchronization signal	94
7.4.2.3.1	Sequence generation	94
7.4.2.3.2	Mapping to physical resources	94
7.4.3	SS/PBCH block	94
7.4.3.1	Time-frequency structure of an SS/PBCH block	94
7.4.3.1.1	Mapping of PSS within an SS/PBCH block	95
7.4.3.1.2	Mapping of SSS within an SS/PBCH block	95
7.4.3.1.3	Mapping of PBCH and DM-RS within an SS/PBCH block	95
7.4.3.2	Time location of an SS/PBCH block	96
Annex A:	Change history	97

Foreword

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1 Scope

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

2 References

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

- [1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".
- [2] 3GPP TS 38.201: "NR; Physical Layer – General Description"
- [3] 3GPP TS 38.202: "NR; Services provided by the physical layer"
- [4] 3GPP TS 38.212: "NR; Multiplexing and channel coding"
- [5] 3GPP TS 38.213: "NR; Physical layer procedures for control "
- [6] 3GPP TS 38.214: "NR; Physical layer procedures for data "
- [7] 3GPP TS 38.215: "NR; Physical layer measurements"
- [8] 3GPP TS 38.104: "NR; Base Station (BS) radio transmission and reception"
- [9] void
- [10] 3GPP TS 38.306: "NR; User Equipment (UE) radio access capabilities"

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 μ ; see clause 4.4.3
$a_{k, l}^{(p, \mu)}$	Value of resource element (k, l) for antenna port p and subcarrier spacing configuration μ ; see clause 4.4.3
β	Amplitude scaling for a physical channel/signal
$c(n)$	PN sequence; see clause 5.2.1
Δf	Subcarrier spacing
Δf_{RA}	Subcarrier spacing for random-access preambles
κ	The ratio between T_s and T_c ; see clause 4.1
k	Subcarrier index relative to a reference
l	OFDM symbol index relative to a reference
μ	Subcarrier spacing configuration, $\Delta f = 2^\mu \cdot 15 [\text{kHz}]$
$M_{\text{bit}}^{(q)}$	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
ν	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
$N_{\text{CP},l}^{\mu}$	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
$N_{\text{RB}}^{\text{CORESET}}$	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 μ , see clause 4.3.2
$N_{\text{slot}}^{\text{frame},\mu}$	Number of slots per frame for subcarrier spacing configuration μ , 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 μ ; see clause 4.3.1
$N_{\text{symb}}^{\text{slot}}$	Number of symbols per slot
N_{TA}	Timing advance between downlink and uplink; see clause 4.3.1
$N_{\text{TA,offset}}$	A fixed offset used to calculate the timing advance; 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_{CRB}^{μ}	Common resource block number for subcarrier spacing configuration μ , see clause 4.4.4.3
n_{PRB}	Physical resource block number; see clause 4.4.4.4
n_{RNTI}	Radio network temporary identifier
n_s^{μ}	Slot number within a subframe for subcarrier spacing configuration μ ; see clause 4.3.2
$n_{s,f}^{\mu}$	Slot number within a frame for subcarrier spacing configuration μ ; see clause 4.3.2
p	Antenna port number
Q_m	Modulation order
ρ	Number of antenna ports
$\bar{r}_{u,v}(n)$	Low-PAPR base sequence; see clause 5.2.2
$r_{u,v}^{(\alpha,\delta)}(n)$	Low-PAPR sequence; see clause 5.2.2
$s_l^{(p,\mu)}(t)$	The time-continuous signal on antenna port p and subcarrier spacing configuration μ for OFDM symbol l in a subframe; see clause 5.3.1
T_c	Basic time unit for NR; see clause 4.1
T_f	Radio frame duration; see clause 4.3.1
T_s	Basic time unit for LTE
T_{sf}	Subframe duration; see clause 4.3.1
T_{slot}	Slot duration; see clause 4.3.2
T_{TA}	Timing advance between downlink and uplink; see clause 4.3.1
W	Precoding matrix for spatial multiplexing

3.3 Abbreviations

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

BWP	Bandwidth part
CCE	Control channel element
CORESET	Control resource set
CRB	Common resource block
CSI	Channel-state information

CSI-RS	CSI reference signal
DCI	Downlink Control Information
DM-RS	Demodulation reference signal
FR1	Frequency range 1 as defined in [8, TS 38.104]
FR2	Frequency range 2 as defined in [8, TS 38.104]
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
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 $T_c = 1/(\Delta f_{\max} \cdot N_f)$ where $\Delta f_{\max} = 480 \cdot 10^3$ Hz and $N_f = 4096$. The constant $\kappa = T_s/T_c = 64$ where

$$T_s = 1/(\Delta f_{\text{ref}} \cdot N_{f,\text{ref}}), \Delta f_{\text{ref}} = 15 \cdot 10^3 \text{ Hz} \text{ and } N_{f,\text{ref}} = 2048.$$

4.2 Numerologies

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

Table 4.2-1: Supported transmission numerologies.

μ	$\Delta f = 2^\mu \cdot 15$ [kHz]	Cyclic prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

4.3 Frame structure

4.3.1 Frames and subframes

Downlink and uplink 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 $N_{\text{symb}}^{\text{subframe},\mu} = N_{\text{symb}}^{\text{slot}} N_{\text{slot}}^{\text{subframe},\mu}$. 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 $T_{TA} = (N_{TA} + N_{TA,\text{offset}}) T_c$ before the start of the corresponding downlink frame at the UE where $N_{TA,\text{offset}}$ is given by [5, TS 38.213].

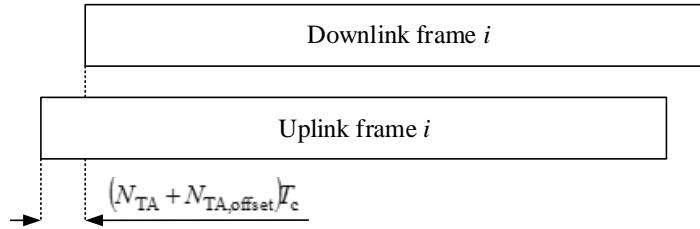


Figure 4.3.1-1: Uplink-downlink timing relation.

4.3.2 Slots

For subcarrier spacing configuration μ , 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 $N_{\text{symb}}^{\text{slot}}$ consecutive OFDM symbols in a slot where $N_{\text{symb}}^{\text{slot}}$ depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2. The start of slot n_s^μ in a subframe is aligned in time with the start of OFDM symbol $n_s^\mu N_{\text{symb}}^{\text{slot}}$ in the same subframe.

OFDM symbols in a slot can be classified as 'downlink', 'flexible', or 'uplink'. Signaling of slot formats is described in subclause 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.

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.

μ	$N_{\text{symb}}^{\text{slot}}$	$N_{\text{slot}}^{\text{frame},\mu}$	$N_{\text{slot}}^{\text{subframe},\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

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

μ	$N_{\text{symb}}^{\text{slot}}$	$N_{\text{slot}}^{\text{frame}, \mu}$	$N_{\text{slot}}^{\text{subframe}, \mu}$
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.

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.

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 $N_{\text{symb}}^{\text{subframe}, \mu}$ 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 or downlink) with the subscript x set to DL and UL for downlink and uplink, respectively. When there is no risk for confusion, the subscript x may be dropped. There is one resource grid for a given antenna port p , subcarrier spacing configuration μ , and transmission direction (downlink or uplink).

The carrier bandwidth $N_{\text{grid}}^{\text{size}, \mu}$ for subcarrier spacing configuration μ 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 μ is given by the higher-layer parameter *offsetToCarrier* in the *SCS-SpecificCarrier* IE.

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

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

For the uplink, the higher-layer parameter *txDirectCurrentLocation* in the *UplinkTxDirectCurrentBWP* IE indicates the location of the transmitter DC subcarrier in the uplink for each of the configured bandwidth parts, including whether the

DC subcarrier location is offset by 7.5 kHz relative to the center of the indicated subcarrier or not. Values in the range 0 – 3299 represent the number of the DC subcarrier, the value 3300 indicates that the DC subcarrier is located outside the resource grid, and the value 3301 indicates that the position of the DC subcarrier in the uplink is undetermined.

4.4.3 Resource elements

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

4.4.4 Resource blocks

4.4.4.1 General

A resource block is defined as $N_{\text{sc}}^{\text{RB}} = 12$ 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 has the subcarrier spacing provided by the higher-layer parameter *subCarrierSpacingCommon* and 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;
- *absoluteFrequencyPointA* for all other cases where *absoluteFrequencyPointA* represents the frequency-location of point A expressed as in ARFCN.

4.4.4.3 Common resource blocks

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

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

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

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 configuration μ 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_{PRB}^{μ} in bandwidth part i and the common resource block n_{CRB}^{μ} is given by

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

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 μ may be dropped.

4.4.4.5 Virtual resource blocks

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

4.4.5 Bandwidth part

A bandwidth part is a subset of contiguous common resource blocks defined in subclause 4.4.4.3 for a given numerology μ_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 $N_{\text{grid},x}^{\text{start},\mu} \leq N_{\text{BWP},i}^{\text{start},\mu} < N_{\text{grid},x}^{\text{start},\mu} + N_{\text{grid},x}^{\text{size},\mu}$ 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 μ 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 $N_{\text{grid},x}^{\text{size},\mu}$.

4.5 Carrier aggregation

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

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

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

5.1.5 64QAM

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

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

5.1.6 256QAM

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

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

5.2 Sequence generation

5.2.1 Pseudo-random sequence generation

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

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

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

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

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

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

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

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

where

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

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

5.2.2.2 Base sequences of length less than 36

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

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

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 $\phi(n)$ for $M_{\text{ZC}} = 6$.

u	$\phi(0), \dots, \phi(5)$						
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

- μ_0 is the largest μ value among the subcarrier spacing configurations by the higher-layer parameter *scs-SpecificCarrierList*.

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

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

5.3.2 OFDM baseband signal generation for PRACH

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

$$\begin{aligned} s_l^{(p,\mu)}(t) &= \sum_{k=0}^{L_{\text{RA}}-1} a_k^{(p,\text{RA})} e^{j2\pi(k+Kk_1+\bar{k})\Delta f_{\text{RA}}(t-N_{\text{CP},l}^{\text{RA}}T_c-t_{\text{start}}^{\text{RA}})} \\ K &= \Delta f / \Delta f_{\text{RA}} \\ k_1 &= k_0^{\mu} + (N_{\text{BWP},i}^{\text{start}} - N_{\text{grid}}^{\text{start},\mu})N_{\text{sc}}^{\text{RB}} + n_{\text{RA}}^{\text{start}}N_{\text{sc}}^{\text{RB}} + n_{\text{RA}}N_{\text{RB}}^{\text{RA}}N_{\text{sc}}^{\text{RB}} - N_{\text{grid}}^{\text{size},\mu}N_{\text{sc}}^{\text{RB}}/2 \\ k_0^{\mu} &= (N_{\text{grid}}^{\text{start},\mu} + N_{\text{grid}}^{\text{size},\mu}/2)N_{\text{sc}}^{\text{RB}} - (N_{\text{grid}}^{\text{start},\mu_0} + N_{\text{grid}}^{\text{size},\mu_0}/2)N_{\text{sc}}^{\text{RB}}2^{\mu_0-\mu} \end{aligned}$$

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

- \bar{k} is given by clause 6.3.3;
- Δf is the subcarrier spacing of the initial uplink bandwidth part during initial access. Otherwise, Δf is the subcarrier spacing of the active uplink bandwidth part;
- μ_0 is the largest μ value among the subcarrier spacing configurations by the higher-layer parameter *scs-SpecificCarrierList*;
- $N_{\text{BWP},i}^{\text{start}}$ 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 lowest PRACH transmission occasion in frequency domain with respect to PRB 0 of the initial uplink bandwidth part given by the higher-layer parameter *msg1-FrequencyStart* during initial access associated with the initial uplink bandwidth part. Otherwise, $n_{\text{RA}}^{\text{start}}$ is the frequency offset of lowest PRACH transmission occasion in frequency domain with respect to physical resource block 0 of the active uplink bandwidth part given by the higher-layer parameter *msg1-FrequencyStart* associated with the active uplink bandwidth part;
- n_{RA} is the PRACH transmission occasion index in frequency domain for a given PRACH transmission occasion in one time instance as given by clause 6.3.3.2;
- $N_{\text{RB}}^{\text{RA}}$ 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.
- L_{RA} and N_u are given by clause 6.3.3
- $N_{\text{CP},l}^{\text{RA}} = N_{\text{CP}}^{\text{RA}} + n \cdot 16\kappa$ where
 - for $\Delta f_{\text{RA}} \in \{1.25, 5\} \text{ kHz}$, $n = 0$
 - for $\Delta f_{\text{RA}} \in \{15, 30, 60, 120\} \text{ kHz}$, n is the number of times the interval $[t_{\text{start}}^{\text{RA}}, t_{\text{start}}^{\text{RA}} + (N_u^{\text{RA}} + N_{\text{CP}}^{\text{RA}})T_c]$ overlaps with either time instance 0 or time instance $(\Delta f_{\text{max}} N_f / 2000) \cdot T_c = 0.5 \text{ ms}$ in a subframe

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

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

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

where

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

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

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

If 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 $n_t^{\text{RA}} = N_t^{\text{RA},\text{slot}} - 1$, 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

5.4 Modulation and upconversion

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

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

for all channels and signals except PRACH and by

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

for PRACH.

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 intra-slot frequency hopping is not enabled by higher layer parameter 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 if the two symbols correspond to the same slot.

If intra-slot frequency hopping is enabled by higher layer parameter 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.

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

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

where

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

and where n_{RNTI} corresponds to the RNTI associated with the PUSCH transmission as described in clause 6.1 of [6, TS 38.214].

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
		$\pi/2\text{-BPSK}$	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

$d^{(q)}(0), \dots, d^{(q)}(M_{\text{symb}}^{\text{layer}} - 1)$ 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 $N_{\text{group}}^{\text{PTRS}}$ 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

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

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

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

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 $\begin{bmatrix} y^{(0)}(i) & \dots & y^{(v-1)}(i) \end{bmatrix}^T$, $i = 0, 1, \dots, M_{\text{symb}}^{\text{layer}} - 1$ 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)							
	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 0 \end{bmatrix}$	$\frac{1}{\sqrt{2}} \begin{bmatrix} 0 \\ 1 \end{bmatrix}$	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix}$	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -1 \end{bmatrix}$	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ j \end{bmatrix}$	$\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -j \end{bmatrix}$	-	-
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)							
	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -j \\ 0 \end{bmatrix}$
0 – 7	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -j \\ 0 \end{bmatrix}$
8 – 15	$\frac{1}{2} \begin{bmatrix} 0 \\ 1 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ 1 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ j \end{bmatrix}$
16 – 23	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ j \\ -j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -1 \\ -j \end{bmatrix}$
24 – 27	$\frac{1}{2} \begin{bmatrix} 1 \\ -j \\ 1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -j \\ j \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -j \\ -1 \end{bmatrix}$	$\frac{1}{2} \begin{bmatrix} 1 \\ -j \\ j \end{bmatrix}$	-	-	-	-

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	$\begin{bmatrix} 1 \\ 0 \\ \frac{1}{2} \\ 0 \\ 0 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 1 \\ \frac{1}{2} \\ 0 \\ 0 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 0 \\ \frac{1}{2} \\ 1 \\ 0 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 0 \\ \frac{1}{2} \\ 0 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ \frac{1}{2} \\ 1 \\ 0 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ \frac{1}{2} \\ -1 \\ 0 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ \frac{1}{2} \\ j \\ 0 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 0 \\ \frac{1}{2} \\ -j \\ 0 \end{bmatrix}$
8 – 15	$\begin{bmatrix} 0 \\ 1 \\ \frac{1}{2} \\ 0 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 1 \\ \frac{1}{2} \\ 0 \\ -1 \end{bmatrix}$	$\begin{bmatrix} 0 \\ 1 \\ \frac{1}{2} \\ 0 \\ j \end{bmatrix}$	$\begin{bmatrix} 0 \\ 1 \\ \frac{1}{2} \\ 0 \\ -j \end{bmatrix}$	$\begin{bmatrix} 1 \\ 1 \\ \frac{1}{2} \\ 1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 1 \\ \frac{1}{2} \\ j \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 1 \\ \frac{1}{2} \\ -1 \\ -1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ 1 \\ \frac{1}{2} \\ -j \\ -j \end{bmatrix}$
16 – 23	$\begin{bmatrix} 1 \\ j \\ \frac{1}{2} \\ 1 \\ j \end{bmatrix}$	$\begin{bmatrix} 1 \\ j \\ \frac{1}{2} \\ j \\ -1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ j \\ \frac{1}{2} \\ -1 \\ -j \end{bmatrix}$	$\begin{bmatrix} 1 \\ j \\ \frac{1}{2} \\ -j \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ -1 \\ \frac{1}{2} \\ 1 \\ -1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ -1 \\ \frac{1}{2} \\ j \\ -j \end{bmatrix}$	$\begin{bmatrix} 1 \\ -1 \\ \frac{1}{2} \\ -1 \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ -1 \\ \frac{1}{2} \\ -j \\ j \end{bmatrix}$
24 – 27	$\begin{bmatrix} 1 \\ -j \\ \frac{1}{2} \\ 1 \\ -j \end{bmatrix}$	$\begin{bmatrix} 1 \\ -j \\ \frac{1}{2} \\ j \\ 1 \end{bmatrix}$	$\begin{bmatrix} 1 \\ -j \\ \frac{1}{2} \\ -1 \\ j \end{bmatrix}$	$\begin{bmatrix} 1 \\ -j \\ \frac{1}{2} \\ -j \\ -1 \end{bmatrix}$	-	-	-	-

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

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

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

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

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

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

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

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

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 β_{PUSCH} in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $z^{(p)}(0)$ to resource elements $(k', l)_{p,\mu}$ in the virtual resource blocks assigned for transmission which meet all of the following criteria:

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

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

6.3.1.7 Mapping from virtual to physical resource blocks

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

For non-interleaved VRB-to-PRB mapping, 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 $n + N_{\text{BWP},0}^{\text{start}} - N_{\text{BWP},i}^{\text{start}}$.

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	≤ 2
1	4 – 14	≤ 2
2	1 – 2	> 2
3	4 – 14	> 2
4	4 – 14	> 2

6.3.2.2 Sequence and cyclic shift hopping

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

6.3.2.2.1 Group and sequence hopping

The sequence group $u = (f_{\text{gh}} + f_{\text{ss}}) \bmod 30$ 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_{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'

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

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_{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_{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 α varies as a function of the symbol and slot number according to

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

where

- $n_{s,f}^{\mu}$ 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 subclause 6.4.1.3.3.1
- $m_{cs} = 0$ except for PUCCH format 0 when it depends on the information to be transmitted according to subclause 9.2 of [5, TS 38.213].

The function $n_{cs}(n_c, l)$ is given by

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

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

6.3.2.3 PUCCH format 0

6.3.2.3.1 Sequence generation

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

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

where $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 6.3.2.2 with m_{cs} depending on the information to be transmitted according to subclause 9.2 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 $\beta_{PUCCH,0}$ 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 subclause 9.2.1 of [5, TS 38.213] in increasing order of first the index k over the assigned physical resources, and then the index l on antenna port $p = 2000$.

6.3.2.4 PUCCH format 1

6.3.2.4.1 Sequence modulation

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

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

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

where $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 6.3.2.2. The block of complex-valued symbols $y(0), \dots, y(N_{\text{sc}}^{\text{RB}} - 1)$ shall be block-wise spread with the orthogonal sequence $w_i(m)$ according to

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

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

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

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

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, 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 subclause 9.2.1 of [5, TS 38.213]. In case of a PUCCH transmission spanning multiple slots according to subclause 9.2.6 of [5, TS 38.213], the complex-valued symbol $d(0)$ is repeated for the subsequent slots.

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

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

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

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

6.3.2.4.2 Mapping to physical resources

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

- they are in the resource blocks assigned for transmission according to subclause 9.2.1 of [5, TS 38.213],
- 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 block, and then the index l on antenna port $p = 2000$.

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

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

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

6.3.2.5.3 Mapping to physical resources

The block of modulation symbols $d(0), \dots, d(M_{\text{symb}} - 1)$ shall be multiplied with the amplitude scaling factor $\beta_{\text{PUCCH},2}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $d(0)$ 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 subclause 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_{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

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

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_{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 subclauses 9.2.3, 9.2.5.1 and 9.2.5.2 of [5, TS 38.213] and shall fulfil

$$M_{\text{RB}}^{\text{PUCCH},s} = \begin{cases} 2^{\alpha_2} \cdot 3^{\alpha_3} \cdot 5^{\alpha_5} & \text{for PUCCH format 3} \\ 1 & \text{for PUCCH format 4} \end{cases}$$

where $\alpha_2, \alpha_3, \alpha_5$ is a set of non-negative integers and $s \in \{3,4\}$.

For PUCCH format 3, no block-wise spreading is applied and

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

where $M_{\text{RB}}^{\text{PUCCH},3} \geq 1$ is given by subclauses 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 4, block-wise spreading shall be applied according to

$$\begin{aligned} y(lM_{\text{sc}}^{\text{PUCCH},4} + k) &= w_n(k) \cdot d\left(l \frac{M_{\text{sc}}^{\text{PUCCH},4}}{N_{\text{SF}}^{\text{PUCCH},4}} + k \bmod \frac{M_{\text{sc}}^{\text{PUCCH},4}}{N_{\text{SF}}^{\text{PUCCH},4}}\right) \\ k &= 0,1,\dots, M_{\text{sc}}^{\text{PUCCH},4} - 1 \\ l &= 0,1,\dots, \left(N_{\text{SF}}^{\text{PUCCH},4} M_{\text{symb}} / M_{\text{sc}}^{\text{PUCCH},4}\right) - 1 \end{aligned}$$

where $M_{\text{RB}}^{\text{PUCCH},4} = 1$, $N_{\text{SF}}^{\text{PUCCH},4} \in \{2,4\}$ and w_n are given by Tables 6.3.2.6.3-1 and 6.3.2.6.3-2 where n is the index of the orthogonal sequence to use according to subclause 9.2.1 of [5, TS 38.213].

Table 6.3.2.6.3-1: Orthogonal sequences $w_n(m)$ for PUCCH format 4 when $N_{\text{SF}}^{\text{PUCCH},4} = 2$.

n	w_n
0	[+1 +1 +1 +1 +1 +1 +1 +1 +1 +1 +1 +1]
1	[+1 +1 +1 +1 +1 +1 -1 -1 -1 -1 -1 -1]

Table 6.3.2.6.3-2: Orthogonal sequences $w_n(m)$ for PUCCH format 4 when $N_{\text{SF}}^{\text{PUCCH},4} = 4$.

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

6.3.2.6.4 Transform precoding

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

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

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

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

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

6.3.2.6.5 Mapping to physical resources

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

6.3.3 Physical random-access channel

6.3.3.1 Sequence generation

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

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

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

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

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

where $L_{\text{RA}} = 839$ or $L_{\text{RA}} = 139$ 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*. 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 837 when $L_{\text{RA}} = 839$ and is consecutive to 137 when $L_{\text{RA}} = 139$. The sequence number u is obtained from the logical root sequence index according to Tables 6.3.3.1-3 and 6.3.3.1-4.

The cyclic shift C_v is given by

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

where N_{CS} is given by Tables 6.3.3.1-5 to 6.3.3.1-7, 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

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

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

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

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

$$n_{\text{shift}}^{\text{RA}} = \lfloor d_u / N_{\text{CS}} \rfloor$$

$$d_{\text{start}} = 2d_u + n_{\text{shift}}^{\text{RA}} N_{\text{CS}}$$

$$n_{\text{group}}^{\text{RA}} = \lfloor L_{\text{RA}} / d_{\text{start}} \rfloor$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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 $\Delta f^{\text{RA}} \in \{1, 2.5, 5\} \text{ kHz}$.

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

Table 6.3.3.1-2: Preamble formats for $L_{\text{RA}} = 139$ and $\Delta f^{\text{RA}} = 15 \cdot 2^\mu \text{ kHz}$ where $\mu \in \{0, 1, 2, 3\}$.

Format	L_{RA}	Δf^{RA}	N_u	$N_{\text{CP}}^{\text{RA}}$	Support for restricted sets
A1	139	$15 \cdot 2^\mu \text{ kHz}$	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$288\kappa \cdot 2^{-\mu}$	-
A2	139	$15 \cdot 2^\mu \text{ kHz}$	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$576\kappa \cdot 2^{-\mu}$	-
A3	139	$15 \cdot 2^\mu \text{ kHz}$	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$864\kappa \cdot 2^{-\mu}$	-
B1	139	$15 \cdot 2^\mu \text{ kHz}$	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$216\kappa \cdot 2^{-\mu}$	-
B2	139	$15 \cdot 2^\mu \text{ kHz}$	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$360\kappa \cdot 2^{-\mu}$	-
B3	139	$15 \cdot 2^\mu \text{ kHz}$	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$504\kappa \cdot 2^{-\mu}$	-
B4	139	$15 \cdot 2^\mu \text{ kHz}$	$12 \cdot 2048\kappa \cdot 2^{-\mu}$	$936\kappa \cdot 2^{-\mu}$	-
C0	139	$15 \cdot 2^\mu \text{ kHz}$	$2048\kappa \cdot 2^{-\mu}$	$1240\kappa \cdot 2^{-\mu}$	-
C2	139	$15 \cdot 2^\mu \text{ kHz}$	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$	-

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

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

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

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

Table 6.3.3.1-7: N_{CS} for preamble formats with $\Delta f^{\text{RA}} = 15 \cdot 2^{\mu} \text{ kHz}$ where $\mu \in \{0,1,2,3\}$.

zeroCorrelationZoneConfig	N_{CS} value for unrestricted set
0	0
1	2
2	4
3	6
4	8
5	10
6	12
7	13
8	15
9	17
10	19
11	23
12	27
13	34
14	46
15	69

6.3.3.2 Mapping to physical resources

The preamble sequence shall be mapped to physical resources according to

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

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

Random access pREAMbles can only be transmitted in the time resources given by the higher-layer parameter *prach-ConfigurationIndex* according to 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].

Random access pREAMbles can only be transmitted in the frequency resources given by the higher-layer parameter *msg1-FrequencyStart*. The PRACH frequency resources $n_{\text{RA}} \in \{0,1,\dots,M-1\}$, where M equals the higher-layer parameter *msg1-FDM*, are numbered in increasing order within the initial uplink bandwidth part during initial access, starting from the lowest frequency. Otherwise, n_{RA} are numbered in increasing order within the active uplink bandwidth part, starting from the lowest frequency.

For 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 Section 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 Δf^{RA} and Δf , and the corresponding value of \bar{k} .

L_{RA}	Δf^{RA} for PRACH	Δf for PUSCH	$N_{\text{RB}}^{\text{RA}}$, allocation expressed in number of RBs for PUSCH	\bar{k}
839	1.25	15	6	7
839	1.25	30	3	1
839	1.25	60	2	133
839	5	15	24	12
839	5	30	12	10
839	5	60	6	7
139	15	15	12	2
139	15	30	6	2
139	15	60	3	2
139	30	15	24	2
139	30	30	12	2
139	30	60	6	2
139	60	60	12	2
139	60	120	6	2
139	120	60	24	2
139	120	120	12	2

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

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	$n_{SFN} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{\text{RA},\text{slot}}$, number of time-domain PRACH occasions within a PRACH slot	$N_{\text{dur}}^{\text{RA}}$, PRACH duration
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

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

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

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

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

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

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 in [4, TS 38.212] is used or by the higher layer parameter *dmrs-SeqInitialization*, if present, for a Type 1 PUSCH transmission with a configured grant, 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

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

where $r_{u,v}^{(\alpha,\delta)}(m)$ is given by clause 5.2.2 with $\delta = 1$ and $\alpha = 0$ for a PUSCH transmission.

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

where f_{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

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

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

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

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 except for the case of double-symbol DMRS in which case l is the OFDM symbol number 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,

$$\begin{aligned} \tilde{a}_{k,l}^{(\tilde{p}_j,\mu)} &= w_{\text{f}}(k') w_{\text{t}}(l') r(2n+k') \\ k &= \begin{cases} 4n+2k'+\Delta & \text{Configuration type 1} \\ 6n+k'+\Delta & \text{Configuration type 2} \end{cases} \\ k' &= 0,1 \\ l &= \bar{l} + l' \\ n &= 0,1,\dots \\ j &= 0,1,\dots,v-1 \end{aligned}$$

- if transform precoding is enabled

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

where $w_f(k')$, $w_i(l')$, and Δ are given by Tables 6.4.1.1.3-1 and 6.4.1.1.3-2 and the configuration type is given by the higher-layer parameter *DMRS-UplinkConfig*, and both k' and Δ correspond to $\tilde{p}_0, \dots, \tilde{p}_{v-1}$. The intermediate quantity $\tilde{a}_{k,l}^{(\tilde{p}_0,\mu)} = 0$ if either k' or Δ does not correspond to $\tilde{p}_0, \dots, \tilde{p}_{v-1}$.

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

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

where

- the precoding matrix W is given by clause 6.3.1.5,
- the set of antenna ports $\{p_0, \dots, p_{v-1}\}$ is given by clause 6.3.1.5, 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 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, 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 *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* equal to 'pos3' is only supported when *dmrs-TypeA-Position* is equal to 'pos2'. For PUSCH mapping type A, $l_d = 4$ symbols in Table 6.4.1.1.3-4 is only applicable when *dmrs-TypeA-Position* is equal to 'pos2'.

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

- 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

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

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

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

where l is the 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_{ID} is given by the higher-layer parameter *nPUSCH-Identity*.

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

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

6.4.1.2.2 Mapping to physical resources

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

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

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

$$\begin{aligned} \begin{bmatrix} a_{k,l}^{(p_o,\mu)} \\ \vdots \\ a_{k,l}^{(p_{\rho-1},\mu)} \end{bmatrix} &= \beta_{\text{PT-RS}} W \begin{bmatrix} r^{(\tilde{p}_0)}(2n + k') \\ \vdots \\ r^{(\tilde{p}_{\nu-1})}(2n + k') \end{bmatrix} \\ k &= \begin{cases} 4n + 2k' + \Delta & \text{configuration type 1} \\ 6n + k' + \Delta & \text{configuration type 2} \end{cases} \end{aligned}$$

when all the following conditions are fulfilled

- l is within the OFDM symbols allocated for the PUSCH transmission
- resource element (k, l) is not used for DM-RS

- k' and Δ correspond to $\tilde{p}_0, \dots, \tilde{p}_{\nu-1}$

The quantities k' and Δ are given by Tables 6.4.1.1.3-1 and 6.4.1.1.3-2, the configuration type is given by the higher-layer parameter *DMRS-UplinkConfig*, and the precoding matrix W is given by clause 6.3.1.5. The quantity $\beta_{\text{PT-RS}}$ 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 $\max(l_{\text{ref}} + (i-1)L_{\text{PT-RS}}, l_{\text{ref}}), \dots, l_{\text{ref}} + iL_{\text{PT-RS}}$ overlaps with a symbol used for DM-RS according to clause 6.4.1.1.3
 - set $i = 1$
 - set l_{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 '00' shall be used.
- n_{RNTI} is the RNTI associated with the DCI scheduling the transmission using C-RNTI, CS-RNTI, MCS-C-RNTI, SP-CSI-RNTI, or is the CS-RNTI in case of configured grant
- N_{RB} is the number of resource blocks scheduled
- $K_{\text{PT-RS}} \in \{2, 4\}$ is given by [6, TS 38.214].

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

DM-RS antenna port \tilde{p}	$k_{\text{ref}}^{\text{RE}}$							
	DM-RS Configuration type 1 <i>resourceElementOffset</i>				DM-RS Configuration type 2 <i>resourceElementOffset</i>			
	00	01	10	11	00	01	10	11
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 β' and mapped to $N_{\text{samp}}^{\text{group}} N_{\text{group}}^{\text{PT-RS}}$ complex valued symbols in $\tilde{x}^{(0)}(m)$ where

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

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

1. set $i = 0$ and $l_{\text{ref}} = 0$
2. if any symbol in the interval $\max(l_{\text{ref}} + (i-1)L_{\text{PT-RS}}, l_{\text{ref}}), \dots, l_{\text{ref}} + iL_{\text{PT-RS}}$ overlaps with a symbol used for DM-RS according to clause 6.4.1.1.3
 - set $i = 1$
 - set l_{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 *PTRS-UplinkConfig*.

Table 6.4.1.2.2.2-1: PT-RS symbol mapping.

Number of PT-RS groups $N_{\text{group}}^{\text{PT-RS}}$	Number of samples per PT-RS group $N_{\text{samp}}^{\text{group}}$	Index m of PT-RS samples in OFDM symbol l prior to transform precoding
2	2	$s \lfloor M_{\text{sc}}^{\text{PUSCH}} / 4 \rfloor + k - 1$ where $s = 1,3$ and $k = 0,1$
2	4	$s M_{\text{sc}}^{\text{PUSCH}} + k$ 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

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

where $N_{\text{SF},m'}^{\text{PUCCH},1}$ is given by Table 6.4.1.3.1.1-1 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 $N_{SF,m'}^{\text{PUCCH},1}$.

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

6.4.1.3.1.2 Mapping to physical resources

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

$$a_{k,l}^{(p,\mu)} = \beta_{\text{PUCCH},1} z(m) \\ l = 0, 2, 4, \dots$$

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].

6.4.1.3.2 Demodulation reference signal for PUCCH format 2

6.4.1.3.2.1 Sequence generation

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

$$r_l(m) = \frac{1}{\sqrt{2}} (1 - 2c(2m)) + j \frac{1}{\sqrt{2}} (1 - 2c(2m + 1)) \\ m = 0, 1, \dots$$

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

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

where l is the OFDM symbol number within the slot, $n_{\text{s,f}}^{\mu}$ is the slot number within the radio frame, and $N_{\text{ID}}^0 \in \{0, 1, \dots, 65535\}$ 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 $r(0)$ to resource elements $(k,l)_{p,\mu}$ in a slot on antenna port $p = 2000$ according to

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

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 [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 $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 6.3.2.2.

The cyclic shift α varies with the symbol number and slot number according to clause 6.3.2.2.2 with $m_0 = 0$ for PUCCH format 3 and 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 4.

Table 6.4.1.3.3.1-1: Cyclic shift index for PUCCH format 4.

Orthogonal sequence index n	Cyclic shift index m_0	
	$N_{\text{SF}}^{\text{PUCCH},4} = 2$	$N_{\text{SF}}^{\text{PUCCH},4} = 4$
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 [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 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*, $p_i = 1000 + i$ 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'
- $N_{\text{symb}}^{\text{SRS}} \in \{1, 2, 4\}$ 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 $l_{\text{offset}} \in \{0, 1, \dots, 5\}$ 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

$$\begin{aligned} r^{(p_i)}(n, l') &= r_{u,v}^{(\alpha_i, \delta)}(n) \\ 0 \leq n &\leq M_{\text{sc},b}^{\text{SRS}} - 1 \\ l' &\in \{0, 1, \dots, N_{\text{symb}}^{\text{SRS}} - 1\} \end{aligned}$$

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

$$\begin{aligned} \alpha_i &= 2\pi \frac{n_{\text{SRS}}^{\text{cs},i}}{n_{\text{SRS}}^{\text{cs,max}}} \\ n_{\text{SRS}}^{\text{cs},i} &= \left(n_{\text{SRS}}^{\text{cs}} + \frac{n_{\text{SRS}}^{\text{cs,max}} (p_i - 1000)}{N_{\text{ap}}^{\text{SRS}}} \right) \bmod n_{\text{SRS}}^{\text{cs,max}} \end{aligned}$$

where $n_{\text{SRS}}^{\text{cs}} \in \{0, 1, \dots, n_{\text{SRS}}^{\text{cs,max}} - 1\}$ is contained in the higher layer parameter *transmissionComb*. The maximum number of cyclic shifts is $n_{\text{SRS}}^{\text{cs,max}} = 12$ if $K_{\text{TC}} = 4$ and $n_{\text{SRS}}^{\text{cs,max}} = 8$ if $K_{\text{TC}} = 2$.

The sequence group $u = (f_{\text{gh}}(n_{\text{s,f}}^{\mu}, l') + n_{\text{ID}}^{\text{SRS}}) \bmod 30$ and the sequence number v in clause 5.2.2 depends on the higher-layer parameter *groupOrSequenceHopping* in the *SRS-Config* IE. The SRS sequence identity $n_{\text{ID}}^{\text{SRS}}$ is given by the higher layer parameter *sequenceId* in the *SRS-Config* IE and $l' \in \{0, 1, \dots, N_{\text{symb}}^{\text{SRS}} - 1\}$ is the OFDM symbol number within the SRS resource.

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

$$\begin{aligned} f_{\text{gh}}(n_{\text{s,f}}^{\mu}, l') &= 0 \\ v &= 0 \end{aligned}$$

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

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

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

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

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

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

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 β_{SRS} in order to conform to the transmit power specified in [5, 38.213] and mapped in sequence starting with $r^{(p_i)}(0, l')$ to resource elements (k, l) in a slot for each of the antenna ports p_i according to

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

The length of the sounding reference signal sequence is given by

$$M_{\text{sc},b}^{\text{SRS}} = m_{\text{SRS},b} N_{\text{sc}}^{\text{RB}} / K_{\text{TC}}$$

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

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

$$k_0^{(p_i)} = \bar{k}_0^{(p_i)} + \sum_{b=0}^{B_{\text{SRS}}} K_{\text{TC}} M_{\text{sc},b}^{\text{SRS}} n_b$$

where

$$\bar{k}_0^{(p_i)} = n_{\text{shift}} N_{\text{sc}}^{\text{RB}} + k_{\text{TC}}^{(p_i)}$$

$$k_{\text{TC}}^{(p_i)} = \begin{cases} (\bar{k}_{\text{TC}} + K_{\text{TC}}/2) \bmod K_{\text{TC}} & \text{if } n_{\text{SRS}}^{\text{cs}} \in \{n_{\text{SRS}}^{\text{cs,max}}/2, \dots, n_{\text{SRS}}^{\text{cs,max}} - 1\} \text{ and } N_{\text{ap}}^{\text{SRS}} = 4 \text{ and } p_i \in \{1001, 1003\} \\ \bar{k}_{\text{TC}} & \text{otherwise} \end{cases}$$

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

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-Config* IE. The transmission comb offset $\bar{k}_{\text{TC}} \in \{0, 1, \dots, K_{\text{TC}} - 1\}$ is contained in the higher-layer parameter *transmissionComb* in the *SRS-Config* IE and n_b is a frequency position index.

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

If $b_{\text{hop}} \geq B_{\text{SRS}}$, 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 $N_{\text{symb}}^{\text{SRS}}$ OFDM symbols of the SRS resource. The quantity n_{RRC} is given by the higher-layer parameter *freqDomainPosition* 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_{SRS} .

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

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

where N_b is given by Table 6.4.1.4.3-1,

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

and where $N_{b_{\text{hop}}} = 1$ regardless of the value of N_b . The quantity n_{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 $N_{\text{symb}}^{\text{SRS}}$ symbol SRS resource is transmitted. The quantity $R \leq N_{\text{symb}}^{\text{SRS}}$ is the repetition factor given by the field *repetitionFactor* contained in the higher-layer parameter *resourceMapping*.

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

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

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_{SRS} in slots and slot offset T_{offset} are given in clause 6.4.1.4.4.

Table 6.4.1.4.3-1: SRS bandwidth configuration.

63	272	1	16	17	8	2	4	2
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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_{SRS} (in slots) and slot offset T_{offset} are configured according to the higher-layer parameter *periodicityAndOffset-p* or *periodicityAndOffset-sp*. Candidate slots in which the configured SRS resource may be used for SRS transmission are the slots satisfying

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

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
- 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

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

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

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

7.3.1.2 Modulation

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

Table 7.3.1.2-1: Supported modulation schemes.

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

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 $d^{(q)}(0), \dots, d^{(q)}(M_{\text{symb}}^{(q)} - 1)$ 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.

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

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

7.3.1.4 Antenna port mapping

The block of vectors $[x^{(0)}(i) \dots x^{(v-1)}(i)]^T$, $i = 0, 1, \dots, M_{\text{symb}}^{\text{layer}} - 1$ 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 according to clause 7.4.1.5 if the corresponding physical resource blocks are for PDSCH scheduled by PDCCH with CRC scrambled by C-RNTI, MCS-C-RNTI, CS-RNTI, or 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.

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 $N_{\text{BWP},\text{init}}^{\text{size}}$ resource blocks in CORESET 0 are divided into $N_{\text{bundle}} = \lceil N_{\text{BWP},\text{init}}^{\text{size}} / L \rceil$ resource-block bundles in increasing order of the resource-block number and bundle number where $L = 2$ is the bundle size and $N_{\text{BWP},\text{init}}^{\text{size}}$ is the size of CORESET 0.
 - resource block bundle $N_{\text{bundle}} - 1$ consists of $N_{\text{BWP},\text{init}}^{\text{size}} \bmod L$ resource blocks if $N_{\text{BWP},\text{init}}^{\text{size}} \bmod L > 0$ 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 other than Type0-PDCCH common search space in bandwidth part i with starting position $N_{\text{BWP},i}^{\text{start}}$, the set of $N_{\text{BWP},\text{init}}^{\text{size}}$ virtual resource blocks $\{0, 1, \dots, N_{\text{BWP},\text{init}}^{\text{size}} - 1\}$, where $N_{\text{BWP},\text{init}}^{\text{size}}$ is the size of CORESET 0 if CORESET 0 is configured for the cell and the size of initial downlink bandwidth part if CORESET 0 is not configured for the cell, are divided into N_{bundle} virtual resource-block bundles in increasing order of the virtual resource-block number and virtual bundle number and the set of $N_{\text{BWP},\text{init}}^{\text{size}}$ physical resource blocks $\{N_{\text{start}}^{\text{CORESET}}, N_{\text{start}}^{\text{CORESET}} + 1, \dots, N_{\text{start}}^{\text{CORESET}} + N_{\text{BWP},\text{init}}^{\text{size}} - 1\}$ are divided into N_{bundle} physical resource-block bundles in increasing order of the physical resource-block number and physical bundle number, where $N_{\text{bundle}} = \lceil (N_{\text{BWP},\text{init}}^{\text{size}} + (N_{\text{BWP},i}^{\text{start}} + N_{\text{start}}^{\text{CORESET}}) \bmod L) / L \rceil$, $L = 2$ 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.
 - 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 $(N_{\text{BWP},\text{init}}^{\text{size}} + N_{\text{BWP},i}^{\text{start}} + N_{\text{start}}^{\text{CORESET}}) \bmod L$ resource blocks if $(N_{\text{BWP},\text{init}}^{\text{size}} + N_{\text{BWP},i}^{\text{start}} + N_{\text{start}}^{\text{CORESET}}) \bmod L > 0$ 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* 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]
- If no bundle size is configured, the UE shall assume $L_i = 2$.

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.

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 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*, 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_{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 *pdch-DMRS-ScramblingID* if configured,
- $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ otherwise

and where

- n_{RNTI} is given by the C-RNTI for a PDCCH in a UE-specific search space if the higher-layer parameter *pdch-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 $d(0), \dots, d(M_{\text{symb}} - 1)$.

7.3.2.5 Mapping to physical resources

The UE shall assume the block of complex-valued symbols $d(0), \dots, d(M_{\text{symb}} - 1)$ to be scaled by a factor β_{PDCCH} and mapped to resource elements $(k, l)_{p,\mu}$ used for the monitored PDCCH and not used for the associated PDCCH DMRS in increasing order of first k , then l . The antenna port $p = 2000$.

7.3.3 Physical broadcast channel

7.3.3.1 Scrambling

The UE shall assume the block of bits $b(0), \dots, b(M_{\text{bit}} - 1)$, where M_{bit} is the number of bits transmitted on the physical broadcast channel, are scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0), \dots, \tilde{b}(M_{\text{bit}} - 1)$ 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 $L_{\text{max}} = 4$, v is the two least significant bits of the SS/PBCH block index
- for $L_{\text{max}} = 8$ or $L_{\text{max}} = 64$, v is the three least significant bits of the SS/PBCH block index

with L_{max} being the maximum number of SS/PBCH blocks in an SS/PBCH period for a particular band as given by [38.104].

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

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

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

The quantity $n_{\text{SCID}} \in \{0, 1\}$ is given by the DM-RS sequence initialization field, in the DCI associated with the PDSCH transmission if DCI format 1_1 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

$$\begin{aligned} a_{k,l}^{(p,\mu)} &= \beta_{\text{PDSCH}}^{\text{DMRS}} w_{\text{f}}(k') w_{\text{t}}(l') r(2n+k') \\ k &= \begin{cases} 4n+2k'+\Delta & \text{Configuration type 1} \\ 6n+k'+\Delta & \text{Configuration type 2} \end{cases} \\ k' &= 0, 1 \\ l &= \bar{l} + l' \\ n &= 0, 1, \dots \end{aligned}$$

where $w_{\text{f}}(k')$, $w_{\text{t}}(l')$, and Δ are given by Tables 7.4.1.1.2-1 and 7.4.1.1.2-2 and the following conditions are fulfilled:

- the resource elements are within the common resource blocks allocated for PDSCH transmission

The reference point for k is

- subcarrier 0 of the lowest-numbered resource block in CORESET 0 if the corresponding PDCCH is associated with CORESET 0 and Type0-PDCCH common search space and is addressed to SI-RNTI;
- otherwise, subcarrier 0 in common resource block 0

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

- for PDSCH mapping type A:
 - l is defined relative to the start of the slot
 - $l_0 = 3$ if the higher-layer parameter *dmrs-TypeA-Position* is equal to 'pos3' and $l_0 = 2$ otherwise
- for PDSCH mapping type B:
 - l is defined relative to the start of the scheduled PDSCH resources
 - $l_0 = 0$

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

- for PDSCH mapping type A, l_d is the duration is 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 is the number of OFDM symbols of the scheduled PDSCH resources

and according to Tables 7.4.1.1.2-3 and 7.4.1.1.2-4. The case *dmrs-AdditionalPosition* equals to 'pos3' is only supported when *dmrs-TypeA-Position* is equal to 'pos2'. For PDSCH mapping type A, $l_d = 3$ 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'. For PDSCH

mapping Type A 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* is configured and any PDSCH DM-RS symbol coincides with any symbol containing LTE cell-specific reference signals as indicated by the higher-layer parameter *lte-CRS-ToMatchAround*; and
- the higher-layer parameters *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 is 2, 4, or 7 OFDM symbols for normal cyclic prefix or 2, 4, 6 OFDM symbols for extended cyclic prefix, and 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
 - 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 4 symbols, the UE is not expected to receive a DM-RS symbol beyond the third symbol,
 - if the PDSCH duration l_d is 7 symbols for normal cyclic prefix or 6 symbols for extended cyclic prefix,
 - the UE is not expected to receive the first DM-RS beyond the fourth symbol, and
 - 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 is 2 or 4 OFDM symbols, only single-symbol DM-RS is supported.

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. 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. The UE may assume that DMRS ports associated with a PDSCH are QCL with QCL Type A, Type D (when applicable) and average gain.

The UE may assume that no DM-RS collides with the SS/PBCH block.

Table 7.4.1.1.2-1: Parameters for PDSCH DM-RS configuration type 1.

p	CDM group λ	Δ	$w_f(k')$		$w_t(l')$	
			$k' = 0$	$k' = 1$	$l' = 0$	$l' = 1$
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 λ	Δ	$w_f(k')$		$w_t(l')$	
			$k' = 0$	$k' = 1$	$l' = 0$	$l' = 1$
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			
	dmrs-AdditionalPosition				dmrs-AdditionalPosition			
0	1	2	3	0	1	2	3	
2	-	-	-	-	l_0	l_0		
3	l_0	l_0	l_0	l_0	-	-		
4	l_0	l_0	l_0	l_0	l_0	l_0		
5	l_0	l_0	l_0	l_0	-	-		
6	l_0	l_0	l_0	l_0	l_0	$l_0, 4$		
7	l_0	l_0	l_0	l_0	l_0	$l_0, 4$		
8	l_0	$l_0, 7$	$l_0, 7$	$l_0, 7$	-	-		
9	l_0	$l_0, 7$	$l_0, 7$	$l_0, 7$	-	-		
10	l_0	$l_0, 9$	$l_0, 6, 9$	$l_0, 6, 9$	-	-		
11	l_0	$l_0, 9$	$l_0, 6, 9$	$l_0, 6, 9$	-	-		
12	l_0	$l_0, 9$	$l_0, 6, 9$	$l_0, 5, 8, 11$	-	-		
13	l_0	l_0, l_1	$l_0, 7, 11$	$l_0, 5, 8, 11$	-	-		
14	l_0	l_0, l_1	$l_0, 7, 11$	$l_0, 5, 8, 11$	-	-		

Table 7.4.1.1.2-4: PDSCH DM-RS positions \bar{l} for double-symbol DM-RS.

l_d in symbols	DM-RS positions \bar{l}					
	PDSCH mapping type A			PDSCH mapping type B		
	dmrs-AdditionalPosition 0	1	2	dmrs-AdditionalPosition 0	1	2
<4				-	-	
4	l_0	l_0		-	-	
5	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		-	-	
9	l_0	l_0		-	-	
10	l_0	$l_0, 8$		-	-	
11	l_0	$l_0, 8$		-	-	
12	l_0	$l_0, 8$		-	-	
13	l_0	$l_0, 10$		-	-	
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, TS 38.214], or is declared as 'not available' by clause 5.1.4 of [6, TS 38.214]

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

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

2. if any symbol in the interval $\max(l_{\text{ref}} + (i - 1)L_{\text{PT-RS}} + 1, l_{\text{ref}}), \dots, l_{\text{ref}} + iL_{\text{PT-RS}}$ overlaps with a symbol used for DM-RS according to clause 7.4.1.1.2
 - set $i = 1$
 - set l_{ref} to the symbol index of the DM-RS symbol in case of a single-symbol DM-RS and to the symbol index of the second DM-RS symbol in case of a double-symbol DM-RS
 - repeat from step 2 as long as $l_{\text{ref}} + iL_{\text{PT-RS}}$ is inside the PDSCH allocation
3. add $l_{\text{ref}} + iL_{\text{PT-RS}}$ to the set of time indices for PT-RS
4. increment i by one
5. repeat from step 2 above as long as $l_{\text{ref}} + iL_{\text{PT-RS}}$ is inside the PDSCH allocation

where $L_{\text{PT-RS}} \in \{1,2,4\}$.

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

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

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

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 5.1.6.2 in [6, TS 38.214]. If the higher-layer parameter *resourceElementOffset* in the *PTRS-DownlinkConfig* IE is not configured, the column corresponding to '00' shall be used.
- n_{RNTI} is the RNTI associated with the DCI scheduling the transmission
- N_{RB} is the number of resource blocks scheduled
- $K_{\text{PT-RS}} \in \{2,4\}$ is given by [6, TS 38.214].

Table 7.4.1.2.2-1: The parameter $k_{\text{ref}}^{\text{RE}}$.

DM-RS antenna port p	$k_{\text{ref}}^{\text{RE}}$							
	DM-RS Configuration type 1				DM-RS Configuration type 2			
	resourceElementOffset				resourceElementOffset			
	00	01	10	11	00	01	10	11
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 *pdcch-DMRS-ScramblingID* if provided
- $N_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ 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

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

where

- for $L_{\text{max}} = 4$, $\bar{i}_{\text{SSB}} = i_{\text{SSB}} + 4n_{\text{hf}}$ where n_{hf} is the number of the half-frame in which the PBCH is transmitted in a frame with $n_{\text{hf}} = 0$ for the first half-frame in the frame and $n_{\text{hf}} = 1$ for the second half-frame in the frame, and i_{SSB} is the two least significant bits of the SS/PBCH block index as defined in [5, TS 38.213]
- for $L_{\text{max}} = 8$ or $L_{\text{max}} = 64$, $\bar{i}_{\text{SSB}} = i_{\text{SSB}}$ where i_{SSB} is the three least significant bits of the SS/PBCH block index as defined in [5, TS 38.213]

with L_{max} being the maximum number of SS/PBCH beams in an SS/PBCH period for a particular band as given by [38.104].

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, 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. 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 $n_{\text{s,f}}^{\mu}$ is the slot number within a radio frame, l is the OFDM symbol number within a slot, and n_{ID} equals the higher-layer parameter *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

$$\begin{aligned}
 a_{k,l}^{(p,\mu)} &= \beta_{\text{CSIRS}} w_f(k') \cdot w_t(l') \cdot r_{l,n_{\text{sc}}}^{}(m') \\
 m' &= \lfloor n\alpha \rfloor + k' + \left\lfloor \frac{\bar{k}\rho}{N_{\text{sc}}^{\text{RB}}} \right\rfloor \\
 k &= nN_{\text{sc}}^{\text{RB}} + \bar{k} + k' \\
 l &= \bar{l} + l' \\
 \alpha &= \begin{cases} \rho & \text{for } X = 1 \\ 2\rho & \text{for } X > 1 \end{cases} \\
 n &= 0, 1, \dots
 \end{aligned}$$

when the following conditions are fulfilled:

- the resource element $(k, l)_{p,\mu}$ is within the resource blocks occupied by the CSI-RS resource for which the UE is configured

The reference point for $k = 0$ is subcarrier 0 in common resource block 0.

The value of ρ is given by the higher-layer parameter *density* in the *CSI-RS-ResourceMapping* IE or the *CSI-RS-CellMobility* IE and the number of ports X is given by the higher-layer parameter *nrofPorts*.

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 β_{CSIRS} is selected such that the power offset specified by the higher-layer parameter *powerControlOffsetSS* in the *NZP-CSI-RS-Resource* 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 7.4.1.5.3-6 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. 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.

The frequency-domain location is given by a bitmap provided by the higher-layer parameter *frequencyDomainAllocation* in the *CSI-RS-ResourceMapping* IE or the *CSI-RS-ResourceConfigMobility* IE with the bitmap and value of k_i in Table 7.4.1.5.3-1 given by

- $[b_3 \dots b_0]$, $k_{i-1} = f(i)$ for row 1 of Table 7.4.1.5.3-1
- $[b_{11} \dots b_0]$, $k_{i-1} = f(i)$ for row 2 of Table 7.4.1.5.3-1
- $[b_2 \dots b_0]$, $k_{i-1} = 4f(i)$ for row 4 of Table 7.4.1.5.3-1
- $[b_5 \dots b_0]$, $k_{i-1} = 2f(i)$ for all other cases

where $f(i)$ is the bit number of the i^{th} bit in the bitmap set to one, repeated across every $[1/\rho]$ of the resource blocks configured for CSI-RS reception by the UE. The starting position and number of the resource blocks in which the UE shall assume that CSI-RS is transmitted are given by the higher-layer parameters *freqBand* and *density* in the *CSI-RS-ResourceMapping* IE for the bandwidth part given by the higher-layer parameter *BWP-Id* in the *CSI-ResourceConfig* IE or given by the higher-layer parameters *nrofPRBs* in the *CSI-RS-CellMobility* IE where the the *startPRB* given by *csi-rs-MeasurementBW* is relative to common resource block 0.

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* or configured by the higher-layer parameter *CSI-RS-CellMobility*, the UE shall assume that the CSI-RS is transmitted in slots satisfying

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

where the periodicity $T_{\text{CSI-RS}}$ (in slots) and slot offset T_{offset} are obtained from the higher-layer parameter *CSI-ResourcePeriodicityAndOffset* or *slotConfig*. The UE shall assume that CSI-RS is transmitted in a candidate slot as described in clause 11.1 of [5, TS 38.213].

The UE may assume that antenna ports within a CSI-RS resource are quasi-colocated with QCL Type A, Type D (when applicable), and average gain.

Table 7.4.1.5.3-1: CSI-RS locations within a slot.

Row	Ports X	Density ρ	cdm-Type	(\bar{k}, \bar{l})	CDM group index j	k'	l'
1	1	3	No CDM	$(k_0, l_0), (k_0 + 4, l_0), (k_0 + 8, l_0)$	0,0,0	0	0
2	1	1, 0.5	No CDM	$(k_0, l_0),$	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 'no CDM'.

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	$[w_f(0) \ w_f(1)]$	$w_t(0)$
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'.

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'.

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	$[+1 \ -1]$	$[+1 \ -1 \ -1 \ +1]$

7.4.2 Synchronization signals

7.4.2.1 Physical-layer cell identities

There are 1008 unique physical-layer cell identities given by

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

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

7.4.2.2 Primary synchronization signal

7.4.2.2.1 Sequence generation

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

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

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

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

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_{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* and the 4 least significant bits of k_{SSB} are given by the higher-layer parameter *ssb-SubcarrierOffset* and for SS/PBCH block type A the most significant bit of k_{SSB} is given by $\bar{a}_{\bar{A}+5}$ in the PBCH payload as defined in subclause 7.1.1 of [4, TS 38.212]. If *ssb-SubcarrierOffset* is not provided, k_{SSB} is derived from the frequency difference between the SS/PBCH block and Point A.

The UE may assume that the complex-valued symbols corresponding to resource elements that are part of a common resource block partially or fully overlapping with an SS/PBCH block 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_{SSB} , and $N_{\text{CRB}}^{\text{SSB}}$ expressed in terms of 15 kHz subcarrier spacing, and
- for SS/PBCH block type B, $\mu \in \{3,4\}$ and $k_{\text{SSB}} \in \{0,1,2,\dots,11\}$ with the quantity k_{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;
- 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*. 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.

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 β_{PSS} to conform to the PSS power allocation specified in [5, TS 38.213] and mapped to resource elements $(k, l)_{p, \mu}$ in increasing order of k where k and l are given by Table 7.4.3.1-1 and represent the frequency and time indices, respectively, within one SS/PBCH block.

7.4.3.1.2 Mapping of SSS within an SS/PBCH block

The UE shall assume the sequence of symbols $d_{\text{SSS}}(0), \dots, d_{\text{SSS}}(126)$ constituting the secondary synchronization signal to be scaled by a factor β_{SSS} and mapped to resource elements $(k, l)_{p, \mu}$ in increasing order of k where k and l are given by Table 7.4.3.1-1 and represent the frequency and time indices, respectively, within one SS/PBCH block.

7.4.3.1.3 Mapping of PBCH and DM-RS within an SS/PBCH block

The UE shall assume the sequence of complex-valued symbols $d_{\text{PBCH}}(0), \dots, d_{\text{PBCH}}(M_{\text{symb}} - 1)$ constituting the physical broadcast channel to be scaled by a factor β_{PBCH} to conform to the PBCH power allocation specified in [5, TS 38.213] and mapped in sequence starting with $d_{\text{PBCH}}(0)$ to resource elements $(k, l)_{p, \mu}$ which meet all the following criteria:

- they are not used for PBCH demodulation reference signals

The mapping to resource elements $(k, l)_{p,\mu}$ not reserved for PBCH DM-RS shall be in increasing order of first the index k and then the index l , where k and l represent the frequency and time indices, respectively, within one SS/PBCH block and are given by Table 7.4.3.1-1.

The UE shall assume the sequence of complex-valued symbols $r(0), \dots, r(143)$ 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].

Annex A:

Change history

Change history							
Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2017-04	RAN1#89	R1-1708219				Draft skeleton	0.0.0
2017-05	AH_1706	R1-1711366				Inclusion of agreements up to and including RAN1#89	0.0.1
2017-06	AH_1706	R1-1711886				Updated editor's version	0.0.2
2017-06	AH_1706	R1-1712004				Clean version further to RAN1's endorsement	0.1.0
2017-07	AH_1706	R1-1712011				Inclusion of agreements up to and including RAN1 NR AdHoc #2	0.1.1
2017-08	AH_1706	R1-1712950				Updated editor's version	0.1.2
2017-08	RAN1#90	R1-1713296				Updated editor's version	0.1.3
2017-08	RAN1#90	R1-1714656				Endorsed by RAN1#90	0.2.0
2017-08	RAN1#90	R1-1715321				Inclusion of agreements from RAN1#90	0.2.1
2017-09	RAN1#90	R1-1715329				Updated editor's version	0.2.2
2017-09	RAN#77	RP-171994				For information to plenary	1.0.0
2017-09	AH_1709	R1-1716927				Inclusion of agreements from AdHoc#3	1.0.1
2017-09	AH_1709	R1-1718318				Updated editor's version	1.0.2
2017-10	RAN1#90b	R1-1719105				Endorsed by RAN1#90bis	1.1.0
2017-10	RAN1#90b	R1-1719224				Inclusion of agreements from RAN1#90bis	1.1.1
2017-11	RAN1#90b	R1-1719685				Updated editor's version	1.1.2
2017-11	RAN1#90b	R1-1720850				Updated editor's version	1.1.3
2017-11	RAN1#90b	R1-1721048				Endorsed by RAN1#90bis	1.2.0
2017-12	RAN1#91	R1-17xxxxx				Inclusion of agreements from RAN1#91	1.2.1
2017-12	RAN1#91	R1-1721341				Endorsed by RAN1#91	1.3.0
2017-12	RAN#78	RP-172284				For approval by plenary	2.0.0
2017-12	RAN#78					Approved by plenary – Rel-15 spec under change control	15.0.0
2018-03	RAN#79	RP-180200	0001	-	F	CR capturing the Jan18 ad-hoc and RAN1#92 meeting agreements	15.1.0
2018-06	RAN#80	RP-181172	0002	1	F	CR to 38.211 capturing the RAN1#92bis and RAN1#93 meeting agreements	15.2.0
2018-09	RAN#81	RP-181789	0003	-	F	Corrections according to agreements from RAN1#94	15.3.0
2018-12	RAN#82	RP-182523	0004	1	F	Combined CR of all essential corrections to 38.211 from RAN1#94bis and RAN1#95	15.4.0
2019-03	RAN#83	RP-190447	0005	-	F	CR for PUCCH Format 1	15.5.0
2019-03	RAN#83	RP-190447	0006	-	F	CR on PDSCH mapping to virtual resource blocks	15.5.0
2019-03	RAN#83	RP-190447	0007	2	F	Alignment of terminology across specifications	15.5.0
2019-03	RAN#83	RP-190447	0008	-	F	Correction on physical resource mapping for PUSCH with configured grant	15.5.0
2019-03	RAN#83	RP-190773	0009	1	F	Correction to frequency-domain starting position for SRS resource mapping	15.5.0
2019-06	RAN#84	RP-191281	0010	-	F	CR on PUCCH format 1	15.6.0
2019-06	RAN#84	RP-191281	0011	-	F	Correction on reference name of UE capability of additional DMRS for co-existence with LTE CRS	15.6.0
2019-06	RAN#84	RP-191281	0012	-	F	Correction on mapping from virtual to physical resource blocks	15.6.0
2019-06	RAN#84	RP-191281	0014	2	F	Corrections to 38.211 including alignment of terminology across specifications	15.6.0
2019-06	RAN#84	RP-191281	0015	-	F	Clarification regarding non-full-duplex UE communication	15.6.0
2019-06	RAN#84	RP-191281	0016	-	F	Corrections on PUSCH scheduled by RAR UL grant and Msg3 PUSCH retransmission	15.6.0