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Contents

Foreword

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1 Scope

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

2 References

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

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

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

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

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

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

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

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

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

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, $\Delta f = 2^{\mu} \cdot 15 [\mathrm{kHz}]$
$M_{\mathrm{bit}}^{(q)}$	Number of coded bits to transmit on a physical channel [for codeword q]
$M_{\mathrm{symb}}^{(q)}$	Number of modulation symbols to transmit on a physical channel [for codeword q]
$M_{\mathrm{symb}}^{\mathrm{layer}}$	Number of modulation symbols to transmit per layer for a physical channel
$M_{\mathrm{sc}}^{\mathrm{PUSCH}}$	Scheduled bandwidth for uplink transmission, expressed as a number of subcarriers
$M_{\mathrm{RB}}^{\mathrm{PUSCH}}$	Scheduled bandwidth for uplink transmission, expressed as a number of resource blocks

$M_{\text{symb}}^{\text{ap}}$	Number of modulation symbols to transmit per antenna port for a physical channel
υ	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
$N_{\text{group}}^{\text{PTRS}}$	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 resrouce-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_{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
$n_{\text{s,f}}^{\mu}$	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]
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 sequence
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 sequence
VRB	Virtual resource block

4 Frame structure and physical resources

4.1 General

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

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 given by the higher-layer parameters *DL-BWP-mu* and *DL-BWP-cp* for the downlink and *UL-BWP-mu* and *UL-BWP-cp* for the uplink.

Table 4.2-1: Supported transmission numerologies.

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

4.3 Frame structure

4.3.1 Frames and subframes

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

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

Uplink frame number i for transmission from the UE shall start $T_{\mathrm{TA}} = \left(N_{\mathrm{TA}} + N_{\mathrm{TA,offset}}\right)T_{\mathrm{c}}$ before the start of the corresponding downlink frame at the UE where $N_{\mathrm{TA,offset}}$ depends on the frequency band according to [38.133].

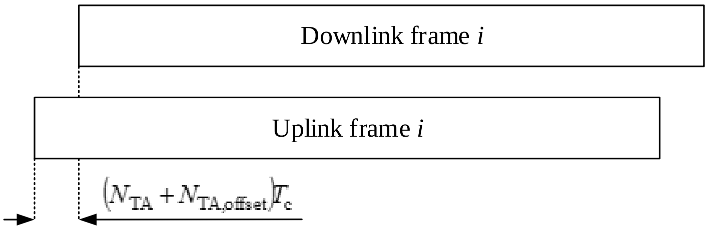

Figure 4.3.1-1: Uplink-downlink timing relation.

4.3.2 Slots

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

OFDM symbols in a slot can be classified as 'downlink' (denoted 'D' in Table 4.3.2-3), 'flexible' (denoted 'X'), or 'uplink' (denoted 'U'). Table 4.3.2-3 is used when the SFI-RNTI is used for slot format indication as described in subclause 11.1.1 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.

Signaling of slot formats is described in subclause 11.1 of [5, TS 38.213].

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

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

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

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

Table 4.3.2-3: Slot formats for normal cyclic prefix.

Format	Symbol number in a slot													
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	D	D	D	D	D	D	D	D	D	D	D	D	D	X
4	D	D	D	D	D	D	D	D	D	D	D	D	X	X
5	D	D	D	D	D	D	D	D	D	D	D	X	X	X
6	D	D	D	D	D	D	D	D	D	D	X	X	X	X
7	D	D	D	D	D	D	D	D	D	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X	X	X	X	X	U
9	X	X	X	X	X	X	X	X	X	X	X	X	U	U
10	X	U	U	U	U	U	U	U	U	U	U	U	U	U
11	X	X	U	U	U	U	U	U	U	U	U	U	U	U
12	X	X	X	U	U	U	U	U	U	U	U	U	U	U
13	X	X	X	X	U	U	U	U	U	U	U	U	U	U
14	X	X	X	X	X	U	U	U	U	U	U	U	U	U
15	X	X	X	X	X	X	U	U	U	U	U	U	U	U
16	D	X	X	X	X	X	X	X	X	X	X	X	X	X
17	D	D	X	X	X	X	X	X	X	X	X	X	X	X
18	D	D	D	X	X	X	X	X	X	X	X	X	X	X
19	D	X	X	X	X	X	X	X	X	X	X	X	X	U
20	D	D	X	X	X	X	X	X	X	X	X	X	X	U
21	D	D	D	X	X	X	X	X	X	X	X	X	X	U
22	D	X	X	X	X	X	X	X	X	X	X	X	U	U
23	D	D	X	X	X	X	X	X	X	X	X	X	U	U
24	D	D	D	X	X	X	X	X	X	X	X	X	U	U
25	D	X	X	X	X	X	X	X	X	X	X	U	U	U
26	D	D	X	X	X	X	X	X	X	X	X	U	U	U
27	D	D	D	X	X	X	X	X	X	X	X	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	X	U
29	D	D	D	D	D	D	D	D	D	D	D	X	X	U
30	D	D	D	D	D	D	D	D	D	D	X	X	X	U
31	D	D	D	D	D	D	D	D	D	D	D	X	U	U
32	D	D	D	D	D	D	D	D	D	D	X	X	U	U
33	D	D	D	D	D	D	D	D	D	X	X	X	U	U
34	D	X	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	X	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	X	U	U	U	U	U	U	U	U	U	U
37	D	X	X	U	U	U	U	U	U	U	U	U	U	U
38	D	D	X	X	U	U	U	U	U	U	U	U	U	U
39	D	D	D	X	X	U	U	U	U	U	U	U	U	U
40	D	X	X	X	U	U	U	U	U	U	U	U	U	U
41	D	D	X	X	X	U	U	U	U	U	U	U	U	U
42	D	D	D	X	X	X	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	X	X	X	X	U
44	D	D	D	D	D	D	X	X	X	X	X	X	U	U
45	D	D	D	D	D	D	X	X	U	U	U	U	U	U
46	D	D	D	D	D	X	U	D	D	D	D	D	X	U
47	D	D	X	U	U	U	U	D	D	X	U	U	U	U
48	D	X	U	U	U	U	U	D	X	U	U	U	U	U
49	D	D	D	D	X	X	U	D	D	D	D	X	X	U
50	D	D	X	X	U	U	U	D	D	X	X	U	U	U
51	D	X	X	U	U	U	U	D	X	X	U	U	U	U
52	D	X	X	X	X	X	U	D	X	X	X	X	X	U
53	D	D	X	X	X	X	U	D	D	X	X	X	X	U
54	X	X	X	X	X	X	X	D	D	D	D	D	D	D
55	D	D	X	X	X	U	U	U	D	D	D	D	D	D
56 – 255	Reserved													

4.4 Physical resources

4.4.1 Antenna ports

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

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

4.4.2 Resource grid

For each numerology and carrier, a resource grid of $N_{\mathrm{grid},x}^{\mathrm{size},\mu} N_{\mathrm{sc}}^{\mathrm{RB}}$ subcarriers and $N_{\mathrm{symb}}^{\mathrm{subframe},\mu}$ OFDM symbols is defined, starting at common resource block $N_{\mathrm{grid}}^{\mathrm{start},\mu}$ indicated by higher-layer signalling. There is one set of resource grids per transmission direction (uplink 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).

4.4.3 Resource elements

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

4.4.4 Resource blocks

4.4.4.1 General

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

4.4.4.2 Point A

Point A serves as a common reference point for resource block grids and is obtained from the following higher-layer parameters:

- *PRB-index-DL-common* for a PCell downlink represents the frequency offset between point A and the lowest subcarrier of the lowest resource block of the SS/PBCH block used by the UE for initial cell selection;

- *PRB-index-UL-common* for a PCell uplink in paired spectrum represents the frequency offset between point A and the frequency location based on ARFCN of the uplink indicated in SIB1;

- *PRB-index-UL-common* for a PCell uplink in unpaired spectrum represents the frequency offset between point A and the lowest subcarrier of the lowest resrouce block of the SS/PBCH block used by the UE for initial cell selection;

- *PRB-index-DL-Dedicated* for an SCell downlink represents the frequency offset between point A and the frequency location based on ARFCN in the higher-layer SCell configuration;

- *PRB-index-UL-Dedicated* for an SCell uplink represents the frequency offset between point A and the frequency location based on ARFCN in the higher-layer SCell configuration;

- *PRB-index-SUL-common* for a supplementary uplink represents the frequency offset between point A and the frequency location based on ARFCN in the higher-layer SUL configuration.

All the above parameters are expressed in units of resource blocks assuming 15 kHz subcarrier spacing for FR1 and 60 kHz subcarrier spacing for FR2.

4.4.4.3 Common resource blocks

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

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

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

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

4.4.4.4 Physical resource blocks

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

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

where $N_{\mathrm{BWP},i}^{\mathrm{start}}$ is the common resource block where bandwidth part starts relative to common resource block 0.

4.4.4.5 Virtual resource blocks

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

4.4.5 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 $N_{\mathrm{BWP},i}^{\mathrm{start}}$ and the number of resource blocks $N_{\mathrm{BWP},i}^{\mathrm{size}}$ in a bandwidth part shall fulfil $0 \le N_{\mathrm{BWP},i}^{\mathrm{start}} < N_{\mathrm{grid},x}^{\mathrm{size}}$ and $0 < N_{\mathrm{BWP},i}^{\mathrm{size}} < N_{\mathrm{grid},x}^{\mathrm{size}}$, respectively.

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.

For unpaired spectrum, the UE may assume that two bandwidth parts with the same index i are paired.

Unless otherwise noted, the description in this specification applies to each of the bandwidth parts.

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 π/2-BPSK

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

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

5.1.2 BPSK

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

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

5.1.3 QPSK

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

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

5.1.4 16QAM

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

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

5.1.5 64QAM

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

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

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

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

5.2 Sequence generation

5.2.1 Pseudo-random sequence generation

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

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

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

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

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

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

5.2.2.1 Base sequences of length 36 or larger

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

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

where

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

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

5.2.2.2 Base sequences of length less than 36

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

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

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

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

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

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

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

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

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

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

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

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

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

5.3 OFDM baseband signal generation

5.3.1 OFDM baseband signal generation for all channels except PRACH

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

$$s_l^{(p,\mu)}(t) = \sum_{k=0}^{N_{\mathrm{grid}}^{\mathrm{size}\,\mu} N_{\mathrm{sc}}^{\mathrm{RB}} - 1} a_{k,l}^{(p,\mu)} \cdot e^{j2\pi\left(k + k_0^\mu - N_{\mathrm{grid}}^{\mathrm{size}\,\mu} N_{\mathrm{sc}}^{\mathrm{RB}}/2\right)\Delta f\left(t - N_{\mathrm{CP},l}^{\mu} T_{\mathrm{c}} - t_{\mathrm{start},l}^{\mu}\right)}$$

where $t_{\mathrm{start},l}^{\mu} \le t < t_{\mathrm{start},l}^{\mu} + \left(N_{\mathrm{u}}^{\mu} + N_{\mathrm{CP},l}^{\mu}\right) T_{\mathrm{c}}$ is the time within the subframe,

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

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

Δf is given by clause 4.2, and μ is the subcarrier spacing configuration. The starting position of OFDM symbol l for subcarrier spacing configuration μ in a subframe is given by

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

The value of $k_0^{\mu} \in \{-6, 0, +6\}$ is obtained from the higher-layer parameter *k0* and is such that the lowest numbered subcarrier in a common resource block for subcarrier spacing configuration μ coincides with the lowest numbered subcarrier in a common resource block for any subcarrier spacing configuration less than μ.

5.3.2 OFDM baseband signal generation for PRACH

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

$$s_l^{(p,\mu)}(t) = \sum_{k=0}^{L_{\mathrm{RA}}-1} a_k^{(p,\mathrm{RA})} \cdot e^{j2\pi\left(k + Kk_1 + \bar{k}\right)\Delta f_{\mathrm{RA}}\left(t - N_{\mathrm{CP},l}^{\mathrm{RA}} T_{\mathrm{c}} - t_{\mathrm{start}}^{\mathrm{RA}}\right)}$$

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

$$k_1 = k_o^{\mu} + N_{\mathrm{BWP},i}^{\mathrm{start}} N_{\mathrm{sc}}^{\mathrm{RB}} + n_{\mathrm{RA}}^{\mathrm{start}} N_{\mathrm{sc}}^{\mathrm{RB}} + n_{\mathrm{RA}} N_{\mathrm{RB}}^{\mathrm{RA}} N_{\mathrm{sc}}^{\mathrm{RB}} - N_{\mathrm{grid}}^{\mathrm{size},\mu} N_{\mathrm{sc}}^{\mathrm{RB}} / 2$$

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

- $\bar{k}$ is given by clause 6.3.3;
- Δf is the subcarrier spacing of the initial active uplink bandwidth part during initial access. Otherwise, Δf is the subcarrier spacing of the active uplink bandwidth part;
- $k_0^{\mu} \in \{-6, 0, +6\}$ is obtained from the higher-layer parameter *k0* and is such that the lowest numbered subcarrier in a common resource block for subcarrier spacing configuration μ coincides with the lowest numbered subcarrier in a common resource block for any subcarrier spacing configuration less than μ;
- $N_{\mathrm{BWP},i}^{\mathrm{start}}$ is the lowest numbered resource block of the initial active uplink bandwidth part based on common resource block indexing and is derived by the higher-layer parameter *initial-UL-BWP* during initial access. Otherwise, $N_{\mathrm{BWP},i}^{\mathrm{start}}$ is the lowest numbered resource block of the active uplink bandwidth part based on common resource block indexing and is derived by the higher-layer parameter *UL-BWP*;
- $n_{\mathrm{RA}}^{\mathrm{start}}$ is the frequency offset of lowest PRACH transmission occasion in frequency domain with respect to PRB 0 of the initial active uplink bandwidth part given by the higher-layer parameter *prach-frequency-start* during initial access associated with the initial active uplink bandwidth part. Otherwise, $n_{\mathrm{RA}}^{\mathrm{start}}$ 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 *prach-frequency-start* 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;

- $N_{\mathrm{RB}}^{\mathrm{RA}}$ is the number of resource blocks occupied and is given by the parameter allocation expressed in number of RBs for PUSCH in Table 6.3.3.2-1.

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

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

where

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

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

where

- l_0 is given by the parameter "starting symbol" in Tables 6.3.3.2-2 to 6.3.3.2-4;
- $n_{\mathrm{t}}^{\mathrm{RA}}$ is the PRACH transmission occasion within the PRACH slot, numbered in increasing order from 0 to $N_{\mathrm{t}}^{\mathrm{RA,slot}} - 1$ within a RACH slot where $N_{\mathrm{t}}^{\mathrm{RA,slot}}$ is given Tables 6.3.3.2-2 to 6.3.3.2-4;
- $N_{\mathrm{dur}}^{\mathrm{RA}}$ is given by Tables 6.3.3.2-2 to 6.3.3.2-4;
- $n_{\mathrm{slot}}^{\mathrm{RA}}$ is given by
  - if $\Delta f_{\mathrm{RA}} \in \{1.25, 5, 15, 60\}$ kHz, then $n_{\mathrm{slot}}^{\mathrm{RA}} = 0$
  - if $\Delta f_{\mathrm{RA}} \in \{30, 120\}$ 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 $n_{\mathrm{slot}}^{\mathrm{RA}} = 1$
- otherwise, $n_{\mathrm{slot}}^{\mathrm{RA}} \in \{0, 1\}$

The quantities L_{RA} and N_{u} are given by clause 6.3.3 and $N_{\mathrm{CP},l}^{\mathrm{RA}} = N_{\mathrm{CP}}^{\mathrm{RA}} + n \cdot 16\kappa$ where

- for $\Delta f_{\mathrm{RA}} \in \{1.25, 5\}$ kHz, $n = 0$
- for $\Delta f_{\mathrm{RA}} \in \{15, 30, 60, 120\}$ kHz, n is the number of times the interval $\left[t_{\mathrm{start}}^{\mathrm{RA}}, t_{\mathrm{start}}^{\mathrm{RA}} + \left(N_{\mathrm{u}}^{\mathrm{RA}} + N_{\mathrm{CP}}^{\mathrm{RA}}\right) T_{\mathrm{c}}\right[$ overlaps with either time instance 0 or time instance $\left(\Delta f_{\max} N_{\mathrm{f}} / 2000\right) \cdot T_{\mathrm{c}} = 0.5\,\mathrm{ms}$ in a subframe

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

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

for all channels and signals except PRACH and by

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

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

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 $b^{(q)}(0),...,b^{(q)}(M_{\text{bit}}^{(q)} - 1)$, 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 $\tilde{b}^{(q)}(0),...,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)} - 1)$ according to the following pseudo code

Set $i = 0$

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

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

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

else

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

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

else

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

end if

end if

$i = i + 1$

end while

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

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

where

- $n_{\mathrm{ID}} \in \{0,1,...,1023\}$ equals the higher-layer parameter *Data-scrambling-Identity* if configured and the RNTI equals the C-RNTI,
- $n_{\mathrm{ID}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ 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 $\tilde{b}^{(q)}(0),...,\tilde{b}^{(q)}(M_{\mathrm{bit}}^{(q)} - 1)$ 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 $d^{(q)}(0),...,d^{(q)}(M_{\mathrm{symb}}^{(q)} - 1)$.

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}**
		π/2-BPSK	1
QPSK	2	QPSK	2
16QAM	4	16QAM	4
64QAM	6	64QAM	6
256QAM	8	256QAM	8

6.3.1.3 Layer mapping

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

$d^{(q)}(0),...,d^{(q)}(M_{\text{symb}}^{(q)}-1)$ for codeword q shall be mapped onto the layers $x(i)=\left[x^{(0)}(i) \quad ... \quad x^{(\upsilon-1)}(i)\right]^T$, $i=0,1,...,M_{\text{symb}}^{\text{layer}}-1$ where υ 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, $y^{(\lambda)}(i)=x^{(\lambda)}(i)$ for each layer $\lambda=0,1,...,\upsilon-1$.

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

If the procedure in [6, TS 38.214] indicates that phase-tracking reference signals are not being used, the block of complex-valued symbols $x^{(0)}(0),...,x^{(0)}(M_{\text{symb}}^{\text{layer}}-1)$ 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 $x^{(0)}(0),...,x^{(0)}(M_{\text{symb}}^{\text{layer}}-1)$ 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 $i'\in\left\{0,1,...,M_{\text{sc}}^{\text{PUSCH}}-1\right\}$ 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

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

resulting in a block of complex-valued symbols $y^{(0)}(0),...,y^{(0)}(M_{\text{symb}}^{\text{layer}}-1)$. 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 $\left[y^{(0)}(i) \quad ... \quad y^{(\upsilon-1)}(i)\right]^T$, $i=0,1,...,M_{\text{symb}}^{\text{layer}}-1$ shall be precoded according to

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

where $i=0,1,...,M_{\text{symb}}^{\text{ap}}-1$, $M_{\text{symb}}^{\text{ap}}=M_{\text{symb}}^{\text{layer}}$. The set of antenna ports $\{p_{0,...,}p_{\rho-1}\}$ 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.

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

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

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

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

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

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

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

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

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

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

Table 6.3.1.5.4-6: Precoding matrix W for three-layer transmission using four antenna ports with transform precoding disabled.

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

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

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

6.3.1.6 Mapping to virtual resource blocks

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

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

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

6.3.1.7 Mapping from virtual to physical resource blocks

Virtual resource blocks shall be mapped to physical resource blocks according to the indicated mapping scheme, non-interleaved or interleaved mapping.

For non-interleaved VRB-to-PRB mapping, virtual resource block n is mapped to physical resource block n.

For interleaved VRB-to-PRB mapping, the mapping process is defined in terms of resource block bundles:

- Resource block bundle i is defined as resource blocks $\{iL, iL+1,...,iL+L-1\}$ where L is the bundle size provided by the higher-layer parameter *VRB-to-PRB-interleaver*
- Virtual resource block bundle j is mapped to physical resource block bundle $f(j)$ where

$$\begin{aligned}&f(j)=rC+c\\&j=cR+r\\&r=0,1,...,R-1\\&c=0,1,...,C-1\\&R=2\\&C=\left\lceil N_{\text{BWP},i}^{\text{size}}/(LR)\right\rceil\end{aligned}$$

with $N_{\text{BWP},i}^{\text{size}}$ representing the size of the bandwidth part in which the PUSCH is transmitted.

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 frequency hopping is configured for PUCCH format 1, 3, or 4, 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'

$$f_{\text{gh}} = 0$$
$$f_{\text{ss}} = n_{\text{ID}} \bmod 30$$
$$v = 0$$

  where n_{ID} is given by the higher-layer parameter *hoppingId*.

- if *PUCCH-GroupHopping* equals 'enabled'

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

  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 *PUCCH-GroupHopping* equals 'disabled'

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

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

The frequency hopping index $n_{\text{hop}} = 0$ if frequency hopping is disabled by the higher-layer parameter *PUCCH-frequency-hopping*. If frequency hopping is enabled by the higher-layer parameter *PUCCH-frequency-hopping*, $n_{\text{hop}} = 0$ 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

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

where

- $n_{\text{s,f}}^{\mu}$ is the slot number in the radio frame
- l is the OFDM symbol number in the PUCCH transmission where $l = 0$ corresponds to the first OFDM symbol of the PUCCH transmission,
- l' is the index of the OFDM symbol in the slot that corresponds to the first OFDM symbol of the PUCCH transmission in the slot given by [5, TS 38.213]
- m_0 is given by [5, TS 38.213] for PUCCH format 0 and 1 while for PUCCH format 3 and 4 is defined in subclause 6.4.1.3.3.1
- $m_{\text{cs}} = 0$ except for PUCCH format 0 when it depends on the information to be transmitted according to subclause 9.2 of [5, TS 38.213].

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

$$n_{\text{cs}}(n_{\text{s,f}}^{\mu}, l) = \sum_{m=0}^{7} 2^m c\left(14 \cdot 8 n_{\text{s,f}}^{\mu} + 8l + m\right)$$

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

6.3.2.3 PUCCH format 0

6.3.2.3.1 Sequence generation

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

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

where $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 6.3.2.2 with m_{cs} depending on the information to be transmitted according to 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 $\beta_{\text{PUCCH},0}$ in order to conform to the transmit power specified in [5, TS 38.213] and mapped in sequence starting with $x(0)$ to resource elements $(k,l)_{p,\mu}$ assigned for transmission according to 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 $b(0),...,b(M_{\text{bit}}-1)$ shall be modulated as described in clause 5.1 using BPSK if $M_{\text{bit}}=1$ and QPSK if $M_{\text{bit}}=2$, resulting in a complex-valued symbol $d(0)$.

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

$$y(n) = d(0)\cdot r_{u,v}^{(\alpha,\delta)}(n)$$
$$n = 0,1,...,N_{\text{sc}}^{\text{RB}}-1$$

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

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

where $N_{\text{SF},m'}^{\text{PUCCH,1}}$ is given by Table 6.3.2.4.1-1.

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, 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	**Intra-slot hopping**	
	$m'=0$	$m'=0$	$m'=1$
4	2	1	1
5	2	1	1
6	3	1	2
7	3	1	2
8	4	2	2
9	4	2	2
10	5	2	3
11	5	2	3
12	6	3	3
13	6	3	3
14	7	3	4

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

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

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

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

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

where

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

6.3.2.5.2 Modulation

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

6.3.2.5.3 Mapping to physical resources

The block of modulation symbols $d(0),...,d(M_{\mathrm{symb}}-1)$ shall be multiplied with the amplitude scaling factor $\beta_{\mathrm{PUCCH,2}}$ 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 $b(0),...,b(M_{\mathrm{bit}}-1)$, where M_{bit} is the number of bits transmitted on the physical channel, shall be scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0),...,\tilde{b}(M_{\mathrm{bit}}-1)$ according to

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

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

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

where

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

6.3.2.6.2 Modulation

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

6.3.2.6.3 Block-wise spreading

For both PUCCH format 3 and 4, $M_{\mathrm{sc}}^{\mathrm{PUCCH},s} = M_{\mathrm{RB}}^{\mathrm{PUCCH},s} \cdot N_{\mathrm{sc}}^{\mathrm{RB}}$ with $M_{\mathrm{RB}}^{\mathrm{PUCCH},s}$ representing the bandwidth of the PUCCH in terms of resource blocks according to subclause 9.2.1 of [5, TS 38.213] and shall fulfil

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

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

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

where $M_{\mathrm{RB}}^{\mathrm{PUCCH,3}} \geq 1$ is given by subclause 9.2.1 of [5, TS 38.213] and $N_{\mathrm{SF}}^{\mathrm{PUCCH,3}} = 1$.

For PUCCH format 4, block-wise spreading shall be applied according to

$$y\left(lM_{\mathrm{sc}}^{\mathrm{PUCCH,4}} + k\right) = w_n(k) \cdot d\left(l \frac{M_{\mathrm{sc}}^{\mathrm{PUCCH,4}}}{N_{\mathrm{SF}}^{\mathrm{PUCCH,4}}} + k \bmod \frac{M_{\mathrm{sc}}^{\mathrm{PUCCH,4}}}{N_{\mathrm{SF}}^{\mathrm{PUCCH,4}}} \right)$$
$$k = 0,1,\ldots,M_{\mathrm{sc}}^{\mathrm{PUCCH,4}} - 1$$
$$l = 0,1,\ldots,\left(N_{\mathrm{SF}}^{\mathrm{PUCCH,4}} M_{\mathrm{symb}} \big/ M_{\mathrm{sc}}^{\mathrm{PUCCH,4}}\right) - 1$$

where $M_{\mathrm{RB}}^{\mathrm{PUCCH,4}} = 1$, $N_{\mathrm{SF}}^{\mathrm{PUCCH,4}} \in \{2,4\}$ 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 $N_{\mathrm{SF}}^{\mathrm{PUCCH,4}} = 2$.

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 $N_{\mathrm{SF}}^{\mathrm{PUCCH,4}} = 4$.

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

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

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

6.3.2.6.5 Mapping to physical resources

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

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

The mapping to resource elements $(k,l)_{p,\mu}$ not reserved for other purposes shall be in increasing order of first the index k over the assigned physical resource blocks according to 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, $\lfloor N_{\text{symb}}^{\text{PUCCH},s} / 2 \rfloor$ 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

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

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

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

where $L_{\text{RA}} = 839$ 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 *PRACHRootSequenceIndex*. 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

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

where N_{CS} is given by Tables 6.3.3.1-5 to 6.3.3.1-7, the higher-layer parameter *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 $N_{\text{CS}} \leq d_u < L_{\text{RA}}/3$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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 $L_{\mathrm{RA}} = 139$ and $\Delta f^{\mathrm{RA}} = 15 \cdot 2^{\mu}$ kHz where $\mu \in \{0,1,2,3\}$.

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

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

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

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

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

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

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

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

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

Table 6.3.3.1-7: N_{CS} for preamble formats with $\Delta f^{\text{RA}} = 15 \cdot 2^{\mu}$ 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

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

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 *PRACHConfigurationIndex* 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 parameter *prach-FDM*. The PRACH frequency resources $n_{\text{RA}} \in \{0,1,\ldots,M-1\}$, where M equals the higher-layer parameter *prach-FDM*, are numbered in increasing order within the initial active 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:

- $15\,\text{kHz}$ for PRACH preamble formats 0 – 3
- $15 \cdot 2^{\mu}$ kHz for PRACH preamble formats A1, A2, A3, B1, B2, B3, B4, C0, C2 where μ is the configured PRACH subcarrier spacing.

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	$N_{\mathrm{RB}}^{\mathrm{RA}}$, 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.

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

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

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

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

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

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

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

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

121	A3	1	0	9	0	2	2	6
122	A3	1	0	9	7	1	1	6
123	A3	1	0	9	0	1	2	6
124	A3	1	0	8,9	0	2	2	6
125	A3	1	0	4,9	0	1	2	6
126	A3	1	0	7,9	7	1	1	6
127	A3	1	0	3,4,8,9	0	1	2	6
128	A3	1	0	3,4,8,9	0	2	2	6
129	A3	1	0	0,1,2,3,4,5,6,7,8,9	7	1	1	6
130	A3	1	0	1,3,5,7,9	0	1	2	6
131	B1	16	1	9	2	2	6	2
132	B1	8	1	9	2	2	6	2
133	B1	4	1	9	2	1	6	2
134	B1	2	1	2,3,4,7,8,9	2	1	6	2
135	B1	2	1	8,9	2	2	6	2
136	B1	2	1	7,9	2	1	6	2
137	B1	2	1	7,9	8	1	3	2
138	B1	2	1	4,9	8	1	3	2
139	B1	2	1	4,9	2	2	6	2
140	B1	2	1	9	2	1	6	2
141	B1	1	0	9	2	2	6	2
142	B1	1	0	9	8	1	3	2
143	B1	1	0	9	2	1	6	2
144	B1	1	0	8,9	2	2	6	2
145	B1	1	0	4,9	2	1	6	2
146	B1	1	0	7,9	8	1	3	2
147	B1	1	0	3,4,8,9	2	1	6	2
148	B1	1	0	3,4,8,9	2	2	6	2
149	B1	1	0	0,1,2,3,4,5,6,7,8,9	8	1	3	2
150	B1	1	0	1,3,5,7,9	2	1	6	2
151	B4	16	1	9	0	2	1	12
152	B4	8	1	9	0	2	1	12
153	B4	4	1	9	2	1	1	12
154	B4	2	1	2,3,4,7,8,9	0	1	1	12
155	B4	2	1	8,9	0	2	1	12
156	B4	2	1	7,9	2	1	1	12
157	B4	2	1	4,9	2	1	1	12
158	B4	2	1	4,9	0	2	1	12
159	B4	2	1	9	2	1	1	12
160	B4	1	0	9	0	2	1	12
161	B4	1	0	9	2	1	1	12
162	B4	1	0	8,9	0	2	1	12
163	B4	1	0	4,9	2	1	1	12
164	B4	1	0	7,9	2	1	1	12
165	B4	1	0	3,4,8,9	2	1	1	12
166	B4	1	0	3,4,8,9	0	2	1	12
167	B4	1	0	0,1,2,3,4,5,6,7,8,9	2	1	1	12
168	B4	1	0	1,3,5,7,9	2	1	1	12
169	A1/B1	2	1	8,9	2	2	6	2
170	A1/B1	2	1	7,9	2	1	6	2
171	A1/B1	2	1	7,9	8	1	3	2
172	A1/B1	2	1	4,9	8	1	3	2
173	A1/B1	2	1	4,9	2	2	6	2
174	A1/B1	2	1	9	2	1	6	2
175	A1/B1	1	0	9	2	2	6	2
176	A1/B1	1	0	9	8	1	3	2
177	A1/B1	1	0	9	2	1	6	2
178	A1/B1	1	0	8,9	2	2	6	2
179	A1/B1	1	0	4,9	2	1	6	2
180	A1/B1	1	0	7,9	8	1	3	2
181	A1/B1	1	0	3,4,8,9	2	2	6	2
182	A1/B1	1	0	0,1,2,3,4,5,6,7,8,9	8	1	3	2
183	A1/B1	1	0	1,3,5,7,9	2	1	6	2
184	A2/B2	2	1	8,9	0	2	3	4
185	A2/B2	2	1	7,9	6	1	2	4

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

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

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

PRACH Config. Index	Preamble format	$n_{\mathrm{SFN}} \bmod x = y$		Slot number	Starting symbol	Number of PRACH slots within a 60 kHz slot	$N_{\mathrm{t}}^{\mathrm{RA,slot}}$, number of time-domain PRACH occasions within a RACH slot	$N_{\mathrm{dur}}^{\mathrm{RA}}$, PRACH duration
		x	y					
0	A1	1	0	4,9,14,19,24,29,34,39	0	[2 or 1]	6	2
1	A1	1	0	4,9,14,19,24,29,34,39	7	1	3	2
2	A1	1	0	24,29,34,39	0	[2 or 1]	6	2
3	A1	1	0	24,29,34,39	7	1	3	2
4	A1	1	0	18,19,38,39	0	[2 or 1]	6	2
5	A1	1	0	18,19,38,39	7	1	3	2
6	A1	1	0	0,1,2,…,39	0	[2 or 1]	6	2
7	A1	1	0	0,1,2,…,39	7	1	3	2
8	A1	1	0	23,27,31,35,39	0	[2 or 1]	6	2
9	A1	1	0	23,27,31,35,39	7	1	3	2
10	A1	1	0	3,7,11,15,19,23,27,31,35,39	0	[2 or 1]	6	2
11	A1	1	0	3,7,11,15,19,23,27,31,35,39	7	1	3	2
12	A1	1	0	1,3,5,7,…,37,39	0	[2 or 1]	6	2
13	A1	1	0	7,15,23,31,39	0	[2 or 1]	6	2
14	A1	1	0	7,15,23,31,39	7	1	3	2
15	A1	16	[0]	4,9,14,19,24,29,34,39	0	[2 or 1]	6	2
16	A1	16	[1]	[3],7,[11],15,[19],23,[27],31,[35],39	[0 or 7]	1	[6 or 3]	2
17	A1	8	[1]	4,9,14,19,24,29,34,39	0	[2 or 1]	6	2
18	A1	8	[1]	[3],7,[11],15,[19],23,[27],31,[35],39	[0 or 7]	1	[6 or 3]	2
19	A1	4	[1]	4,9,14,19,24,29,34,39	0	[2 or 1]	6	2
20	A1	4	[1]	[3],7,[11],15,[19],23,[27],31,[35],39	[0 or 7]	1	[6 or 3]	2
21	A1	2	[1]	4,9,14,19,24,29,34,39	0	[2 or 1]	6	2
22	A1	2	[1]	[3],7,[11],15,[19],23,[27],31,[35],39	[0 or 7]	1	[6 or 3]	2
23	A1	[1]	[0]	23,31,39	0	1	6	2
24	A1	[1]	[0]	1,3,5,7,…,37,39	7	1	3	2

6.4 Physical signals

6.4.1 Reference signals

6.4.1.1 Demodulation reference signal for PUSCH

6.4.1.1.1 Sequence generation

6.4.1.1.1.1 Sequence generation when transform precoding is disabled

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

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

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

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

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

- $n_{\text{SCID}} \in \{0,1\}$ and $N_{\text{ID}}^{n_{\text{SCID}}} \in \{0,1,...,65535\}$ is given by the higher-layer parameter *UL-DMRS-Scrambling-ID* if provided and the PUSCH is not a msg3 PUSCH according to clause 8.3 in [5, TS 38.213].

- $n_{\text{SCID}} = 0$ and $N_{\text{ID}}^{n_{\text{SCID}}} = N_{\text{ID}}^{\text{cell}}$ otherwise

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

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

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

The sequence group $u = \left(f_{\text{gh}} + n_{\text{ID}}^{\text{RS}}\right) \bmod 30$, 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-Transform-precoding* and the PUSCH is not a msg3 PUSCH 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 shall be used

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

- if group hopping but not sequence hopping shall be used

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

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

- if sequence hopping but not group hopping shall be used

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

  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

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,

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

- if transform precoding is enabled

$$\begin{aligned}
\tilde{a}_{k,l}^{(\tilde{p}_0,\mu)} &= w_\mathrm{f}(k')\,w_\mathrm{t}(l')\,r(2n+k') \\
k &= 4n+2k'+\Delta \\
k' &= 0,1 \\
l &= \bar{l}+l' \\
n &= 0,1,...
\end{aligned}$$

where $w_\mathrm{f}(k')$, $w_\mathrm{t}(l')$, and Δ are given by Tables 6.4.1.1.3-1 and 6.4.1.1.3-2 and the configuration type is given by the higher-layer parameter *UL-DMRS-config-type*.

The intermediate quantity $\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)}$ shall be precoded, multiplied with the amplitude scaling factor $\beta_{\mathrm{PUSCH}}^{\mathrm{DMRS}}$ in order to conform to the transmit power specified in [5, TS 38.213], and mapped to physical resources according to

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

where

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

and the following conditions are fulfilled:

- the resource elements $a_{k,l}^{(p_j,\mu)}$ 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 *DL-DMRS-typeA-pos*
- 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

- the signalled 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 frequency hopping is not used, or
- the signalled 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 frequency hopping is not used, or
- the signalled duration per hop according to Table 6.4.1.1.3-6 if frequency hopping is used.

For PUSCH mapping type A, the case *UL-DMRS-add-pos* equal to 3 is only supported when *DL-DMRS-typeA-pos* is equal to 2.

The time-domain index l' and the supported antenna ports $\tilde{p}_j$ are given by Tables 6.4.1.1.3-3 through 6.4.1.1.3-6:

- if the higher-layer parameter *UL-DMRS-max-len* is equal to 1 and frequency hopping is disabled, the tables shall be used according to single-symbol DM-RS
- if the higher-layer parameter *UL-DMRS-max-len* is equal to 2 and frequency hopping is disabled, the associated DCI determines whether single-symbol or double-symbol DM-RS shall be used
- if frequency hopping is enabled according to clause 7.3.1.1.2 in [5, TS 38.212], Table 6.4.1.1.3-6 shall be used. If $l_0 = 3$, only *UL-DMRS-add-pos* equal to 0 is supported.

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

$\tilde{p}$	CDM group	Δ	$w_f(k')$		$w_t(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
0	0	0	+1	+1	+1	+1
1	0	0	+1	-1	+1	+1
2	1	1	+1	+1	+1	+1
3	1	1	+1	-1	+1	+1
4	0	0	+1	+1	+1	-1
5	0	0	+1	-1	+1	-1
6	1	1	+1	+1	+1	-1
7	1	1	+1	-1	+1	-1

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

$\tilde{p}$	CDM group	Δ	$w_f(k')$		$w_t(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
0	0	0	+1	+1	+1	+1
1	0	0	+1	-1	+1	+1
2	1	2	+1	+1	+1	+1
3	1	2	+1	-1	+1	+1
4	2	4	+1	+1	+1	+1
5	2	4	+1	-1	+1	+1
6	0	0	+1	+1	+1	-1
7	0	0	+1	-1	+1	-1
8	1	2	+1	+1	+1	-1
9	1	2	+1	-1	+1	-1
10	2	4	+1	+1	+1	-1
11	2	4	+1	-1	+1	-1

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

Duration in symbols	DM-RS positions $\bar{l}$							
	PUSCH mapping type A				**PUSCH mapping type B**			
	UL-DMRS-add-pos				***UL-DMRS-add-pos***			
	0	***1***	***2***	***3***	***0***	***1***	***2***	***3***
<4	-	-	-	-	l_0	l_0	l_0	l_0
4	l_0	l_0	l_0	l_0	l_0	l_0	l_0	l_0
5	l_0	l_0	l_0	l_0	l_0	l_0 , [4]	l_0 , [4]	l_0 , [4]
6	l_0	l_0	l_0	l_0	l_0	l_0 , 4	l_0 , 4	l_0 , 4
7	l_0	l_0	l_0	l_0	l_0	l_0 , 4	l_0 , 4	l_0 , 4
8	l_0	l_0 , [7]	l_0 , [7]	l_0 , [7]	l_0	l_0 , 6	l_0 , 3, 6	l_0 , 3, 6
9	l_0	l_0 , 7	l_0 , 7	l_0 , 7	l_0	l_0 , 6	l_0 , 3, 6	l_0 , 3, 6
10	l_0	l_0 , 9	l_0 , 6, 9	l_0 , 6, 9	l_0	l_0 , 8	l_0 , 4, 8	l_0 , 3, 6, 9
11	l_0	l_0 , 9	l_0 , 6, 9	l_0 , 6, 9	l_0	l_0 , 8	l_0 , 4, 8	l_0 , 3, 6, 9
12	l_0	l_0 , 9	l_0 , 6, 9	l_0 , 5, 8, 11	l_0	l_0 , 10	l_0 , 5, 10	l_0 , 3, 6, 9
13	l_0	l_0 , 11	l_0 , 7, 11	l_0 , 5, 8, 11	l_0	l_0 , 10	l_0 , 5, 10	l_0 , 3, 6, 9
14	l_0	l_0 , 11	l_0 , 7, 11	l_0 , 5, 8, 11	l_0	l_0 , 10	l_0 , 5, 10	l_0 , 3, 6, 9

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

Duration in symbols	DM-RS positions $\bar{l}$							
	PUSCH mapping type A				PUSCH mapping type B			
	UL-DMRS-add-pos				*UL-DMRS-add-pos*			
	0	*1*	*2*	*3*	*0*	*1*	*2*	*3*
<4	-	-			-	-		
4	l_0	l_0			-	-		
5	l_0	l_0			l_0	l_0		
6	l_0	l_0			l_0	l_0		
7	l_0	l_0			l_0	l_0		
8	l_0	l_0			l_0	l_0, 5		
9	l_0	l_0			l_0	l_0, 5		
10	l_0	l_0, 8			l_0	l_0, 7		
11	l_0	l_0, 8			l_0	l_0, 7		
12	l_0	l_0, 8			l_0	l_0, 9		
13	l_0	l_0, 10			l_0	l_0, 9		
14	l_0	l_0, 10			l_0	l_0, 9		

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

DM-RS duration	l'	*Supported antenna ports p*	
		Configuration type 1	*Configuration type 2*
single-symbol DM-RS	0	0 – 3	0 – 5
double-symbol DM-RS	0, 1	0 – 7	0 – 11

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

Duration in symbols	DM-RS positions $\bar{l}$							
	PUSCH mapping type A				PUSCH mapping type B			
	UL-DMRS-add-pos				UL-DMRS-add-pos			
	0		1		0		1	
	First hop	Second hop	First hop	Second hop	First hop	Second hop	First hop	Second hop
≤ 3	-	-	-	-	l_0	0	-	-
4	l_0	0	-	-	l_0	0	-	-
5, 6	l_0	0	-	-	l_0	0	l_0, l_0+4	0, 4
7	l_0	0	l_0, l_0+4	0, 4	l_0	0	l_0, l_0+4	0, 4

6.4.1.2 Phase-tracking reference signals for PUSCH

6.4.1.2.1 Sequence generation

6.4.1.2.1.1 Sequence generation and precoding if transform precoding is not enabled

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

$$\begin{bmatrix} r_k^{(p_0)}(m) \\ \vdots \\ r_k^{(p_{\rho-1})}(m) \end{bmatrix} = W \begin{bmatrix} r^{(\tilde{p}_0)}(m) \\ \vdots \\ r^{(\tilde{p}_{\upsilon-1})}(m) \end{bmatrix}$$

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

where

- antenna ports $\tilde{p}_{j'}$ or $\{\tilde{p}_{j'}, \tilde{p}_{j''}\}$ associated with PT-RS transmission are given by clause 6.2.3 of [6, TS 38.214]
- the precoding matrix W is given by clause 6.3.1.5.
- $r(m)$ is given by clause 6.4.1.1.1.1
  - at the position of the first DM-RS symbol in absence of PUSCH intra-slot frequency hopping
  - at the position of the first DM-RS symbol in hop $h \in \{0,1\}$ in presence of PUSCH intra-slot frequency hopping
- k' is defined in clause 6.4.1.1.3.

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 $N_{\text{group}}^{\text{PTRS}}$, 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

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

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

$$c_{\text{init}} = \left(2^{17}\left(14 n_{\text{s,f}}^{\mu} + l + 1\right)\left(2N_{\text{ID}} + 1\right) + 2N_{\text{ID}}\right) \bmod 2^{31}$$

where l is the lowest OFDM symbol number in the PUSCH allocation in slot n_{s} 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-Transform-precoding*.

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

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

6.4.1.2.2 Mapping to physical resources

6.4.1.2.2.1 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

$$a_{k,l}^{(p,\mu)} = \beta_{\text{PTRS}} r_k^{(p)}(m)$$

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

The quantity β_{PTRS} is an amplitude scaling factor to conform with the transmit power specified in clause 6.2.2 of [6, TS 38.214].

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

1. set $i=0$ and $l_{\text{ref}}=0$
2. if any symbol in the interval $\max(l_{\text{ref}}+(i-1)L_{\text{PTRS}}+1, l_{\text{ref}}),\ldots,l_{\text{ref}}+iL_{\text{PTRS}}$ 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 $l_{\text{ref}}+iL_{\text{PTRS}}$ is inside the PUSCH allocation
3. add $l_{\text{ref}}+iL_{\text{PTRS}}$ to the set of time indices for PT-RS
4. increment i by one
5. repeat from step 2 above as long as $l_{\text{ref}}+iL_{\text{PTRS}}$ is inside the PUSCH allocation

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

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

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

where

- $i = 0,1,2,\ldots$
- $k_{\text{ref}}^{\text{RE}}$ is given by Table 6.4.1.2.2.1-1 for the DM-RS port associated with the PT-RS port according to clause 6.2.3 in [6, TS 38.214]. If the higher-layer parameter *UL-PTRS-RE-offset* 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
- $K_{\text{PTRS}} \in \{2,4\}$ is given by [6, TS 38.214].

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

DM-RS antenna port $\tilde{p}$	$k_{\text{ref}}^{\text{RE}}$							
	DM-RS Configuration type 1				**DM-RS Configuration type 2**			
	UL-PTRS-RE-offset				***UL-PTRS-RE-offset***			
	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 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 $N_{\text{samp}}^{\text{group}} N_{\text{group}}^{\text{PTRS}}$ 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 $N_{\text{group}}^{\text{PTRS}}$, 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 π/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 $\max(l_{\text{ref}} + (i-1)L_{\text{PTRS}} + 1, l_{\text{ref}}),...,l_{\text{ref}} + iL_{\text{PTRS}}$ 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 $l_{\text{ref}} + iL_{\text{PTRS}}$ is inside the PUSCH allocation
3. add $l_{\text{ref}} + iL_{\text{PTRS}}$ to the set of time indices for PT-RS
4. increment i by one
5. repeat from step 2 above as long as $l_{\text{ref}} + iL_{\text{PTRS}}$ is inside the PUSCH allocation

where $L_{\text{PTRS}} \in \{1,2\}$ is given by the higher-layer parameter *UL-PTRS-time-density-transform-precoding*.

Table 6.4.1.2.2.2-1: PT-RS symbol mapping.

Number of PT-RS groups $N_{\text{group}}^{\text{PTRS}}$	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	$s\left\lfloor M_{\text{sc}}^{\text{PUSCH}}/4\right\rfloor + k - 1$ where $s = 1,3$ and $k = 0,1$
2	4	$sM_{\text{sc}}^{\text{PUSCH}} + k$ where $\begin{cases} s = 0 & \text{and} \quad k = 0,1,2,3 \\ s = 1 & \text{and} \quad k = -4,-3,-2,-1 \end{cases}$
4	2	$\left\lfloor sM_{\text{sc}}^{\text{PUSCH}}/8\right\rfloor + k - 1$ where $s = 1,3,5,7$ and $k = 0,1$
4	4	$sM_{\text{sc}}^{\text{PUSCH}}/4 + n + k$ where $\begin{cases} s = 0 & \text{and} \quad k = 0,1,2,3 & n = 0 \\ s = 1,2 & \text{and} \quad k = -2,-1,0,1 & n = \left\lfloor M_{\text{sc}}^{\text{PUSCH}}/8\right\rfloor \\ s = 4 & \text{and} \quad k = -4,-3,-2,-1 & n = 0 \end{cases}$
8	4	$\left\lfloor sM_{\text{sc}}^{\text{PUSCH}}/8\right\rfloor + n + k$ where $\begin{cases} s = 0 & \text{and} \quad k = 0,1,2,3 & n = 0 \\ s = 1,2,3,4,5,6 & \text{and} \quad k = -2,-1,0,1 & n = \left\lfloor M_{\text{sc}}^{\text{PUSCH}}/16\right\rfloor \\ s = 8 & \text{and} \quad k = -4,-3,-2,-1 & n = 0 \end{cases}$

6.4.1.3 Demodulation reference signal for PUCCH

6.4.1.3.1 Demodulation reference signal for PUCCH format 1

6.4.1.3.1.1 Sequence generation

The reference signal sequence is defined by

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

where $N_{\text{SF},m'}$ is given by Table 6.4.1.3.1.1-1. The sequence $r_{u,v}^{(\alpha,\delta)}(n)$ is given by clause 5.2.2.

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

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

6.4.1.3.1.2 Mapping to physical resources

The sequence shall be multiplied with the amplitude scaling factor $\beta_{\mathrm{PUCCH},1}$ 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

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

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 $r(m)$ shall be generated according to

$$r(m) = \frac{1}{\sqrt{2}}\left(1-2\cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1-2\cdot c(2m+1)\right)$$
$$m = 0,1,...,M_{\mathrm{symb}}/3-1$$
.

where the pseudo-random sequence $c(i)$ is defined in clause 5.2 and M_{symb} is given by clause 6.3.2.5.2. The pseudo-random sequence generator shall be initialized with

$$c_{\mathrm{init}} = \left(2^{17}\left(14n_{\mathrm{s,f}}^{\mu} + l + 1\right)\left(2N_{\mathrm{ID}}^{0}+1\right) + 2N_{\mathrm{ID}}^{0}\right) \bmod 2^{31}$$

where l is the OFDM symbol number within the slot, $n_{\mathrm{s,f}}^{\mu}$ is the slot number within the radio frame, and $N_{\mathrm{ID}}^{0} \in \{0,1,...,65535\}$ is given by the higher-layer parameter *UL-DMRS-Scrambling-ID* if provided and by $N_{\mathrm{ID}}^{\mathrm{cell}}$ otherwise.

6.4.1.3.2.2 Mapping to physical resources

The sequence shall be multiplied with the amplitude scaling factor $\beta_{\mathrm{PUCCH},2}$ 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

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

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 $r(m)$ shall be generated according to

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

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

$$a_{k,l}^{(p,\mu)} = \beta_{\text{PUCCH,s}} \cdot r_l(m).$$
$$m = 0,1,\ldots,M_{\text{sc}}^{\text{PUCCH},s}/3 - 1$$

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 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 consists of

- $N_{\text{ap}}^{\text{SRS}} \in \{1,2,4\}$ antenna ports $\{p_i\}_{i=0}^{N_{\text{ap}}^{\text{SRS}}-1}$, $p_i \in \{1000,1001,...\}$, given by the higher layer parameter *NrofSRS-Ports*
- $N_{\text{symb}}^{\text{SRS}} \in \{1,2,4\}$ consecutive OFDM symbols contained in the higher layer parameter *SRS-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 $l_{\text{offset}} \in \{0,1,\ldots,5\}$ counts symbols backwards from the end of the slot and is contained in the higher layer parameter *SRS-ResourceMapping*
- 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

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

where $M_{\text{sc},b}^{\text{RS}}$ 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 *SRS-TransmissionComb*. The cyclic shift α_i for antenna port p_i is given as

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

where $n_{\text{SRS}}^{\text{cs}} \in \{0,1,...,n_{\text{SRS}}^{\text{cs,max}} - 1\}$ is given by the higher layer parameter *SRS-CyclicShiftConfig*. 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 $u = \left(f_{\text{gh}}\left(n_{\text{s,f}}^{\mu}, l'\right) + n_{\text{ID}}^{\text{SRS}}\right) \bmod 30$ and the sequence number v in clause 5.2.2 depends on the higher-layer parameter *SRS-GroupSequenceHopping*. The SRS sequence identity $n_{\text{ID}}^{\text{SRS}}$ is given by the higher layer parameter *SRS-SequenceId* and $l' \in \left\{0,1,...,N_{\text{symb}}^{\text{SRS}}-1\right\}$ is the OFDM symbol number within the SRS resource.

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

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

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

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

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

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

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

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

6.4.1.4.3 Mapping to physical resources

When SRS is transmitted on a given SRS resource, the sequence $r^{(p_i)}\left(n, l'\right)$ 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

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

The length of the sounding reference signal sequence is given by

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

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 higher-layer parameter *SRS-FreqHopping*. The row of the table is selected according to the index $C_{\text{SRS}} \in \{0,1,...,63\}$ contained in the higher-layer parameter *SRS-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

$$\bar{k}_0^{(p_i)} = n_{\text{shift}} N_{\text{sc}}^{\text{RB}} + k_{\text{TC}}^{(p_i)}$$
$$k_{\text{TC}}^{(p_i)} = \begin{cases} \left(\bar{k}_{\text{TC}} + K_{\text{TC}}/2\right) \bmod K_{\text{TC}} & \text{if } n_{\text{SRS}}^{\text{cs}} \in \left\{n_{\text{SRS}}^{\text{cs,max}}/2, \ldots, n_{\text{SRS}}^{\text{cs,max}} - 1\right\} \text{ and } N_{\text{ap}} = 4 \text{ and } p_i \in \{1001, 1003\} \\ \bar{k}_{\text{TC}} & \text{otherwise} \end{cases}$$

The frequency domain shift value n_{shift} adjusts the SRS allocation to align with the common resource block grid in multiples of four and is contained in the higher layer parameter *SRS-FreqDomainPosition*. The transmission comb offset $\bar{k}_{\text{TC}} \in \{0, 1, \ldots, K_{\text{TC}} - 1\}$ is contained in the higher layer parameter *SRS-TransmissionComb* and n_{b} is a frequency position index.

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

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

for all $N_{\text{symb}}^{\text{SRS}}$ OFDM symbols of the SRS resource. The quantity n_{RRC} is contained in the higher-layer parameters *SRS-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

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

where

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

and where $N_{b_{\text{hop}}} = 1$ regardless of the value of N_b. The quantity n_{SRS} counts the number of SRS transmissions. For the case of an SRS resource configured as aperiodic by the higher layer parameter *SRS-ResourceConfigType*, 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 $R \leq N_{\text{sym}}^{\text{SRS}}$ is the repetition factor and is contained in the higher layer parameter *SRS-ResourceMapping*.
For the case of an SRS resource configured as periodic or semi-persistent by the higher layer parameter *SRS-ResourceConfigType*, the SRS counter is given by

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

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

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

63	272	1	16	17	8	2	4	2

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 *SRS-ResourceConfigType*, a periodicity T_{SRS} (in slots) and slot offset T_{offset} are configured according to the higher layer parameter *SRS-SlotConfig*. Candidate slots in which the configured SRS resource may be used for SRS transmission are the slots satisfying

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

SRS may be transmitted only if all OFDM symbols corresponding to the configured SRS resource are semi-statically configured as 'uplink' or 'flexible' in the candidate slot and SRS transmission is allowed by the procedure 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, for PDSCH and PBCH
- 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

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 $b^{(q)}(0),...,b^{(q)}(M_{\text{bit}}^{(q)} - 1)$, 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 $\tilde{b}^{(q)}(0),...,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)} - 1)$ according to

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

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

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

where

- $n_{\text{ID}} \in \{0,1,...,1023\}$ equals the higher-layer parameter *Data-scrambling-Identity* if configured and the RNTI equals the C-RNTI,

- $n_{\text{ID}} = N_{\text{ID}}^{\text{cell}}$ 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 $\tilde{b}^{(q)}(0),...,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)} - 1)$ 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 $d^{(q)}(0),...,d^{(q)}(M_{\text{symb}}^{(q)} - 1)$.

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 $d^{(q)}(0),...,d^{(q)}(M_{\text{symb}}^{(q)} - 1)$ for codeword q shall be mapped onto the layers $x(i) = \left[x^{(0)}(i) \quad ... \quad x^{(\upsilon-1)}(i)\right]^T$, $i = 0,1,...,M_{\text{symb}}^{\text{layer}} - 1$ where υ 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 $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1$	
1	1	$x^{(0)}(i) = d^{(0)}(i)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}$
2	1	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2$
3	1	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/3$
4	1	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/4$
5	2	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$ $x^{(2)}(i) = d^{(1)}(3i)$ $x^{(3)}(i) = d^{(1)}(3i+1)$ $x^{(4)}(i) = d^{(1)}(3i+2)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2 = M_{\text{symb}}^{(1)}/3$
6	2	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $x^{(3)}(i) = d^{(1)}(3i)$ $x^{(4)}(i) = d^{(1)}(3i+1)$ $x^{(5)}(i) = d^{(1)}(3i+2)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/3 = M_{\text{symb}}^{(1)}/3$
7	2	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $x^{(3)}(i) = d^{(1)}(4i)$ $x^{(4)}(i) = d^{(1)}(4i+1)$ $x^{(5)}(i) = d^{(1)}(4i+2)$ $x^{(6)}(i) = d^{(1)}(4i+3)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/3 = M_{\text{symb}}^{(1)}/4$
8	2	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$ $x^{(4)}(i) = d^{(1)}(4i)$ $x^{(5)}(i) = d^{(1)}(4i+1)$ $x^{(6)}(i) = d^{(1)}(4i+2)$ $x^{(7)}(i) = d^{(1)}(4i+3)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/4 = M_{\text{symb}}^{(1)}/4$

7.3.1.4 Antenna port mapping

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

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

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

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 $y^{(p)}(0),...,y^{(p)}(M_{\text{symb}}^{\text{ap}} - 1)$ 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.
- they are declared as available for PDSCH according to clause 5.1.2.2.3 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 zero-power or non-zero-power CSI-RS according to clause 7.4.1.5, except for non-zero-power CSI-RSs configured by the higher-layer parameter *CSI-RS-Resource-Mobility*.
  - 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]

Any common resource block partially or fully overlapping with an SS/PBCH block shall be viewed as occupied and assumed not used for transmission of PDSCH in the OFDM symbols where SS/PBCH block is transmitted.

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.

For interleaved VRB-to-PRB mapping, the mapping process is defined in terms of resource block bundles:

- The set of $N_{\text{BWP},i}^{\text{size}}$ resource blocks in bandwidth part i with starting position $N_{\text{BWP},i}^{\text{start}}$ are divided into $N_{\text{bundle}} = \left\lceil \left(N_{\text{BWP},i}^{\text{size}} + \left(N_{\text{BWP},i}^{\text{start}} \bmod L \right) \right) / L_i \right\rceil$ resource-block bundles in increasing order of the resource-block number and bundle number where L_i is the bundle size for bandwidth part i provided by the higher-layer parameter *VRB-to-PRB-interleaver* and
  - resource block bundle 0 consists of $L_i - \left(N_{\text{BWP},i}^{\text{start}} \bmod L_i \right)$ resource blocks,
  - resource block bundle $N_{\text{bundle}} - 1$ consists of $\left(N_{\text{BWP},i}^{\text{start}} + N_{\text{BWP},i}^{\text{size}} \right) \bmod L_i$ resource blocks if $\left(N_{\text{BWP},i}^{\text{start}} + N_{\text{BWP},i}^{\text{size}} \right) \bmod L_i > 0$ and L_i resource blocks otherwise,

  - all other resource block bundles consists of L_i resource blocks.

- Virtual resource blocks in the interval $j \in \{0,1,...,N_{\text{bundle}} - 1\}$ 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 $j \in \{0,1,...,N_{\text{bundle}} - 2\}$ is mapped to physical resource block bundle $f(j)$ where

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

- The UE is not expected to be configured with $L_i = 2$ simultaneosuly 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, given by the higher-layer parameter *CORESET-freq-dom*, and $N_{\text{symb}}^{\text{CORESET}} \in \{1,2,3\}$ symbols in the time domain, given by the higher-layer parameter *CORESET-time-dur*, where $N_{\text{symb}}^{\text{CORESET}} = 3$ is supported only if higher-layer parameter *DL-DMRS-typeA-pos* equals 3.

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, configured by the higher-layer parameter *CORESET-CCE-REG-mapping-type*, and is described by REG bundles:

- REG bundle i is defined as REGs $\{iL, iL+1, ..., iL+L-1\}$ where L is the REG bundle size, $i = 0,1,..., N_{\text{REG}}^{\text{CORESET}}/L - 1$, 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 $\{f(6j/L), f(6j/L+1), ..., f(6j/L + 6/L - 1)\}$ where $f(\cdot)$ is an interleaver

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

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 $N_{\text{symb}}^{\text{CORESET}} \in \{2,3\}$ where L is configured by the higher-layer parameter *CORESET-REG-bundle-size*. The interleaver is defined by

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

where $R \in \{2,3,6\}$ is given by the higher-layer parameter *CORESET-interleaver-size* and where

- $n_{\text{shift}} = N_{\text{ID}}^{\text{cell}}$ for a PDCCH transmitted in a CORESET configured by the PBCH or SIB1, and

- otherwise $n_{\text{shift}} \in \{0,1,...,274\}$ is given by the higher-layer parameter *CORESET-shift-index*.

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

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 *CORESET-precoder-granularity* equals L

- the same precoding being used across the all resource-element groups within the set of contiguous resource blocks in the CORESET if the higher-layer parameter *CORESET-precoder-granularity* equals the size of the CORESET in the frequency domain

For a CORESET configured by PBCH the UE may assume, $L = 6$, $R = 2$, and the same precoding being used within a REG bundle.

7.3.2.3 Scrambling

The UE shall assume the block of bits $b(0),...,b(M_{\text{bit}}-1)$, 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 $\tilde{b}(0),...,\tilde{b}(M_{\text{bit}}-1)$ according to

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

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

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

where

- for a UE-specific search space as defined in clause 10 of [5, TS 38.213], $n_{\text{ID}} \in \{0,1,...,65535\}$ equals the higher-layer parameter *PDCCH-DMRS-Scrambling-ID* 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 *PDCCH-DMRS-Scrambling-ID* is configured, and
- $n_{\text{RNTI}} = 0$ otherwise.

7.3.2.4 PDCCH modulation

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

7.3.2.5 Mapping to physical resources

The UE shall assume the block of complex-valued symbols $d(0),...,d(M_{\text{symb}}-1)$ 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 $b(0),...,b(M_{\text{bit}}-1)$, 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 $\tilde{b}(0),...,\tilde{b}(M_{\text{bit}}-1)$ according to

$$\tilde{b}(i) = \left(b(i) + c(i + vM_{\text{bit}})\right) \bmod 2$$

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 $L_{\max} = 4$, v is the two least significant bits of the SS/PBCH block index
- for $L_{\max} = 8$ or $L_{\max} = 64$, 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 $\tilde{b}(0),...,\tilde{b}(M_{\text{bit}}-1)$ are QPSK modulated as described in clause 5.1.3, resulting in a block of complex-valued modulation symbols $d_{\text{PBCH}}(0),...,d_{\text{PBCH}}(M_{\text{symb}}-1)$.

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

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

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

$$c_{\text{init}} = \left(2^{17}\left(14n_{\text{s,f}}^{\mu} + l + 1\right)\left(2N_{\text{ID}}^{n_{\text{SCID}}} + 1\right) + 2N_{\text{ID}}^{n_{\text{SCID}}}\right) \bmod 2^{31}$$

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

- $n_{\text{SCID}} \in \{0,1\}$ and $N_{\text{ID}}^{n_{\text{SCID}}} \in \{0,1,\ldots,65535\}$ is given by the higher-layer parameter *DL-DMRS-Scrambling-ID* if provided and the PDSCH is scheduled by PDCCH with CRC scrambled by C-RNTI or CS-RNTI
- $n_{\text{SCID}} = 0$ and $N_{\text{ID}}^{n_{\text{SCID}}} = N_{\text{ID}}^{\text{cell}}$ otherwise

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 *DL-DMRS-config-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 [5, TS 38.213] and mapped to resource elements $(k,l)_{p,\mu}$ according to

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

where $w_{\text{f}}(k')$, $w_{\text{t}}(l')$, Δ, and λ 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

- for PDSCH transmission carrying SIB1, subcarrier 0 of the lowest-numbered common resource block in the CORESET configured by the PBCH
- 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 *DL-DMRS-typeA-pos* equals 3 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

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

and according to Tables 7.4.1.1.2-3 and 7.4.1.1.2-4. The case *DL-DMRS-add-pos* equal to 3 is only supported when *DL-DMRS-typeA-pos* is equal to 2.

For PDSCH mapping type B

- if the PDSCH duration is 2, 4, or 7 OFDM symbols, and the PDSCH allocation collides with resources reserved for a CORESET, $\bar{l}$ shall be incremented such that the first DM-RS symbol occurs immediately after the CORESETand
  - if the PDSCH duration is 4 symbols, the UE is not expected to receive a DM-RS symbol beyond the third symbol,
  - if the PDSCH duration is 7 symbols,
    - 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 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 *DL-DMRS-max-len* is equal to 1
- single-symbol or double-symbol DM-RS is determined by the associated DCI if the higher-layer parameter *DL-DMRS-max-len* is equal to 2.

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 spatial Rx. 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 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	$w_{\mathrm{f}}(k')$		$w_{\mathrm{t}}(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
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	$w_{\mathrm{f}}(k')$		$w_{\mathrm{t}}(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
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.

Duration in symbols	DM-RS positions $\bar{l}$							
	PDSCH mapping type A				PDSCH mapping type B			
	DL-DMRS-add-pos				*DL-DMRS-add-pos*			
	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	-	-		
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 ,11	l_0 , 7, 11	l_0 , 5, 8, 11	-	-		
14	l_0	l_0 ,11	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.

Duration in symbols	DM-RS positions $\bar{l}$					
	PDSCH mapping type A			PDSCH mapping type B		
	DL-DMRS-add-pos			DL-DMRS-add-pos		
	0	1	2	0	1	2
<4				-	-	
4	l_0	l_0		-	-	
5	l_0	l_0		-	-	
6	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 $\beta_{\mathrm{PTRS},i}$ 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

$$a_{k,l}^{(p,\mu)} = \beta_{\mathrm{PTRS},i} r_k$$

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, CSI-RS, SS/PBCH block, a detected PDCCH, or is declared as 'not available' by clause 5.1.4.1 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 $l_{\mathrm{ref}} = 0$

2. if any symbol in the interval $\max\left(l_{\mathrm{ref}}+(i-1)L_{\mathrm{PTRS}}+1, l_{\mathrm{ref}}\right),\ldots,l_{\mathrm{ref}}+iL_{\mathrm{PTRS}}$ 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 $l_{\mathrm{ref}}+iL_{\mathrm{PTRS}}$ is inside the PDSCH allocation
3. add $l_{\mathrm{ref}}+iL_{\mathrm{PTRS}}$ to the set of time indices for PT-RS
4. increment i by one
5. repeat from step 2 above as long as $l_{\mathrm{ref}}+iL_{\mathrm{PTRS}}$ 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 $N_{\mathrm{RB}}-1$ 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 $N_{\mathrm{sc}}^{\mathrm{RB}}N_{\mathrm{RB}}-1$. The subcarriers to which the UE shall assume the PT-RS is mapped are given by

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

where

- $i=0,1,2,...$
- $k_{\mathrm{ref}}^{\mathrm{RE}}$ 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 *DL-PTRS-RE-offset* is not configured, the column corresponding to '00' shall be used.
- n_{RNTI} is the RNTI associated with the DCI scheduling the transmission
- $K_{\mathrm{PTRS}}\in\{2,4\}$ is given by [6, TS 38.214].

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

DM-RS antenna port p	$k_{\mathrm{ref}}^{\mathrm{RE}}$							
	DM-RS Configuration type 1				**DM-RS Configuration type 2**			
	UL-PTRS-RE-offset				***UL-PTRS-RE-offset***			
	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

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

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

$$c_{\text{init}}=\left(2^{17}\left(14n_{\text{s,f}}^{\mu}+l+1\right)\left(2N_{\text{ID}}+1\right)+2N_{\text{ID}}\right)\bmod 2^{31}$$

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

- $N_{\text{ID}}\in\{0,1,...,65535\}$ is given by the higher-layer parameter *PDCCH-DMRS-Scrambling-ID* 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

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

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 *CORESET-precoder-granularity* equals *CORESET-REG-bundle-size*,
- 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 *CORESET-precoder-granularity* equals the size of the CORESET in the frequency domain.

The reference point for k is

- subcarrier 0 of the lowest-numbered common resource block in the CORESET if the CORESET is configured by the PBCH or SIB1,
- 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 spatial Rx.

7.4.1.4 Demodulation reference signals for PBCH

7.4.1.4.1 Sequence generation

The UE shall assume the reference-signal sequence $r(m)$ for an SS/PBCH block is defined by

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

where $c(n)$ is given by clause 5.2. The scrambling sequence generator shall be initialized at the start of each SS/PBCH block occasion with

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

where

- for $L_{\max}=4$, 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 $L_{\max}=8$ or $L_{\max}=64$, $n_{\text{hf}}=0$ and 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 and non-zero-power CSI-RS are defined

- for a non-zero-power CSI-RS, 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, the UE shall assume that the resource elements defined in clause 7.4.1.5.3 are not used for PDSCH transmission and shall make no assumption on downlink transmission in those resource elements

7.4.1.5.2 Sequence generation

The UE shall assume the reference-signal sequence $r(m)$ is defined by

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

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

$$c_{\text{init}}=\left(2^{10}\cdot\left(14n_{\text{s,f}}^{\mu}+l+1\right)\left(2n_{\text{ID}}+1\right)+n_{\text{ID}}\right)\bmod 2^{31}$$

at the start of each OFDM symbol where $n_{\text{s,f}}$ 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*.

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

$$
\begin{aligned}
a_{k,l}^{(p,\mu)} &= \beta_{\mathrm{CSIRS}} w_{\mathrm{f}}(k') \cdot w_{\mathrm{t}}(l') \cdot r_{l,n_{\mathrm{s,f}}}(m') \\
m' &= \lfloor n\alpha \rfloor + k' + \left\lfloor \frac{\bar{k}\rho}{N_{\mathrm{sc}}^{\mathrm{RB}}} \right\rfloor \\
k &= nN_{\mathrm{sc}}^{\mathrm{RB}} + \bar{k} + k' \\
l &= \bar{l} + l' \\
\alpha &= \begin{cases} \rho & \text{for } X = 1 \\ 2\rho & \text{for } X > 1 \end{cases} \\
n &= 0,1,\ldots
\end{aligned}
$$

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 *CSI-RS-Density*.

The UE is not expected to receive CSI-RS and DM-RS on the same resource elements.

The UE shall assume $\beta_{\mathrm{CSIRS}} > 0$ for a non-zero-power CSI-RS where β_{CSIRS} is selected such that the power offset specified by the higher-layer parameter *Pc_SS*, if provided, is fulfilled.

The quantities k', l', $w_{\mathrm{f}}(k')$, and $w_{\mathrm{t}}(l')$ are given by Tables 7.4.1.5.3-1 to 7.4.1.5.3-6 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 indices k' and l' index resource elements within a CDM group.

The time-domain locations l_0 and l_1 are defined relative to the start of a slot with the starting positions of a CSI-RS in a slot $\bar{l} \in \{0,1,\ldots,13\}$ configured by the higher-layer parameter *CSI-RS-ResourceMapping*.

The frequency-domain location is given by a bitmap provided by the higher-layer parameter *CSI-RS-ResourceMapping* where k_i in Table 7.4.1.5.3-1 corresponds to the i^{th} bit in the bitmap set to one, starting from b_0, with the bitmap and value of k_i in Table 7.4.1.5.3-1 given by

- $[b_3 \cdots b_0]$, $k_i = f(i)$ for row 1 of Table 7.4.1.5.3-1
- $[b_{11} \cdots b_0]$, $k_i = f(i)$ for row 2 of Table 7.4.1.5.3-1
- $[b_2 \cdots b_0]$, $k_i = 4f(i)$ for row 4 of Table 7.4.1.5.3-1
- $[b_5 \cdots b_0]$, $k_i = 2f(i)$ 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 when $\rho \le 1$. 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 parameter *CSI-RS-FreqBand* and *CSI-RS-Density* for the bandwidth part given by the higher-layer parameter *BWP-Info.*

The UE shall assume that a CSI-RS is transmitted using antenna ports p numbered according to

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

where s is the sequence index provided by Tables 7.4.1.5.3-2 to 7.4.1.5.3-5, $L \in \{1,2,4,8\}$ is the CDM group size, and N is the number of CSI-RS ports. The CDM group index j given in Table 7.4.1.5.3-1 corresponds to the time/frequency locations $(\bar{k},\bar{l})$ for a given row of the table. The CDM groups are numbered in order of increasing frequency domain allocation first and then increasing time domain allocation.For a CSI-RS resource configured as periodic or semi-persistent by the higher layer parameter ResourceConfigType,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 given by the higher layer parameter *CSI-RS-timeConfig*. The UE shall assume that CSI-RS is transmitted in a candidate slot only if all OFDM symbols of that slot corresponding to the configured CSI-RS resource are classified as 'downlink'.

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

Row	Ports	Density ρ	*CDMtype*	$(\bar{k},\bar{l})$	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 $w_{\text{f}}(k')$ and $w_{\text{t}}(l')$ for *CDMType* equal to 'no CDM'.

Index	$w_{\text{f}}(k')$	$w_{\text{t}}(l')$
0	1	1

Table 7.4.1.5.3-3: The sequences $w_{\mathrm{f}}(k')$ and $w_{\mathrm{t}}(l')$ for *CDMType* equal to 'FD-CDM2'.

Index	$w_{\mathrm{f}}(k')$	$w_{\mathrm{t}}(l')$
0	$[+1 \quad +1]$	1
1	$[+1 \quad -1]$	1

Table 7.4.1.5.3-4: The sequences $w_{\mathrm{f}}(k')$ and $w_{\mathrm{t}}(l')$ for *CDMType* equal to 'CDM4'.

Index	$w_{\mathrm{f}}(k')$	$w_{\mathrm{t}}(l')$
0	$[+1 \quad +1]$	$[+1 \quad +1]$
1	$[+1 \quad -1]$	$[+1 \quad +1]$
2	$[+1 \quad +1]$	$[+1 \quad -1]$
3	$[+1 \quad -1]$	$[+1 \quad -1]$

Table 7.4.1.5.3-5: The sequences $w_{\mathrm{f}}(k')$ and $w_{\mathrm{t}}(l')$ for *CDMType* equal to 'CDM8'.

Index	$w_{\mathrm{f}}(k')$	$w_{\mathrm{t}}(l')$
0	$[+1 \quad +1]$	$[+1 \quad +1 \quad +1 \quad +1]$
1	$[+1 \quad -1]$	$[+1 \quad +1 \quad +1 \quad +1]$
2	$[+1 \quad +1]$	$[+1 \quad -1 \quad +1 \quad -1]$
3	$[+1 \quad -1]$	$[+1 \quad -1 \quad +1 \quad -1]$
4	$[+1 \quad +1]$	$[+1 \quad +1 \quad -1 \quad -1]$
5	$[+1 \quad -1]$	$[+1 \quad +1 \quad -1 \quad -1]$
6	$[+1 \quad +1]$	$[+1 \quad -1 \quad -1 \quad +1]$
7	$[+1 \quad -1]$	$[+1 \quad -1 \quad -1 \quad +1]$

7.4.2 Synchronization signals

7.4.2.1 Physical-layer cell identities

There are 1008 unique physical-layer cell identities given by

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

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

7.4.2.2 Primary synchronization signal

7.4.2.2.1 Sequence generation

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

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

where

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

and

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

7.4.2.2.2 Mapping to physical resources

Mapping to physical resources is described in clause 7.4.3.

7.4.2.3 Secondary synchronization signal

7.4.2.3.1 Sequence generation

The sequence $d_{\mathrm{SSS}}(n)$ for the secondary synchronization signal is defined by

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

where

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

and

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

7.4.2.3.2 Mapping to physical resources

Mapping to physical resources is described in clause 7.4.3.

7.4.3 SS/PBCH block

7.4.3.1 Time-frequency structure of an SS/PBCH block

In the time domain, an SS/PBCH block consists of 4 OFDM symbols, numbered in increasing order from 0 to 3 within the SS/PBCH block, where PSS, SSS, and PBCH with associated DM-RS are mapped to symbols as given by Table 7.4.3.1-1.

In the frequency domain, an SS/PBCH block consists of 240 contiguous subcarriers with the subcarriers numbered in increasing order from 0 to 239 within the SS/PBCH block. The quantities k and l represent the frequency and time indices, respectively, within one SS/PBCH block. The UE may assume that the complex-valued symbols corresponding to resource elements denoted as 'Set to 0' in Table 7.4.3.1-1 are set to zero. The quantity v in Table 7.4.3.1-1 is given by $v = N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 4$. The quantity k_{SSB} is the subcarrier offset from subcarrier 0 in common resource block $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ to subcarrier 0 of the SS/PBCH block, where $N_{\mathrm{CRB}}^{\mathrm{SSB}}$ is obtained from the higher-layer parameter *offset-ref-low-scs-ref-PRB* and where 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 bits of k_{SSB} are given by $a_{\bar{A}+5}$ in the PBCH payload as defined in subclause 7.1.1 of [4, TS 38.212].

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 set to zero in the OFDM symbols where SS/PBCH block is transmitted.

For an SS/PBCH block, the UE shall assume

- antenna port $p = 4000$ is used for transmission of PSS, SSS and PBCH,

- the same cyclic prefix length and subcarrier spacing for the PSS, SSS, and PBCH,

- for SS/PBCH block type A, $\mu \in \{0,1\}$ and $k_{\text{SSB}} \in \{0,1,2,...,23\}$ 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 $k_{\text{SSB}} \in \{0,1,2,...,11\}$ with the quantity k_{SSB} expressed in terms of the subcarrier spacing provided by the higher-layer parameter *subCarrierSpacingCommon* and $N_{\text{CRB}}^{\text{SSB}}$ is expressed in terms of 60 kHz subcarrier spacing.

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 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	$0+v,4+v,8+v,...,236+v$
	2	$0+v,4+v,8+v,...,44+v$ $192+v,196+v,...,236+v$

7.4.3.1.1 Mapping of PSS within an SS/PBCH block

The UE shall assume the sequence of symbols $d_{\text{PSS}}(0),...,d_{\text{PSS}}(126)$ 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 $d_{\text{SSS}}(0),...,d_{\text{SSS}}(126)$ 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 $d_{\text{PBCH}}(0),...,d_{\text{PBCH}}(M_{\text{symb}}-1)$ 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 $r(0),...,r(143)$ 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