Foreword

This Technical Specification has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

3 or greater indicates TSG approved document under change control.

y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

1 Scope

The present document describes the physical channels for evolved UTRA.

2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non- specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

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

[2] 3GPP TS 36.201: "Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description".

[3] 3GPP TS 36.212: "Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding".

[4] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures".

[5] 3GPP TS 36.214: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer; Measurements".

[6] 3GPP TS 36.104: "Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception".

[7] 3GPP TS 36.101: "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception".

[8] 3GPP TS 36.321, "Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification".

[9] 3GPP TS 36.331, "Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC) Protocol specification"

[10] 3GPP TS 36.304, "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) procedures in idle mode"

[11] 3GPP TS 37.213: "Physical layer procedures for shared spectrum channel access"

3 Symbols and abbreviations

3.1 Symbols

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

(k,l)	Resource element with frequency-domain index k and time-domain index l
$a_{k,l}^{(p)}$	Value of resource element (k,l) [for antenna port p]
D	Matrix for supporting cyclic delay diversity
D_{RA}	Density of random access opportunities per radio frame
f_0	Carrier frequency
f_{RA}	PRACH resource frequency index within the considered time-domain location
$f_{\mathrm{PRB,hop}}^{\mathrm{PRACH}}$	PRACH frequency hopping offset, expressed as a number of resource blocks
$l_{\mathrm{NPDCCHStart}}$	Start symbol in slot 0 for NPDCCH
$l_{\mathrm{NPDSCHStart}}$	Start symbol in slot 0 for NPDSCH
$M_{\mathrm{sc}}^{\mathrm{PSBCH}}$	Bandwidth for PSBCH transmission, expressed as a number of subcarriers
$M_{\mathrm{RB}}^{\mathrm{PSBCH}}$	Bandwidth for PSBCH transmission, expressed as a number of resource blocks
$M_{\mathrm{sc}}^{\mathrm{PSCCH}}$	Bandwidth for PSCCH transmission, expressed as a number of subcarriers
$M_{\mathrm{RB}}^{\mathrm{PSCCH}}$	Bandwidth for PSCCH transmission, expressed as a number of resource blocks
$M_{\mathrm{sc}}^{\mathrm{PSDCH}}$	Bandwidth for PSDCH transmission, expressed as a number of subcarriers
$M_{\mathrm{RB}}^{\mathrm{PSDCH}}$	Bandwidth for PSDCH transmission, expressed as a number of resource blocks
$M_{\mathrm{sc}}^{\mathrm{PSSCH}}$	Scheduled bandwidth for PSSCH transmission, expressed as a number of subcarriers
$M_{\mathrm{RB}}^{\mathrm{PSSCH}}$	Scheduled bandwidth for PSSCH transmission, expressed as a number of resource blocks
$M_{\mathrm{sc}}^{\mathrm{PUSCH}}$	Scheduled bandwidth for uplink transmission, expressed as a number of subcarriers
$M_{\mathrm{RB}}^{\mathrm{PUSCH}}$	Scheduled bandwidth for uplink transmission, expressed as a number of resource blocks
$M_{\mathrm{rep}}^{\mathrm{NPUSCH}}$	Scheduled number of repetitions of a NPUSCH transmission
$M_{\mathrm{rep}}^{\mathrm{NPDSCH}}$	Scheduled number of repetitions of a NPDSCH transmission
$M_{\mathrm{sc}}^{\mathrm{NPUSCH}}$	Scheduled bandwidth for uplink NPUSCH transmission, expressed as a number of subcarriers
$M_{\mathrm{identical}}^{\mathrm{NPUSCH}}$	Number of repetitions of identical slots for NPUSCH
$M_{\mathrm{bit}}^{(q)}$	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
$M_{\mathrm{symb}}^{\mathrm{ap}}$	Number of modulation symbols to transmit per antenna port for a physical channel
$M_{\mathrm{sc}}^{\mathrm{RU}}$	Number of consecutive subcarriers in an UL resource unit for PUSCH sub-PRB allocation
$M_{\mathrm{slots}}^{\mathrm{UL}}$	Number of slots in an UL resource unit for PUSCH sub-PRB allocation
$M_{\mathrm{symb}}^{\mathrm{UL}}$	Number of SC-FDMA symbols in an uplink slot for PUSCH sub-PRB allocation
	Number of subcarriers in the frequency domain for PUSCH sub-PRB allocation
$M_{\mathrm{seq}}^{\mathrm{RU}}$	Number of reference signal sequences available for the UL resource unit size for PUSCH sub-PRB allocation
M_{RU}	Number of scheduled UL resource units for PUSCH sub-PRB allocation
N	A constant equal to 2048 for $\Delta f = 15\,\mathrm{kHz}$, 4096 for $\Delta f = 7.5\,\mathrm{kHz}$ and 8192 for $\Delta f = 3.75\,\mathrm{kHz}$
$N_{\mathrm{CP},l}$	Downlink cyclic prefix length for OFDM symbol l in a slot
N_{CS}	Cyclic shift value used for random access preamble generation

$N_{\mathrm{cs}}^{(1)}$	Number of cyclic shifts used for PUCCH formats 1/1a/1b in a resource block with a mix of formats 1/1a/1b and 2/2a/2b
$N_{\mathrm{RB}}^{(2)}$	Bandwidth available for use by PUCCH formats 2/2a/2b, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
$N_{\mathrm{RB}}^{\mathrm{HO}}$	The offset used for PUSCH frequency hopping, expressed in number of resource blocks (set by higher layers)
$N_{\mathrm{ID}}^{\mathrm{cell}}$	Physical layer cell identity
$N_{\mathrm{ID}}^{\mathrm{Ncell}}$	Narrowband physical layer cell identity
$N_{\mathrm{ID}}^{\mathrm{MBSFN}}$	MBSFN area identity
$N_{\mathrm{ID}}^{\mathrm{SL}}$	Physical layer sidelink synchronization identity
$N_{\mathrm{ID}}^{\mathrm{PRS}}$	Positioning reference signal identity
$N_{\mathrm{RB}}^{\mathrm{DL}}$	Downlink bandwidth configuration, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
$N_{\mathrm{RB}}^{\mathrm{min,DL}}$	Smallest downlink bandwidth configuration, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
$N_{\mathrm{RB}}^{\mathrm{max,DL}}$	Largest downlink bandwidth configuration, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
$N_{\mathrm{RB}}^{\mathrm{UL}}$	Uplink bandwidth configuration, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
$N_{\mathrm{RB}}^{\mathrm{min,UL}}$	Smallest uplink bandwidth configuration, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
$N_{\mathrm{RB}}^{\mathrm{max,UL}}$	Largest uplink bandwidth configuration, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
$N_{\mathrm{RB}}^{\mathrm{SL}}$	Sidelink bandwidth configuration, expressed in multiples of $N_{\mathrm{sc}}^{\mathrm{RB}}$
N_{RSS}	Duration of RSS measured in subframes
N_{SF}	Number of scheduled subframes for NPDSCH transmission
$N_{\mathrm{symb}}^{\mathrm{NPSS}}$	Number of symbols for NPSS in a subframe
$N_{\mathrm{symb}}^{\mathrm{NSSS}}$	Number of symbols for NSSS in a subframe
$N_{\mathrm{sc}}^{\mathrm{RU}}$	Number of consecutive subcarriers in an UL resource unit for NB-IoT
$N_{\mathrm{seq}}^{\mathrm{RU}}$	Number of reference signal sequences available for the UL resource unit size
N_{RU}	Number of scheduled UL resource units for NB-IoT
$N_{\mathrm{NB}}^{\mathrm{UL}}$	Total number of uplink narrowbands
$N_{\mathrm{WB}}^{\mathrm{UL}}$	Total number of uplink widebands
$N_{\mathrm{sc}}^{\mathrm{UL}}$	Number of subcarriers in the frequency domain for NB-IoT
N_{acc}	Number of consecutive absolute subframes over which the scrambling sequence stays the same
$N_{\mathrm{abs}}^{\mathrm{PUSCH}}$	Total number of absolute subframes a PUSCH with repetition spans expressed as a number of absolute subframes
$N_{\mathrm{rep}}^{\mathrm{PUSCH}}$	Number of repetititions of a PUSCH transmission
$N_{\mathrm{NB}}^{\mathrm{ch,UL}}$	Number of consecutive absolute subframes over which PUCCH or PUSCH stays at the same narrowband before hopping to another narrowband, expressed as a number of absolute subframes
$f_{\mathrm{NB,hop}}^{\mathrm{PUSCH}}$	Narrowband offset between one narrowband and the next narrowband a PUSCH hops to, expressed as a number of uplink narrowbands
$N_{\mathrm{abs}}^{\mathrm{PUCCH}}$	Total number of absolute subframes a PUCCH with repetition spans, expressed as a number of absolute subframes
$N_{\mathrm{rep}}^{\mathrm{PUCCH}}$	Number of repetititions of a PUCCH transmission
$N_{\mathrm{rep}}^{\mathrm{PRACH}}$	Number of PRACH repetitions per preamble transmission attempt
$N_{\mathrm{sf}}^{\mathrm{RA}}$	Number of subframes allowed for preamble transmission within a 1024-frame interval
$N_{\mathrm{start}}^{\mathrm{PRACH}}$	PRACH starting subframe periodicity
$N_{\mathrm{rep}}^{\mathrm{NPRACH}}$	Number of NPRACH repetitions per preamble transmission attempt
$N_{\mathrm{period}}^{\mathrm{NPRACH}}$	NPRACH resource periodicity

$N_{\text{scoffset}}^{\text{NPRACH}}$	Frequency location of the first sub-carrier allocated to NPRACH
$N_{\text{sc}}^{\text{NPRACH}}$	Number of sub-carriers allocated to NPRACH
$N_{\text{sc\_cont}}^{\text{NPRACH}}$	Number of starting sub-carriers allocated for UE initiated random access
$N_{\text{start}}^{\text{NPRACH}}$	NPRACH starting subframe
$N_{\text{MSG3}}^{\text{NPRACH}}$	Fraction for starting subcarrier index for UE support for multi-tone msg3 transmission
$N_{\text{gap,period}}$	Periodicity for NPDSCH/NPDCCH gaps
$N_{\text{gap,duration}}$	Duration for NPDSCH/NPDCCH gaps
$N_{\text{gap,threshold}}$	Threshold for applying NPDDCH/NPDCCH gaps
$N_{\text{NB}}^{\text{DL}}$	Total number of downlink narrowbands
$N_{\text{WB}}^{\text{DL}}$	Total number of downlink widebands
$N_{\text{abs}}^{\text{PDSCH}}$	Total number of absolute subframes a PDSCH with repetition spans, expressed as a number of absolute subframes
$N_{\text{rep}}^{\text{PDSCH}}$	Number of repetititions of a PDSCH transmission
$N_{\text{NB}}^{\text{ch,DL}}$	Number of consecutive absolute subframes over which MPDCCH or PDSCH stays at the same narrowband before hopping to another narrowband, expressed as a number of absolute subframes
$N_{\text{NB,hop}}^{\text{ch,DL}}$	Number of narrowbands over which MPDCCH or PDSCH frequency hops
$f_{\text{NB,hop}}^{\text{DL}}$	Narrowband offset between one narrowband and the next narrowband an MPDCCH or PDSCH hops to, expressed as a number of downlink narrowbands
$N_{\text{PDSCH}}^{\text{SIB1-BR}}$	Number of times a PDSCH carrying SIB1-BR is transmitted over 8 radio frames
$N_{\text{abs}}^{\text{MPDCCH}}$	Total number of absolute subframes a MPDCCH with repetition spans , expressed as a number of absolute subframes
$N_{\text{rep}}^{\text{MPDCCH}}$	Number of repetitions of a MPDCCH transmission
$N_{\text{abs,ss}}^{\text{MPDCCH}}$	Total number of absolute subframes a MPDCCH search space with maximum repetition level spans, expressed as a number of absolute subframes
$N_{\text{rep,ss}}^{\text{MPDCCH}}$	Maximum repetition level of a MPDCCH search space
$N_{\text{ECCE}}^{\text{MPDCCH}}$	Number of ECCEs in a subframe for one MPDCCH
$N_{\text{symb}}^{\text{DL}}$	Number of OFDM symbols in a downlink slot
$N_{\text{symb}}^{\text{UL}}$	Number of SC-FDMA symbols in an uplink slot
$N_{\text{symb}}^{\text{retune}}$	Number of symbols in a guard period for narrowband or wideband retuning
$N_{\text{slots}}^{\text{UL}}$	Number of consecutive slots in an UL resource unit for NB-IoT
$N_{\text{symb}}^{\text{SL}}$	Number of SC-FDMA symbols in a sidelink slot
$N_{\text{sc}}^{\text{RB}}$	Resource block size in the frequency domain, expressed as a number of subcarriers
N_{sb}	Number of sub-bands for PUSCH frequency-hopping with predefined hopping pattern
$N_{\text{RB}}^{\text{sb}}$	Size of each sub-band for PUSCH frequency-hopping with predefined hopping pattern, expressed as a number of resource blocks
$N_{\text{sc}}^{\text{RA}}$	Size of narrow-band random-access resource in number of subcarriers
N_{SP}	Number of downlink to uplink switch points within the radio frame
$N_{\text{RS}}^{\text{PUCCH}}$	Number of reference symbols per slot for PUCCH
$N_{\text{RS}}^{\text{SPUCCH}}$	Number of reference symbols per subslot or per slot for SPUCCH
N_{TA}	Timing offset between uplink and downlink radio frames at the UE, expressed in units of T_{s}
$N_{\text{TA offset}}$	Fixed timing advance offset, expressed in units of T_{s}
$N_{\text{TA,SL}}$	Timing offset between sidelink and timing reference frames at the UE, expressed in units of T_{s}

$n_{\text{PUCCH}}^{(1,\tilde{p})}$	Resource index for PUCCH formats 1/1a/1b
$n_{\text{PUCCH}}^{(2,\tilde{p})}$	Resource index for PUCCH formats 2/2a/2b
$n_{\text{PUCCH}}^{(3,\tilde{p})}$	Resource index for PUCCH format 3
n_{PDCCH}	Number of PDCCHs present in a subframe
n_{PRB}	Physical resource block number
$n_{\text{PRB}}^{\text{RA}}$	First physical resource block occupied by PRACH resource considered
$n_{\text{PRB offset}}^{\text{RA}}$	First physical resource block available for PRACH
$n_{PRB,RSS}$	Lowest PRB number of RSS
$n_{\text{sc}}^{\text{RA}}$	Subcarrier occupied by NPRACH resource considered
n_{VRB}	Virtual resource block number
n_{RNTI}	Radio network temporary identifier
$n_{\text{ID}}^{\text{SA}}$	Sidelink group destination identity
n_{f}	System frame number
n_{s}	Slot number within a radio frame
$n_{\text{sf}}^{\text{abs}}$	Absolute subframe number
$n_{\text{sf}}^{\text{RA}}$	Index for subframes allowed for preamble transmission
O_{RSS}	Starting frame offset of RSS in each RSS period
P	Number of antenna ports used for transmission of a channel
p	Antenna port number
P_{RSS}	Period of RSS measured in frames
q	Codeword number
r_{RA}	Index for PRACH versions with same preamble format and PRACH density
Q_m	Modulation order: 2 for QPSK, 4 for 16QAM, 6 for 64QAM and 8 for 256QAM transmissions
$s_l^{(p)}(t)$	Time-continuous baseband signal for antenna port p and OFDM symbol l in a slot
$t_{\text{RA}}^{(0)}$	Radio frame indicator index of PRACH opportunity
$t_{\text{RA}}^{(1)}$	Half frame index of PRACH opportunity within the radio frame
$t_{\text{RA}}^{(2)}$	Uplink subframe number for start of PRACH opportunity within the half frame
T_{f}	Radio frame duration
T_{s}	Basic time unit
T_{slot}	Slot duration
W	Precoding matrix for downlink spatial multiplexing
β_{PRACH}	Amplitude scaling for PRACH
β_{NPRACH}	Amplitude scaling for NPRACH
β_{PUCCH}	Amplitude scaling for PUCCH
β_{PUSCH}	Amplitude scaling for PUSCH
β_{NPUSCH}	Amplitude scaling for NPUSCH
β_{SPUCCH}	Amplitude scaling for SPUCCH
β_{SRS}	Amplitude scaling for sounding reference symbols
Δf	Subcarrier spacing
Δf_{RA}	Subcarrier spacing for the random access preamble
υ	Number of transmission layers

3.2 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply.
An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

CCE	Control Channel Element
CDD	Cyclic Delay Diversity
CRS	Cell-specific Reference Signal
CSI	Channel-State Information
DCI	Downlink Control Information
DM-RS	Demodulation Reference Signal
ECCE	Enhanced Control Channel Element
EPDCCH	Enhanced Physical Downlink Control CHannel
EREG	Enhanced Resource-Element Group
MPDCCH	MTC Physical Downlink Control Channel
MWUS	MTC Wake-Up Signal
NCCE	Narrowband Control Channel Element
NPBCH	Narrowband Physical Broadcast CHannel
NPDCCH	Narrowband Physical Downlink Control CHannel
NPDSCH	Narrowband Physical Downlink Shared CHannel
NPRACH	Narrowband Physical Random Access CHannel
NPUSCH	Narrowband Physical Uplink Shared CHannel
NPRS	Narrowband Positioning Reference Signal
NPSS	Narrowband Primary Synchronization Signal
NSSS	Narrowband Secondary Synchronization Signal
NRS	Narrowband Reference Signal PBCH Physical Broadcast CHannel
PCFICH	Physical Control Format Indicator CHannel
PDCCH	Physical Downlink Control CHannel
PDSCH	Physical Downlink Shared CHannel
PHICH	Physical Hybrid-ARQ Indicator CHannel
PMCH	Physical Multicast CHannel
PRACH	Physical Random Access CHannel
PRB	Physical Resource Block
PRG	Precoding Resource Block Group
PRS	Positioning Reference Signal
PSBCH	Physical Sidelink Broadcast CHannel
PSCCH	Physical Sidelink Control CHannel
PSDCH	Physical Sidelink Discovery CHannel
PSSCH	Physical Sidelink Shared CHannel
PUCCH	Physical Uplink Control CHannel
PUSCH	Physical Uplink Shared CHannel
REG	Resource-Element Group
RSS	Resynchronization Signal
SCCE	Short Control Channel Element
SCG	Secondary Cell Group
SPDCCH	Short Physical Downlink Control CHannel
SPUCCH	Short Physical Uplink Control CHannel
SREG	Short Resource-Element Group
SRS	Sounding Reference Signal
VRB	Virtual Resource Block

4 Frame structure

Throughout this specification, unless otherwise noted, the size of various fields in the time domain is expressed as a number of time units $T_\mathrm{s} = 1/(15000 \times 2048)$ seconds.

Downlink, uplink and sidelink transmissions are organized into radio frames with $T_\mathrm{f} = 307200 \times T_\mathrm{s} = 10\ \mathrm{ms}$ duration. Three radio frame structures are supported:

- Type 1, applicable to FDD only,
- Type 2, applicable to TDD only,
- Type 3, applicable to LAA secondary cell operation only.

NOTE: LAA secondary cell operation only applies to frame structure type 3.

Transmissions in multiple cells can be aggregated where up to 31 secondary cells can be used in addition to the primary cell. Unless otherwise noted, the description in this specification applies to each of the up to 32 serving cells. In case of multi-cell aggregation, different frame structures can be used in the different serving cells.

4.1 Frame structure type 1

Frame structure type 1 is applicable to both full duplex and half duplex FDD only. Each radio frame is $T_{\mathrm{f}} = 307200 \cdot T_{\mathrm{s}} = 10\,\mathrm{ms}$ long and consists of 10 subframes of length $30720 \cdot T_{\mathrm{s}} = 1\,\mathrm{ms}$, numbered from 0 to 9. Subframe i in frame n_{f} has an absolute subframe number $n_{\mathrm{sf}}^{\mathrm{abs}} = 10 n_{\mathrm{f}} + i$ where n_{f} is the system frame number.

For subframes using $\Delta f = 7.5\,\mathrm{kHz}$ or $\Delta f = 15\,\mathrm{kHz}$, subframe i is defined as two slots, $2i$ and $2i+1$, of length $T_{\mathrm{slot}} = 15360 \cdot T_{\mathrm{s}} = 0.5\,\mathrm{ms}$ each.

For subframes using $\Delta f = 1.25\,\mathrm{kHz}$, subframe i is defined as one slot, $2i$, of length $T_{\mathrm{slot}} = 30720 \cdot \mathrm{T_s} = 1\,\mathrm{ms}$.

For subframes using $\Delta f = 15\,\mathrm{kHz}$, the subframe can further be divided into six subslots according to Table 4.1-1. Downlink subslot pattern 1 is applied if the number of symbols used for PDCCH is equal to 1 or 3 and downlink subslot pattern 2 is applied if the number of symbols used for PDCCH is equal to 2. For system bandwidths $N_{\mathrm{RB}}^{\mathrm{DL}} \leq 10$, subslot transmission is not supported in case 4 symbols used for PDCCH.

For FDD, 10 subframes, 20 slots, or up to 60 subslots are available for downlink transmission and 10 subframes, 20 slots, or up to 60 subslots are available for uplink transmissions in each 10 ms interval. Uplink and downlink transmissions are separated in the frequency domain. In half-duplex FDD operation, the UE cannot transmit and receive at the same time while there are no such restrictions in full-duplex FDD.

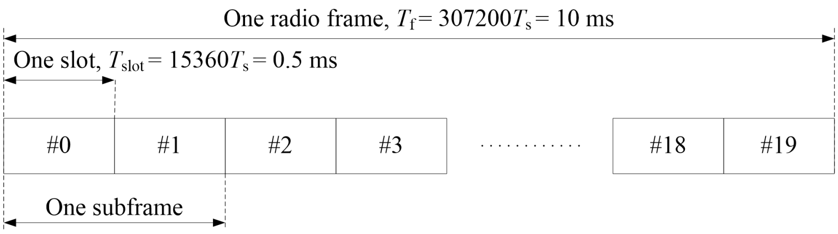

Figure 4.1-1: Frame structure type 1

Table 4.1-1: SC-FDMA/OFDM symbols in different subslots of subframe *i*

Subslot number	**0**	**1**	**2**	**3**	**4**	**5**
Slot number		***2i***			***2i+1***	
Uplink subslot pattern	0, 1, 2	3, 4	5, 6	0, 1	2, 3	4, 5, 6
Downlink subslot pattern 1	0, 1, 2	3, 4	5, 6	0, 1	2, 3	4, 5, 6
Downlink subslot pattern 2	0, 1	2, 3, 4	5, 6	0, 1	2, 3	4, 5, 6

4.2 Frame structure type 2

Frame structure type 2 is applicable to TDD only. Each radio frame of length $T_{\mathrm{f}} = 307200 \cdot T_{\mathrm{s}} = 10\ \mathrm{ms}$ consists of two half-frames of length $153600 \cdot T_{\mathrm{s}} = 5\ \mathrm{ms}$ each. Each half-frame consists of five subframes of length $30720 \cdot T_{\mathrm{s}} = 1\ \mathrm{ms}$. Each subframe i is defined as two slots, $2i$ and $2i+1$, of length $T_{\mathrm{slot}} = 15360 \cdot T_{\mathrm{s}} = 0.5\ \mathrm{ms}$ each. Subframe i in frame n_{f} has an absolute subframe number $n_{\mathrm{sf}}^{\mathrm{abs}} = 10 n_{\mathrm{f}} + i$ where n_{f} is the system frame number.

The uplink-downlink configuration in a cell may vary between frames and controls in which subframes uplink or downlink transmissions may take place in the current frame. The uplink-downlink configuration in the current frame is obtained according to Clause 13 in [4].

The supported uplink-downlink configurations are listed in Table 4.2-2 where, for each subframe in a radio frame, "D" denotes a downlink subframe reserved for downlink transmissions, "U" denotes an uplink subframe reserved for uplink transmissions and "S" denotes a special subframe with the three fields DwPTS, GP and UpPTS. The length of DwPTS and UpPTS is given by Table 4.2-1 subject to the total length of DwPTS, GP and UpPTS being equal to $30720 \cdot T_{\mathrm{s}} = 1\ \mathrm{ms}$ where X is the number of additional SC-FDMA symbols in UpPTS provided by the higher layer parameter *srs-UpPtsAdd* if configured otherwise X is equal to 0. The UE is not expected to be configured with 2 additional UpPTS SC-FDMA symbols for special subframe configurations $\{3, 4, 7, 8\}$ for normal cyclic prefix in downlink and special subframe configurations $\{2, 3, 5, 6\}$ for extended cyclic prefix in downlink and 4 additional UpPTS SC-FDMA symbols for special subframe configurations $\{1, 2, 3, 4, 6, 7, 8\}$ for normal cyclic prefix in downlink and special subframe configurations $\{1, 2, 3, 5, 6\}$ for extended cyclic prefix in downlink.

Uplink-downlink configurations with both 5 ms and 10 ms downlink-to-uplink switch-point periodicity are supported.

- In case of 5 ms downlink-to-uplink switch-point periodicity, the special subframe exists in both half-frames.
- In case of 10 ms downlink-to-uplink switch-point periodicity, the special subframe exists in the first half-frame only.

Subframes 0 and 5 and DwPTS are always reserved for downlink transmission. For special subframe configurations 1, 2, 3, 4, 6, 7 and 8, DwPTS is split into two parts, of which the first part is a slot and the second part is of *X*-symbol duration within the second slot. Downlink subframes, downlink slots in the downlink subframe and DwPTS, and the X–symbol duration in the second slot of DwPTS are available for downlink transmission. The X-symbol transmission opportunity is only available for special subframe configuration 3,4 and 8.

UpPTS and the subframe immediately following the special subframe are always reserved for uplink transmission. Uplink subframes, uplink slots and UpPTS with special subframe configuration 10 are available for uplink transmission. Note that UpPTS with special subframe configuration 10 are not available for SPUCCH transmission.

In case multiple cells are aggregated, the UE may assume that the guard period of the special subframe in the cells using frame structure type 2 have an overlap of at least $1456 \cdot T_{\mathrm{s}}$.

In case multiple cells with different uplink-downlink configurations in the current radio frame are aggregated and the UE is not capable of simultaneous reception and transmission in the aggregated cells, the following constraints apply:

- if the subframe in the primary cell is a downlink subframe, the UE shall not transmit any signal or channel on a secondary cell in the same subframe
- if the subframe in the primary cell is an uplink subframe, the UE is not expected to receive any downlink transmissions on a secondary cell in the same subframe
- if the subframe in the primary cell is a special subframe and the same subframe in a secondary cell is a downlink subframe, the UE is not expected to receive PDSCH/EPDCCH/PMCH/PRS transmissions in the secondary cell in the same subframe, and the UE is not expected to receive any other signals on the secondary cell in OFDM symbols that overlaps with the guard period or UpPTS in the primary cell.

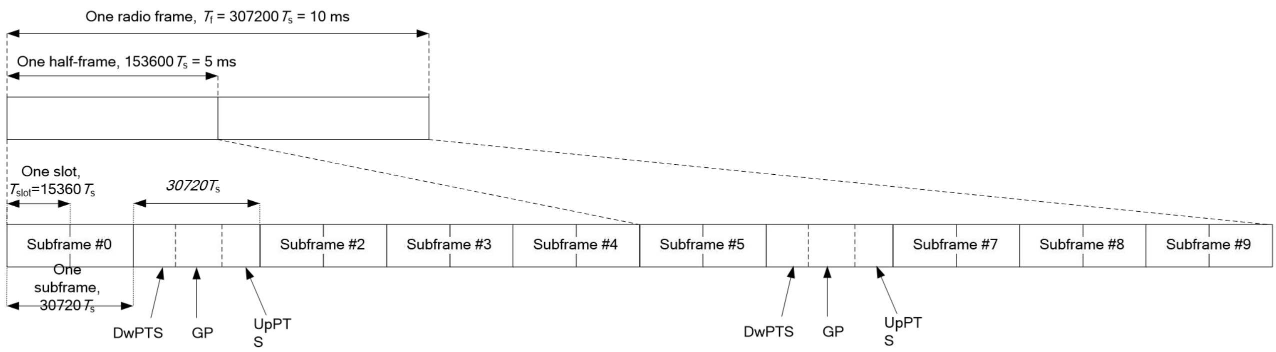

Figure 4.2-1: Frame structure type 2 (for 5 ms switch-point periodicity)

Table 4.2-1: Configuration of special subframe (lengths of DwPTS/GP/UpPTS)

<table>
<tr><th rowspan="3">Special subframe configuration</th><th colspan="3">Normal cyclic prefix in downlink</th><th colspan="3">Extended cyclic prefix in downlink</th></tr>
<tr><th>DwPTS</th><th colspan="2">UpPTS</th><th>DwPTS</th><th colspan="2">UpPTS</th></tr>
<tr><th></th><th>Normal cyclic prefix in uplink</th><th>Extended cyclic prefix in uplink</th><th></th><th>Normal cyclic prefix in uplink</th><th>Extended cyclic prefix in uplink</th></tr>
<tr><td>0</td><td>$6592 \cdot T_s$</td><td rowspan="5">$(1+X) \cdot 2192 \cdot T_s$</td><td rowspan="5">$(1+X) \cdot 2560 \cdot T_s$</td><td>$7680 \cdot T_s$</td><td rowspan="4">$(1+X) \cdot 2192 \cdot T_s$</td><td rowspan="4">$(1+X) \cdot 2560 \cdot T_s$</td></tr>
<tr><td>1</td><td>$19760 \cdot T_s$</td><td>$20480 \cdot T_s$</td></tr>
<tr><td>2</td><td>$21952 \cdot T_s$</td><td>$23040 \cdot T_s$</td></tr>
<tr><td>3</td><td>$24144 \cdot T_s$</td><td>$25600 \cdot T_s$</td></tr>
<tr><td>4</td><td>$26336 \cdot T_s$</td><td>$7680 \cdot T_s$</td><td rowspan="4">$(2+X) \cdot 2192 \cdot T_s$</td><td rowspan="4">$(2+X) \cdot 2560 \cdot T_s$</td></tr>
<tr><td>5</td><td>$6592 \cdot T_s$</td><td rowspan="5">$(2+X) \cdot 2192 \cdot T_s$</td><td rowspan="5">$(2+X) \cdot 2560 \cdot T_s$</td><td>$20480 \cdot T_s$</td></tr>
<tr><td>6</td><td>$19760 \cdot T_s$</td><td>$23040 \cdot T_s$</td></tr>
<tr><td>7</td><td>$21952 \cdot T_s$</td><td>$12800 \cdot T_s$</td></tr>
<tr><td>8</td><td>$24144 \cdot T_s$</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>9</td><td>$13168 \cdot T_s$</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>10</td><td>$13168 \cdot T_s$</td><td>$13152 \cdot T_s$</td><td>$12800 \cdot T_s$</td><td>-</td><td>-</td><td>-</td></tr>
</table>

Table 4.2-2: Uplink-downlink configurations

Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

4.3 Frame structure type 3

Frame structure type 3 is applicable to LAA secondary cell operation with normal cyclic prefix only. Each radio frame is $T_f = 307200 \cdot T_s = 10\,\text{ms}$ long and consists of 20 slots of length $T_{slot} = 15360 \cdot T_s = 0.5\,\text{ms}$, numbered from 0 to 19. A subframe is defined as two consecutive slots where subframe i consists of slots $2i$ and $2i+1$.

The 10 subframes within a radio frame are available for downlink or uplink transmissions. Downlink transmissions occupy one or more consecutive subframes, starting anywhere within a subframe and ending with the last subframe either fully occupied or following one of the DwPTS durations in Table 4.2-1. Uplink transmisisons occupy one or more consecutive subframes.

5 Uplink

5.1 Overview

The smallest resource unit for uplink transmissions is denoted a resource element and is defined in clause 5.2.2.

5.1.1 Physical channels

An uplink physical channel corresponds to a set of resource elements carrying information originating from higher layers and is the interface defined between 3GPP TS 36.212 [3] and the present document 3GPP TS 36.211.
The following uplink physical channels are defined:

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

5.1.2 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:

- Reference signal

5.2 Slot structure and physical resources

5.2.1 Resource grid

The transmitted signal in each slot is described by one or several resource grids of $N_{\mathrm{RB}}^{\mathrm{UL}} N_{\mathrm{sc}}^{\mathrm{RB}}$ subcarriers and $N_{\mathrm{symb}}^{\mathrm{UL}}$ SC-FDMA symbols. The resource grid is illustrated in Figure 5.2.1-1. The quantity $N_{\mathrm{RB}}^{\mathrm{UL}}$ depends on the uplink transmission bandwidth configured in the cell and shall fulfil

$$N_{\mathrm{RB}}^{\mathrm{min,UL}} \le N_{\mathrm{RB}}^{\mathrm{UL}} \le N_{\mathrm{RB}}^{\mathrm{max,UL}}$$

where $N_{\mathrm{RB}}^{\mathrm{min,UL}} = 6$ and $N_{\mathrm{RB}}^{\mathrm{max,UL}} = 110$ are the smallest and largest uplink bandwidths, respectively, supported by the current version of this specification. The set of allowed values for $N_{\mathrm{RB}}^{\mathrm{UL}}$ is given by 3GPP TS 36.101 [7].

The number of SC-FDMA symbols in a slot depends on the cyclic prefix length configured by the higher layer parameter *UL-CyclicPrefixLength* and is given in Table 5.2.3-1.

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. There is one resource grid per antenna port. The antenna ports used for transmission of a physical channel or signal depends on the number of antenna ports configured for the physical channel or signal as shown in Table 5.2.1-1. The index $\tilde{p}$ is used throughout clause 5 when a sequential numbering of the antenna ports is necessary.

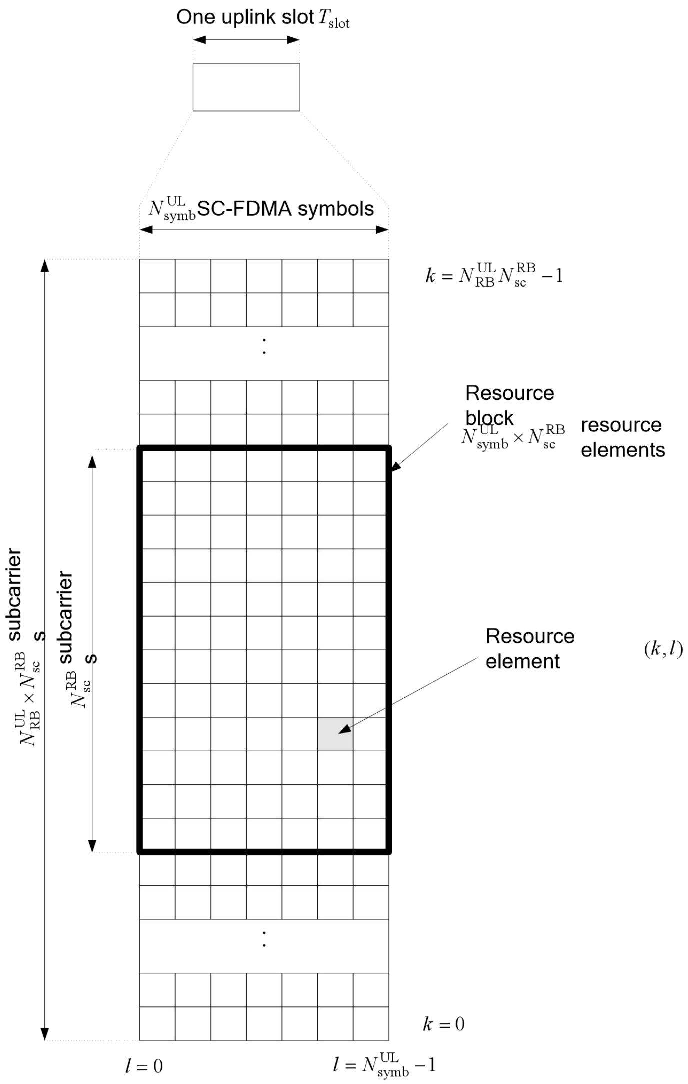

Figure 5.2.1-1: Uplink resource grid

Table 5.2.1-1: Antenna ports used for different physical channels and signals

Physical channel or signal	Index $\widetilde{p}$	Antenna port number p as a function of the number of antenna ports configured for the respective physical channel/signal		
		1	2	4
PUSCH	0	10	20	40
	1	-	21	41
	2	-	-	42
	3	-	-	43
SRS	0	10	20	40
	1	-	21	41
	2	-	-	42
	3	-	-	43
PUCCH, SPUCCH	0	100	200	-
	1	-	201	-

5.2.2 Resource elements

Each element in the resource grid is called a resource element and is uniquely defined by the index pair (k,l) in a slot where $k = 0,...,N_{\text{RB}}^{\text{UL}} N_{\text{sc}}^{\text{RB}} - 1$ and $l = 0,...,N_{\text{symb}}^{\text{UL}} - 1$ are the indices in the frequency and time domains, respectively. Resource element (k,l) on antenna port p corresponds to the complex value $a_{k,l}^{(p)}$.
When there is no risk for confusion, or no particular antenna port is specified, the index p may be dropped. Quantities $a_{k,l}^{(p)}$ corresponding to resource elements not used for transmission of a physical channel or a physical signal in a slot shall be set to zero.

5.2.3 Resource blocks

A physical resource block is defined as $N_{\text{symb}}^{\text{UL}}$ consecutive SC-FDMA symbols in the time domain and $N_{\text{sc}}^{\text{RB}}$ consecutive subcarriers in the frequency domain, where $N_{\text{symb}}^{\text{UL}}$ and $N_{\text{sc}}^{\text{RB}}$ are given by Table 5.2.3-1.
A physical resource block in the uplink thus consists of $N_{\text{symb}}^{\text{UL}} \times N_{\text{sc}}^{\text{RB}}$ resource elements, corresponding to one slot in the time domain and 180 kHz in the frequency domain.

Table 5.2.3-1: Resource block parameters

Configuration	$N_{\text{sc}}^{\text{RB}}$	$N_{\text{symb}}^{\text{UL}}$
Normal cyclic prefix	12	7
Extended cyclic prefix	12	6

The relation between the physical resource block number n_{PRB} in the frequency domain and resource elements (k,l) in a slot is given by

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

5.2.3A Resource unit

Resource units are used to describe the mapping of PUSCH using sub-PRB allocations to resource elements for BL/CE UEs. A resource unit is defined as $M_{\text{symb}}^{\text{UL}} M_{\text{slots}}^{\text{UL}}$ SC-FDMA symbols in the time domain and $M_{\text{sc}}^{\text{RU}}$ consecutive subcarriers in the frequency domain, where $M_{\text{sc}}^{\text{RU}}$ and $M_{\text{symb}}^{\text{UL}}$ are given by Table 5.2.3A-1.

Table 5.2.3A-1: Supported combinations of $M_{\text{sc}}^{\text{RU}}$, $M_{\text{slots}}^{\text{UL}}$, and $M_{\text{symb}}^{\text{UL}}$ for PUSCH using sub-PRB allocations for Frame Structure type 1 and Frame Structure type 2.

Physical channel	Δf	Modulation scheme	$M_{\text{sc}}^{\text{UL}}$	$M_{\text{sc}}^{\text{RU}}$	$M_{\text{slots}}^{\text{UL}}$	$M_{\text{symb}}^{\text{UL}}$	Comment
PUSCH	15 kHz	π/2-BPSK	12	3	16	7	2 out of 3 subcarriers used
		QPSK		3	8		
				6	4		

5.2.4 Narrowbands and widebands

A narrowband is defined as six non-overlapping consecutive physical resource blocks in the frequency domain. The total number of uplink narrowbands in the uplink transmission bandwidth configured in the cell is given by

$$N_{\text{NB}}^{\text{UL}} = \left\lfloor \frac{N_{\text{RB}}^{\text{UL}}}{6} \right\rfloor$$

The narrowbands are numbered $n_{\mathrm{NB}} = 0,\ldots,N_{\mathrm{NB}}^{\mathrm{UL}}-1$ in order of increasing physical resource-block number where narrowband n_{NB} is composed of physical resource-block indices

$$\begin{cases} 6n_{\mathrm{NB}} + i_0 + i & \text{if } N_{\mathrm{RB}}^{\mathrm{UL}} \bmod 2 = 0 \\ 6n_{\mathrm{NB}} + i_0 + i & \text{if } N_{\mathrm{RB}}^{\mathrm{UL}} \bmod 2 = 1 \text{ and } n_{\mathrm{NB}} < N_{\mathrm{NB}}^{\mathrm{UL}}/2 \\ 6n_{\mathrm{NB}} + i_0 + i + 1 & \text{if } N_{\mathrm{RB}}^{\mathrm{UL}} \bmod 2 = 1 \text{ and } n_{\mathrm{NB}} \geq N_{\mathrm{NB}}^{\mathrm{UL}}/2 \end{cases}$$

where

$$i = 0,1,\ldots,5$$
$$i_0 = \left\lfloor \frac{N_{\mathrm{RB}}^{\mathrm{UL}}}{2} \right\rfloor - \frac{6N_{\mathrm{NB}}^{\mathrm{UL}}}{2}$$

If $N_{\mathrm{NB}}^{\mathrm{UL}} \geq 4$, a wideband is defined as four non-overlapping narrowbands in the frequency domain. The total number of uplink widebands in the uplink transmission bandwidth configured in the cell is given by

$$N_{\mathrm{WB}}^{\mathrm{UL}} = \left\lfloor \frac{N_{\mathrm{NB}}^{\mathrm{UL}}}{4} \right\rfloor$$

and the widebands are numbered $n_{\mathrm{WB}} = 0,\ldots,N_{\mathrm{WB}}^{\mathrm{UL}}-1$ in order of increasing narrowband number where wideband n_{WB} is composed of narrowband indices $4n_{\mathrm{WB}} + i$ where $i = 0,1,\ldots,3$.

If $N_{\mathrm{NB}}^{\mathrm{UL}} < 4$, then $N_{\mathrm{WB}}^{\mathrm{UL}} = 1$ and the single wideband is composed of the $N_{\mathrm{NB}}^{\mathrm{UL}}$ non-overlapping narrowband(s).

5.2.5 Guard period for narrowband and wideband retuning

For BL/CE UEs, a guard period of at most $N_{\mathrm{symb}}^{\mathrm{retune}}$ SC-FDMA symbols is created for Tx-to-Tx frequency retuning between two consecutive subframes. If the higher layer parameter *ce-RetuningSymbols* is set, then $N_{\mathrm{symb}}^{\mathrm{retune}}$ equals *ce-RetuningSymbols*, otherwise $N_{\mathrm{symb}}^{\mathrm{retune}} = 2$. If the higher layer parameter *ce-pusch-maxBandwidth-config* is set to 5 MHz, then the rules for guard period creation defined in the remainder of this clause do not apply for retuning between narrowbands but for retuning between widebands and for transmissions involving multiple widebands.

- If the UE retunes from a first narrowband carrying PUSCH to a second narrowband carrying PUSCH, or if the UE retunes from a first narrowband carrying PUCCH to a second narrowband carrying PUCCH,
  - if $N_{\mathrm{symb}}^{\mathrm{retune}} = 1$, a guard period is created by the UE not transmitting the last SC-FDMA symbol in the first subframe;
  - if $N_{\mathrm{symb}}^{\mathrm{retune}} = 2$, a guard period is created by the UE not transmitting the last SC-FDMA symbol in the first subframe and the first SC-FDMA symbol in the second subframe.
- If the UE retunes from a first narrowband carrying PUCCH to a second narrowband carrying PUSCH,
  - if the PUCCH uses a shortened PUCCH format and $N_{\mathrm{symb}}^{\mathrm{retune}} = 1$, a guard period is created by the UE not transmitting the last SC-FDMA symbol in the first subframe;
  - if the PUCCH uses a shortened PUCCH format and $N_{\mathrm{symb}}^{\mathrm{retune}} = 2$, a guard period is created by the UE not transmitting the last SC-FDMA symbol in the first subframe and the first SC-FDMA symbol in the second subframe;
  - if the PUCCH uses a normal PUCCH format, a guard period is created by the UE not transmitting the first $N_{\mathrm{symb}}^{\mathrm{retune}}$ SC-FDMA symbols in the second subframe.

- If the UE retunes from a first narrowband carrying PUSCH to a second narrowband carrying PUCCH,
  - a guard period is created by the UE not transmitting the last $N_{\text{symb}}^{\text{retune}}$ SC-FDMA symbols in the first subframe.
- For CEModeA, if the PUSCH is associated with C-RNTI or SPS C-RNTI and the higher layer parameter *ce-pusch-maxBandwidth-config* is set to 5 MHz,
  - If the PUSCH resource allocation is within a 5 MHz wideband, the center frequency of the transmission bandwidth is the center frequency of the wideband;
  - If the PUSCH resource allocation spans two 5 MHz widebands, the center frequency of transmission bandwidth is in the center of PUSCH resource allocation.

Furthermore, for BL/CE UEs configured with the higher layer parameter *srs-UpPtsAdd*, a guard period of at most $N_{\text{symb}}^{\text{retune}}$ SC-FDMA symbols is created for Tx-to-Tx frequency retuning between a first special subframe and a second uplink subframe for frame structure type 2 according to:

- If the UE retunes from a first narrowband carrying SRS in the last UpPTS symbol to a second narrowband carrying PUSCH,
  - a guard period is created by the UE not transmitting the first $N_{\text{symb}}^{\text{retune}}$ SC-FDMA symbols in the second subframe.
- If the UE retunes from a first narrowband carrying SRS in the last but one UpPTS symbol, but not in the last UpPTS symbol, to a second narrowband carrying PUSCH,
  - if $N_{\text{symb}}^{\text{retune}} = 1$, a guard period is created by the UE not transmitting the last UpPTS symbol in the first subframe;
  - if $N_{\text{symb}}^{\text{retune}} = 2$, a guard period is created by the UE not transmitting the last UpPTS symbol in the first subframe and the first SC-FDMA symbol in the second subframe.
- If the UE retunes from a first narrowband carrying SRS to a second narrowband carrying PUCCH,
  - if $N_{\text{symb}}^{\text{retune}} = 1$, a guard period is created by the UE not transmitting the last UpPTS symbol in the first subframe;
  - if $N_{\text{symb}}^{\text{retune}} = 2$, a guard period is created by the UE not transmitting the last UpPTS symbol in the first subframe and the first SC-FDMA symbol in the second subframe.

For $N_{\text{symb}}^{\text{retune}} > 0$, and for SRS transmission in a special subframe, a BL/CE UE is not expected to be configured with a first SRS transmission in symbol l and a second SRS transmission in any of symbols $\{l+1,...,l+N_{\text{symb}}^{\text{retune}}\}$ if the first SRS transmission and the second SRS transmission use different narrowbands.

5.3 Physical uplink shared channel

The baseband signal representing the physical uplink shared channel is defined in terms of the following steps:

- scrambling
- modulation of scrambled bits to generate complex-valued symbols
- mapping of the complex-valued modulation symbols onto one or several transmission layers
- transform precoding to generate complex-valued symbols
- precoding of the complex-valued symbols
- mapping of precoded complex-valued symbols to resource elements
- generation of complex-valued time-domain SC-FDMA signal for each antenna port

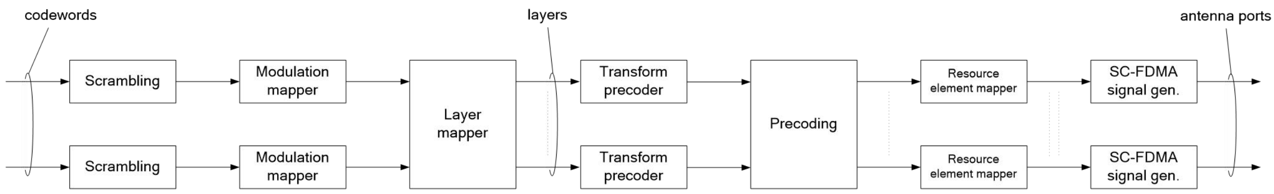

Figure 5.3-1: Overview of uplink physical channel processing

5.3.1 Scrambling

For each codeword q, the block of bits $b^{(q)}(0),...,b^{(q)}(M_{\text{bit}}^{(q)}-1)$, where $M_{\text{bit}}^{(q)}$ is the number of bits transmitted in codeword q on the physical uplink shared channel in one subframe/slot/subslot, shall be scrambled with a UE-specific scrambling sequence 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 $b^{(q)}(i) = \text{x}$ // ACK/NACK or Rank Indication placeholder bits

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

else

if $b^{(q)}(i) = \text{y}$ // ACK/NACK or Rank Indication repetition placeholder bits

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

else // Data or channel quality coded bits, Rank Indication coded bits or ACK/NACK coded bits

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

end if

end if

$i = i + 1$

end while

where x and y are tags defined in 3GPP TS 36.212 [3] clause 5.2.2.6 and where the scrambling sequence $c^{(q)}(i)$ is given by clause 7.2. The scrambling sequence generator shall be initialised with $c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{14} + q \cdot 2^{13} + \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\text{ID}}^{\text{cell}}$ at the start of each subframe where n_{RNTI} corresponds to the RNTI associated with the PUSCH transmission as described in clause 8 in 3GPP TS 36.213 [4]. For AUL PUSCH, $n_{\text{RNTI}} = 0$.

For BL/CE UEs, the same scrambling sequence is applied per subframe to PUSCH for a given block of N_{acc} subframes. The subframe number of the first subframe in each block of N_{acc} consecutive subframes, denoted as $n_{\text{abs},1}$, satisfies $n_{\text{abs},1} \bmod N_{\text{acc}} = 0$. For the j^{th} block of N_{acc} subframes, the scrambling sequence generator shall be initialised with

$$c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{14} + q \cdot 2^{13} + \left[(j_0 + j) N_{\text{acc}} \bmod 10 \right] \cdot 2^9 + N_{\text{ID}}^{\text{cell}}$$

where

$$j = 0,1,\ldots,\left\lfloor \frac{i_0 + N_{\text{abs}}^{\text{PUSCH}} - 1}{N_{\text{acc}}} \right\rfloor - j_0$$
$$j_0 = \lfloor i_0 / N_{\text{acc}} \rfloor$$

and i_0 is the absolute subframe number of the first uplink subframe intended for PUSCH. The PUSCH transmission spans $N_{\text{abs}}^{\text{PUSCH}}$ consecutive subframes including non-BL/CE UL subframes where the UE postpones the PUSCH transmission. For a BL/CE UE configured in CEModeA, $N_{\text{acc}} = 1$. For a BL/CE UE configured with CEModeB, $N_{\text{acc}} = 4$ for frame structure type 1 and $N_{\text{acc}} = 5$ for frame structure type 2.

For PUSCH with a subframe duration, up to two codewords can be transmitted in one subframe, i.e., $q \in \{0,1\}$. In the case of single-codeword transmission, $q = 0$.

5.3.2 Modulation

For each codeword q, the block of scrambled bits $\tilde{b}^{(q)}(0),\ldots,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)} - 1)$ shall be modulated as described in clause 7.1, resulting in a block of complex-valued symbols $d^{(q)}(0),\ldots,d^{(q)}(M_{\text{symb}}^{(q)} - 1)$. Table 5.3.2-1 specifies the modulation mappings applicable for the physical uplink shared channel. For sub-PRB allocations only π/2 BPSK and QPSK are supported.

Table 5.3.2-1: Uplink modulation schemes

Physical channel	Modulation schemes
PUSCH	π/2 BPSK, QPSK, 16QAM, 64QAM, 256QAM

5.3.2A Layer mapping

The complex-valued modulation symbols for each of the codewords to be transmitted are mapped onto one or two layers. 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.

5.3.2A.1 Layer mapping for transmission on a single antenna port

For transmission on a single antenna port, a single layer is used, $\upsilon=1$, and the mapping is defined by

$$x^{(0)}(i)=d^{(0)}(i)$$

with $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}$.

5.3.2A.2 Layer mapping for spatial multiplexing

For spatial multiplexing, the layer mapping shall be done according to Table 5.3.2A.2-1. The number of layers υ is less than or equal to the number of antenna ports P used for transmission of the physical uplink shared channel. The case of a single codeword mapped to multiple layers is only applicable when the number of antenna ports used for PUSCH is four, except for slot-PUSCH and subslot-PUSCH transmission where a single codeword is used irrespective of the number of layers.

Table 5.3.2A.2-1: Codeword-to-layer mapping for spatial multiplexing

Number of layers	Number of codewords	Codeword-to-layer mapping $i=0,1,...,M_{\text{symb}}^{\text{layer}}-1$	
1	1	$x^{(0)}(i)=d^{(0)}(i)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}$
2	1	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/2$
2	2	$x^{(0)}(i)=d^{(0)}(i)$ $x^{(1)}(i)=d^{(1)}(i)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}=M_{\text{symb}}^{(1)}$
3	2	$x^{(0)}(i)=d^{(0)}(i)$ $x^{(1)}(i)=d^{(1)}(2i)$ $x^{(2)}(i)=d^{(1)}(2i+1)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}=M_{\text{symb}}^{(1)}/2$
4	2	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$ $x^{(2)}(i)=d^{(1)}(2i)$ $x^{(3)}(i)=d^{(1)}(2i+1)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/2=M_{\text{symb}}^{(1)}/2$
4[1]	1[1]	$x^{(0)}(i)=d^{(0)}(4i)$ $x^{(1)}(i)=d^{(0)}(4i+1)$ $x^{(2)}(i)=d^{(0)}(4i+2)$ $x^{(3)}(i)=d^{(0)}(4i+3)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/4$
NOTE 1: Only used for slot-PUSCH and subslot-PUSCH			

5.3.3 Transform precoding

For each layer $\lambda = 0,1,...,\upsilon - 1$ the block of complex-valued symbols $x^{(\lambda)}(0),...,x^{(\lambda)}(M_{\text{symb}}^{\text{layer}} - 1)$ is divided into $M_{\text{symb}}^{\text{layer}} \big/ M_{\text{sc}}^{\text{PUSCH}}$ sets, each corresponding to one SC-FDMA symbol. Transform precoding shall be applied according to

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

resulting in a block of complex-valued symbols $y^{(\lambda)}(0),...,y^{(\lambda)}(M_{\text{symb}}^{\text{layer}} - 1)$. 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

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

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

In case of PUSCH transmissions using sub-PRB allocations for BL/CE UEs, the variable $M_{\text{sc}}^{\text{PUSCH}} = M_{sc}^{\text{RU}} + Q_m - 2$.

5.3.3A Precoding

The precoder takes as input a block of vectors $\left[y^{(0)}(i) \;\; ... \;\; y^{(\upsilon-1)}(i) \right]^T$, $i = 0,1,...,M_{\text{symb}}^{\text{layer}} - 1$ from the transform precoder and generates a block of vectors $\left[z^{(0)}(i) \;\; \ldots \;\; z^{(P-1)}(i) \right]^T$, $i = 0,1,...,M_{\text{symb}}^{\text{ap}} - 1$ to be mapped onto resource elements.

5.3.3A.1 Precoding for transmission on a single antenna port

For transmission on a single antenna port, precoding is defined by

$$z^{(0)}(i) = y^{(0)}(i)$$

where $i = 0,1,...,M_{\text{symb}}^{\text{ap}} - 1$, $M_{\text{symb}}^{\text{ap}} = M_{\text{symb}}^{\text{layer}}$.

5.3.3A.2 Precoding for spatial multiplexing

Precoding for spatial multiplexing is only used in combination with layer mapping for spatial multiplexing as described in clause 5.3.2A.2. Spatial multiplexing supports $P = 2$ or $P = 4$ antenna ports where the set of antenna ports used for spatial multiplexing is $p \in \{20,21\}$ and $p \in \{40,41,42,43\}$, respectively.

Precoding for spatial multiplexing is defined by

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

where $i = 0,1,...,M_{\text{symb}}^{\text{ap}} - 1$, $M_{\text{symb}}^{\text{ap}} = M_{\text{symb}}^{\text{layer}}$.

The precoding matrix W of size $P\times\upsilon$ is given by one of the entries in Table 5.3.3A.2-1 for $P=2$ and by Tables 5.3.3A.2-2 through 5.3.3A.2-5 for $P=4$ where the entries in each row are ordered from left to right in increasing order of codebook indices.

Table 5.3.3A.2-1: Codebook for transmission on antenna ports $\{20,21\}$

Codebook index	Number of layers $\upsilon=1$	Number of layers $\upsilon=2$
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1&0\\0&1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	-
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	-
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-
4	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\0\end{bmatrix}$	-
5	$\frac{1}{\sqrt{2}}\begin{bmatrix}0\\1\end{bmatrix}$	-

Table 5.3.3A.2-2: Codebook for transmission on antenna ports $\{40,41,42,43\}$ with $\upsilon=1$

Codebook index	Number of layers $\upsilon=1$							
0 – 7	$\frac{1}{2}\begin{bmatrix}1\\1\\1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\j\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\-1\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\1\\-j\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\j\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\-1\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\j\\-j\\-1\end{bmatrix}$
8 – 15	$\frac{1}{2}\begin{bmatrix}1\\-1\\1\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\j\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\-1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-1\\-j\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\1\\-j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\j\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\-1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\-j\\-j\\1\end{bmatrix}$
16 – 23	$\frac{1}{2}\begin{bmatrix}1\\0\\1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\-1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\j\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\-j\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\-j\end{bmatrix}$

Table 5.3.3A.2-3: Codebook for transmission on antenna ports $\{40,41,42,43\}$ with $\upsilon = 2$

Codebook index	Number of layers $\upsilon = 2$			
0 – 3	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & -j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ -j & 0 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ -j & 0 \\ 0 & 1 \\ 0 & -1 \end{bmatrix}$
4 – 7	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ -1 & 0 \\ 0 & 1 \\ 0 & -j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ -1 & 0 \\ 0 & 1 \\ 0 & j \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ j & 0 \\ 0 & 1 \\ 0 & 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ j & 0 \\ 0 & 1 \\ 0 & -1 \end{bmatrix}$
8 – 11	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & -1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ -1 & 0 \\ 0 & 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ -1 & 0 \\ 0 & -1 \end{bmatrix}$
12 – 15	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ 1 & 0 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & -1 \\ 1 & 0 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 1 \\ -1 & 0 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & -1 \\ -1 & 0 \end{bmatrix}$

Table 5.3.3A.2-4: Codebook for transmission on antenna ports $\{40,41,42,43\}$ with $\upsilon = 3$

Codebook index	Number of layers $\upsilon = 3$			
0 – 3	$\frac{1}{2}\begin{bmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 & 0 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$
4 – 7	$\frac{1}{2}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -1 & 0 & 0 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$
8 – 11	$\frac{1}{2}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \\ -1 & 0 & 0 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$	$\frac{1}{2}\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ -1 & 0 & 0 \end{bmatrix}$

Table 5.3.3A.2-5: Codebook for transmission on antenna ports $\{40,41,42,43\}$ with $\upsilon = 4$

Codebook index	Number of layers $\upsilon = 4$
0	$\frac{1}{2}\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

5.3.4 Mapping to physical resources

For each antenna port p used for transmission of the PUSCH in a subframe the block of complex-valued symbols $z^{(\tilde{p})}(0),...,z^{(\tilde{p})}(M_{\mathrm{symb}}^{\mathrm{ap}}-1)$ shall be multiplied with the amplitude scaling factor β_{PUSCH} in order to conform to the transmit power P_{PUSCH} specified in clause 5.1.1.1 in 3GPP TS 36.213 [4], and mapped in sequence starting with $z^{(\tilde{p})}(0)$ to physical resource blocks on antenna port p and assigned for transmission of PUSCH. The relation between the index $\tilde{p}$ and the antenna port number p is given by Table 5.2.1-1. The mapping to resource elements (k,l) corresponding to the physical resource blocks assigned for transmission shall fulfil the following criteria:

- not used for transmission of reference signals, and
- not part of the last SC-FDMA symbol in a subframe, if the UE transmits SRS in the same subframe in the same serving cell, and
- not part of the last SC-FDMA symbol in a subframe configured with cell-specific SRS for non-BL/CE UEs and BL/CE UEs in CEModeA, if the PUSCH transmission partly or fully overlaps with the cell-specific SRS bandwidth, and
- not part of an SC-FDMA symbol reserved for possible SRS transmission in a UE-specific aperiodic SRS subframe in the same serving cell, and
- not part of an SC-FDMA symbol reserved for possible SRS transmission in a UE-specific periodic SRS subframe in the same serving cell when the UE is configured with multiple TAGs
- not part of the first SC-FDMA symbol in a subframe if the associated DCI indicates PUSCH starting position '01', '10', or '11' and does not indicate PUSCH mode 2.
- not part of the first SC-FDMA symbol in the second slot in a subframe if the associated DCI indicates PUSCH starting position '01', '10', or '11' and PUSCH mode 2.
- not part of the last SC-FDMA symbol in a subframe if the associated DCI indicates PUSCH ending symbol '1' and does not indicate PUSCH mode 3.
- not part of the second slot in a subframe if the associated DCI indicates PUSCH ending symbol '0' and PUSCH mode 3.
- not part of SC-FDMA symbols 5 to 13 in a subframe if the associated DCI indicates PUSCH ending symbol '1' and PUSCH mode 3.

The mapping to resource elements (k,l) shall be in increasing order of first the index k, then the index l. The mapping starts with the first slot in an uplink subframe, except for slot-PUSCH, subslot-PUSCH transmission, or PUSCH mode 2.

In case of PUSCH transmissions using sub-PRB allocations for BL/CE UEs, the mapping starts over in every valid uplink subframe composing an UL resource unit.

In case of slot-PUSCH, the mapping shall start at $l=0$ in the slot assigned for transmission.

In case of PUSCH mode 2, the mapping shall start at $l=0$ in the second slot of the subframe assigned for transmission.

In case of subslot-PUSCH, the mapping shall start at symbol l where the start of the mapping is dependent on the uplink subslot number in the subframe assigned for transmission and the *DMRS-pattern* field in the related uplink DCI format [3] according to Table 5.3.4-1 where starting symbol index "4" for subslot #5 is applied if the UE has indicated the capability *ul-pattern-ddd-r15*.

Table 5.3.4-1: Starting symbol index for subslot-PUSCH transmission

DMRS-pattern field in uplink-related DCI format [3]	Uplink subslot number					
	#0	#1	#2	#3	#4	#5
00	1	4	6	1	3	5
01	0	3	5	0	2	4
10	–	3	–	0	2	–
11	–	3	–	–	2	–

In case of a semi-persistently scheduled subslot-PUSCH, and semi-persistent scheduling (i.e. higher layer parameter *sps-ConfigUL-STTI* is configured, see 3GPP TS 36.331 [9]) with a configured periodicity of 1 subslot (i.e. *semiPersistSchedIntervalUL-STTI* set to *sTTI1*), the mapping shall start at symbol l depending on the *DMRS-pattern* field in the related uplink DCI format [3] according to Table 5.3.4-2.

In case of a semi-persistently scheduled subslot-PUSCH and semi-persistent scheduling (the higher layer parameter *sps-ConfigUL-sTTI-r15* is configured, see 3GPP TS 36.331 [9]) with repetitions enabled (the higher layer parameter *totalNumberPUSCH-SPS-STTI-UL-Repetitions* is configured), the mapping shall start at symbol l depending on the DMRS-pattern field in the related uplink DCI format [3] according to Table 5.3.4-2.

Table 5.3.4-2: Starting symbol index for subslot-PUSCH transmission in case of semi-persistent scheduling with a configured periodicity of 1 subslot

DMRS-pattern field in uplink-related DCI format [3]	Uplink subslot number					
	#0	#1	#2	#3	#4	#5
00	1	4	6	1	3	5
10	1	3	6	0	3	5

In case of subslot-PUSCH and semi-persistent scheduling with a configured periodicity longer than 1 subslot the mapping shall start at symbol l according to the first row of Table 5.3.4-2 (i.e. equivalent to a signalling of *DMRS-pattern* field set to '00').

For the UpPTS, the mapping shall start at symbol $l = 1$ and if *dmrsLess-UpPts* is set to true the mapping shall end at symbol $l = symPUSCH\_UpPts$ in the second slot of a special subframe, otherwise, the mapping shall end at symbol $l = symPUSCH\_UpPts + 1$ in the second slot of a special subframe.

For BL/CE UEs, the PUSCH transmission is restricted as follows:

- For CEModeA, if the PUSCH is associated with C-RNTI or SPS C-RNTI and the higher layer parameter *ce-pusch-maxBandwidth-config* is set to 5 MHz, the maximum number of allocatable PRBs for PUSCH is 24 PRBs. The allocatable PRBs include the PRBs belonging to the narrowbands defined in clause 5.2.4 and the odd PRB at the center of the uplink system bandwidth in case of odd total number of uplink PRBs. If a resource assignment or frequency hopping would result in a PUSCH resource allocation outside the allocatable PRBs then the PUSCH transmission in that subframe is dropped.

- For all other cases, the maximum number of allocatable PRBs for PUSCH is 6 PRBs restricted to one of the narrowbands defined in clause 5.2.4.

For BL/CE UEs in CEModeB, resource elements in the last SC-FDMA symbol in a subframe configured with cell-specific SRS shall be counted in the PUSCH mapping but not used for transmission of the PUSCH.

For BL/CE UEs, if one or more SC-FDMA symbol(s) are left empty due to guard period for narrowband or wideband retuning, the affected SC-FDMA symbol(s) shall be counted in the PUSCH mapping but not used for transmission of the PUSCH.

For a UE configured with SRS carrier switching, if the first symbol in a subframe overlaps with an SRS transmission (including any interruption due to uplink or downlink RF retuning time) in a carrier without PUSCH/PUCCH, the resource elements in the first SC-FDMA symbol shall be counted in the PUSCH mapping but not used for transmission of PUSCH.

For a UE configured with SRS carrier switching, if the last symbol in a subframe is counted in the PUSCH mapping and the last symbol in the subframe overlaps with an SRS transmission (including any interruption due to uplink or downlink RF retuning time) in a carrier without PUSCH/PUCCH, the resource elements in the last SC-FDMA symbol shall be counted in the PUSCH mapping but not used for transmission of PUSCH.

For a UE configured with SRS carrier switching, if the last symbol in a subframe is not counted in the PUSCH mapping and the second-to-last symbol in the subframe overlaps with an SRS transmission (including any interruption due to uplink or downlink RF retuning time) in a carrier without PUSCH/PUCCH, the resource elements in the second-to-last SC-FDMA symbol shall be counted in the PUSCH mapping but not used for transmission of PUSCH.

For a UE configured with PUSCH Mode 1, if DCI indicates PUSCH mode 1 enabled and the corresponding transmission of PUSCH starts in the second slot of a subframe, the resource elements in the first slot of the subframe shall be counted in the PUSCH mapping but not used for transmission of PUSCH.

For a UE configured with autonomous uplink,

- if the UE indicates PUSCH ending symbol '1' in uplink control information, or *endingSymbolAUL* is set to '12', the resource elements in the last SC-FDMA symbol shall be counted in the PUSCH mapping but not used for transmission of PUSCH;

- if the UE indicates PUSCH starting symbol '1' in uplink control information, the resource elements in the first SC-FDMA symbol shall be counted in the PUSCH mapping but not used for transmission of PUSCH.

If uplink frequency-hopping is disabled or the resource blocks allocated for PUSCH transmission are not contiguous in frequency, the set of physical resource blocks to be used for transmission is given by $n_{\mathrm{PRB}} = n_{\mathrm{VRB}}$ where n_{VRB} is obtained from the uplink scheduling grant as described in clause 8.1 in 3GPP TS 36.213 [4].

If uplink frequency-hopping with type 1 PUSCH hopping is enabled, the set of physical resource blocks to be used for transmission is given by clause 8.4.1 in 3GPP TS 36.213 [4].

If uplink frequency-hopping with predefined hopping pattern is enabled, the set of physical resource blocks to be used for transmission in slot n_{s} is given by the scheduling grant together with a predefined pattern according to

$$\tilde{n}_{\mathrm{PRB}}(n_{\mathrm{s}}) = \left(\tilde{n}_{\mathrm{VRB}} + f_{\mathrm{hop}}(i) \cdot N_{\mathrm{RB}}^{\mathrm{sb}} + \left(\left(N_{\mathrm{RB}}^{\mathrm{sb}} - 1\right) - 2\left(\tilde{n}_{\mathrm{VRB}} \bmod N_{\mathrm{RB}}^{\mathrm{sb}}\right)\right) \cdot f_{\mathrm{m}}(i)\right) \bmod (N_{\mathrm{RB}}^{\mathrm{sb}} \cdot N_{\mathrm{sb}})$$

$$i = \begin{cases} \lfloor n_{\mathrm{s}}/2 \rfloor & \text{inter-subframe hopping} \\ n_{\mathrm{s}} & \text{intra and inter-subframe hopping} \end{cases}$$

$$n_{\mathrm{PRB}}(n_{\mathrm{s}}) = \begin{cases} \tilde{n}_{\mathrm{PRB}}(n_{\mathrm{s}}) & N_{sb} = 1 \\ \tilde{n}_{\mathrm{PRB}}(n_{\mathrm{s}}) + \left\lceil N_{\mathrm{RB}}^{\mathrm{HO}}/2 \right\rceil & N_{sb} > 1 \end{cases}$$

$$\tilde{n}_{\mathrm{VRB}} = \begin{cases} n_{\mathrm{VRB}} & N_{sb} = 1 \\ n_{\mathrm{VRB}} - \left\lceil N_{\mathrm{RB}}^{\mathrm{HO}}/2 \right\rceil & N_{sb} > 1 \end{cases}$$

where n_{VRB} is obtained from the scheduling grant as described in clause 8.1 in 3GPP TS 36.213 [4]. The parameter *pusch-HoppingOffset*, $N_{\mathrm{RB}}^{\mathrm{HO}}$, is provided by higher layers. The size $N_{\mathrm{RB}}^{\mathrm{sb}}$ of each sub-band is given by,

$$N_{\mathrm{RB}}^{\mathrm{sb}} = \begin{cases} N_{\mathrm{RB}}^{\mathrm{UL}} & N_{\mathrm{sb}} = 1 \\ \left\lfloor \left(N_{\mathrm{RB}}^{\mathrm{UL}} - N_{\mathrm{RB}}^{\mathrm{HO}} - N_{\mathrm{RB}}^{\mathrm{HO}} \bmod 2\right) / N_{\mathrm{sb}} \right\rfloor & N_{\mathrm{sb}} > 1 \end{cases}$$

where the number of sub-bands N_{sb} is given by higher layers. The function $f_{\mathrm{m}}(i) \in \{0,1\}$ determines whether mirroring is used or not. The parameter *Hopping-mode* provided by higher layers determines if hopping is "inter-subframe" or "intra and inter-subframe".

The hopping function $f_{\mathrm{hop}}(i)$ and the function $f_{\mathrm{m}}(i)$ are given by

$$f_{\text{hop}}(i)=\begin{cases}0 & N_{\text{sb}}=1\\ \left(f_{\text{hop}}(i-1)+\sum_{k=i\cdot 10+1}^{i\cdot 10+9}c(k)\times 2^{k-(i\cdot 10+1)}\right)\bmod N_{\text{sb}} & N_{\text{sb}}=2\\ \left(f_{\text{hop}}(i-1)+\left(\sum_{k=i\cdot 10+1}^{i\cdot 10+9}c(k)\times 2^{k-(i\cdot 10+1)}\right)\bmod(N_{\text{sb}}-1)+1\right)\bmod N_{\text{sb}} & N_{\text{sb}}>2\end{cases}$$

$$f_{\text{m}}(i)=\begin{cases}i \bmod 2 & N_{\text{sb}}=1 \text{ and intra and inter}-\text{subframe hopping}\\ \text{CURRENT\_TX\_NB} \bmod 2 & N_{\text{sb}}=1 \text{ and inter}-\text{subframe hopping}\\ c(i\cdot 10) & N_{\text{sb}}>1\end{cases}$$

where $f_{\text{hop}}(-1)=0$ and the pseudo-random sequence $c(i)$ is given by clause 7.2 and CURRENT_TX_NB indicates the transmission number for the transport block transmitted in slot n_{s} as defined in [8]. The pseudo-random sequence generator shall be initialised with $c_{\text{init}}=N_{\text{ID}}^{\text{cell}}$ for frame structure type 1 and $c_{\text{init}}=2^9\cdot(n_{\text{f}} \bmod 4)+N_{\text{ID}}^{\text{cell}}$ for frame structure type 2 at the start of each frame.

For BL/CE UEs, the PRB resources for PUSCH transmission in the first subframe are obtained from the DCI as described in clauses 5.3.3.1.10 and 5.3.3.1.11 in [3]. The PUSCH is transmitted with $N_{\text{rep}}^{\text{PUSCH}}\geq 1$ repetitions. The PUSCH transmission spans $N_{\text{abs}}^{\text{PUSCH}}\geq N_{\text{rep}}^{\text{PUSCH}}$ consecutive subframes, including non-BL/CE UL subframes where the UE postpones the PUSCH transmission if $N_{\text{rep}}^{\text{PUSCH}}>1$. In case the UE is a BL/CE configured with higher layer parameter *ce-PUSCH-SubPRB-Config-r15*, the PUSCH transmission spans $N_{\text{abs}}^{\text{PUSCH}}\geq N_{\text{rep}}^{\text{PUSCH}}M_{\text{RU}}\,M_{\text{slots}}^{\text{UL}}/2$ consecutive subframes including non-BL/CE UL subframes where the UE postpones the PUSCH transmission. For BL/CE UE in CEModeA, PUSCH frequency hopping is enabled when the higher-layer parameter *pusch-HoppingConfig* is set and the frequency hopping flag in DCI format 6-0A indicates frequency hopping, otherwise frequency hopping is disabled. For BL/CE UE in CEModeB, PUSCH frequency hopping is enabled when the higher-layer parameter *pusch-HoppingConfig* is set, otherwise frequency hopping is disabled. If frequency hopping is not enabled for PUSCH, all PUSCH repetitions are located at the same PRB resources. If frequency hopping is enabled for PUSCH, PUSCH is transmitted in subframe i within the $N_{\text{abs}}^{\text{PUSCH}}$ consecutive uplink subframes using the same number of consecutive PRBs as in the previous subframe starting from the PRB resources of the narrowband $n_{\text{NB}}^{(i)}$ with the same RIV as that of narrowband $n_{\text{NB}}^{(i_0)}$. The narrowband $n_{\text{NB}}^{(i)}$ is defined as

$$n_{\text{NB}}^{(i)}=\begin{cases}n_{\text{NB}}^{(i_0)} & \text{if } \left\lfloor i/N_{\text{NB}}^{\text{ch,UL}}-j_0\right\rfloor \bmod 2=0\\ \left(n_{\text{NB}}^{(i_0)}+f_{\text{NB,hop}}^{\text{PUSCH}}\right)\bmod N_{\text{NB}}^{\text{UL}} & \text{if } \left\lfloor i/N_{\text{NB}}^{\text{ch,UL}}-j_0\right\rfloor \bmod 2=1\end{cases}$$
$$j_0=\left\lfloor i_0/N_{\text{NB}}^{\text{ch,UL}}\right\rfloor$$
$$i_0\leq i\leq i_0+N_{\text{abs}}^{\text{PUSCH}}-1$$

where i_0 is the absolute subframe number of the first UL subframe intended for carrying the PUSCH and $N_{\text{NB}}^{\text{ch,UL}}$ and $f_{\text{NB,hop}}^{\text{PUSCH}}$ are cell-specific higher-layer parameters. For the $N_{\text{abs}}^{\text{PUSCH}}$ consecutive subframes, the UE shall not transmit PUSCH in subframe i if it is not a BL/CE UL subframe.

For BL/CE UEs, for PUSCH transmission corresponding to the random access response grant and its retransmission, frequency hopping of the PUSCH is enabled when higher layer parameter *rar-HoppingConfig* is set. Further

- if PRACH CE level 0 or 1 is used for the last PRACH attempt, $N_{\text{NB}}^{\text{ch,UL}}$ is set to the higher layer parameter *interval-UlHoppingConfigCommonModeA*;
- if PRACH CE level 2 or 3 is used for the last PRACH attempt, $N_{\text{NB}}^{\text{ch,UL}}$ is set to the higher layer parameter *interval-UlHoppingConfigCommonModeB*.

For BL/CE UEs in CEModeB, for PUSCH transmission not associated with Temporary C-RNTI, for frame structure type 1, after a transmission duration of $256\cdot 30720T_{\text{s}}$ time units (which may include non-BL/CE UL subframes), a gap of $40\cdot 30720T_{\text{s}}$ time units shall be inserted, according to the UE capability *ue-CE-NeedULGaps*, as specified in TS

36.331 [9]. BL/CE UL subframes within the gap of $40 \cdot 30720 T_s$ time units shall be counted for the PUSCH resource mapping but not used for transmission of the PUSCH.

For BL/CE UEs, for PUSCH transmission associated with Temporary C-RNTI for frame structure type 1, and if PRACH CE level 2 or 3 is used for the last PRACH attempt, after a transmission duration of $256 \cdot 30720 T_s$ time units (which may include non-BL/CE UL subframes), a gap of $40 \cdot 30720 T_s$ time units shall be inserted. BL/CE UL subframes within the gap of $40 \cdot 30720 T_s$ time units shall be counted for the PUSCH resource mapping but not used for transmission of the PUSCH.

For UEs configured with *PUSCH-EnhancementsConfig*, the number of PUSCH subframe repetitions $N_{\text{rep}}^{\text{PUSCH}}$ and the PRB resources for PUSCH transmission in the first subframe are obtained from the DCI as described in clause 5.3.3.1.1C in [3]. PUSCH frequency hopping is enabled when the higher-layer parameters *pusch-HoppingOffsetPUSCH-Enh* and *interval-ULHoppingPUSCH-Enh* are set and the frequency hopping flag in DCI format 0C indicates frequency hopping, otherwise frequency hopping is disabled. If frequency hopping is not enabled for PUSCH, the PUSCH repetitions are located at the same PRB resources as in the first subframe. If frequency hopping is enabled for PUSCH, PUSCH is transmitted in subframe i within the $N_{\text{rep}}^{\text{PUSCH}}$ consecutive uplink subframes using the PRB resources starting at PRB index $n_{\text{PRB}}^{(i)}$

$$
\begin{aligned}
n_{\text{PRB}}^{(i)} &= \begin{cases} n_{\text{PRB}}^{(i_0)} & \text{if } \left\lfloor i / N_{\text{PRB,hop}}^{\text{PUSCH}} - j_0 \right\rfloor \bmod 2 = 0 \\ \left(n_{\text{PRB}}^{(i_0)} + f_{\text{PRB,hop}}^{\text{PUSCH}} \right) \bmod N_{\text{PRB}}^{\text{UL}} & \text{if } \left\lfloor i / N_{\text{PRB,hop}}^{\text{PUSCH}} - j_0 \right\rfloor \bmod 2 = 1 \end{cases} \\
j_0 &= \left\lfloor i_0 / N_{\text{PRB,hop}}^{\text{PUSCH}} \right\rfloor \\
i_0 &\le i \le i_0 + N_{\text{rep}}^{\text{PUSCH}} - 1
\end{aligned}
$$

where i_0 is the absolute subframe number of the first UL subframe carrying the PUSCH and $N_{\text{PRB,hop}}^{\text{PUSCH}}$ is given by the higher-layer parameter *interval-ULHoppingPUSCH-Enh* and $f_{\text{PRB,hop}}^{\text{PUSCH}}$ is given by the higher-layer parameter *pusch-HoppingOffsetPUSCH-Enh*.

5.4 Physical uplink control channel

The physical uplink control channel, PUCCH, carries uplink control information. Simultaneous transmission of PUCCH and PUSCH from the same UE is supported if enabled by higher layers. For frame structure type 2, the PUCCH is not transmitted in the UpPTS field.

The physical uplink control channel supports multiple formats as shown in Table 5.4-1 with different number of bits per subframe, where $M_{\text{RB}}^{\text{PUCCH4}}$ represents the bandwidth of the PUCCH format 4 as defined by clause 5.4.2B, and N_0^{PUCCH} and N_1^{PUCCH} are defined in Table 5.4.2C-1.

Formats 2a and 2b are supported for normal cyclic prefix only.

Table 5.4-1: Supported PUCCH formats

PUCCH format	Modulation scheme	Number of bits per subframe, M_{bit}
1	N/A	N/A
1a	BPSK	1
1b	QPSK	2
2	QPSK	20
2a	QPSK+BPSK	21
2b	QPSK+QPSK	22
3	QPSK	48
4	QPSK	$M_{\text{RB}}^{\text{PUCCH4}} \cdot N_{\text{sc}}^{\text{RB}} \cdot \left(N_0^{\text{PUCCH}} + N_1^{\text{PUCCH}} \right) \cdot 2$
5	QPSK	$N_{\text{sc}}^{\text{RB}} \cdot \left(N_0^{\text{PUCCH}} + N_1^{\text{PUCCH}} \right)$

All PUCCH formats use a cyclic shift, $n_{\text{cs}}^{\text{cell}}(n_{\text{s}},l)$, which varies with the symbol number l and the slot number n_{s} according to

$$n_{\text{cs}}^{\text{cell}}(n_{\text{s}},l)=\sum_{i=0}^{7} c(8N_{\text{symb}}^{\text{UL}}\cdot n_{\text{s}}+8l+i)\cdot 2^{i}$$

where the pseudo-random sequence $c(i)$ is defined by clause 7.2. The pseudo-random sequence generator shall be initialized with $c_{\text{init}}=n_{\text{ID}}^{\text{RS}}$, where $n_{\text{ID}}^{\text{RS}}$ is given by clause 5.5.1.5 with $N_{\text{ID}}^{\text{cell}}$ corresponding to the primary cell, at the beginning of each radio frame.

The physical resources used for PUCCH format 1/1a/1b and PUCCH format 2/2a/2b depends on two parameters, $N_{\text{RB}}^{(2)}$ and $N_{\text{cs}}^{(1)}$, given by higher layers.
The variable $N_{\text{RB}}^{(2)}\geq 0$ denotes the bandwidth in terms of resource blocks that are available for use by PUCCH formats 2/2a/2b transmission in each slot. The variable $N_{\text{cs}}^{(1)}$ denotes the number of cyclic shift used for PUCCH formats 1/1a/1b in a resource block used for a mix of formats 1/1a/1b and 2/2a/2b. The value of $N_{\text{cs}}^{(1)}$ is an integer multiple of $\Delta_{\text{shift}}^{\text{PUCCH}}$ within the range of {0, 1, …, 7}, where $\Delta_{\text{shift}}^{\text{PUCCH}}$ is provided by higher layers. No mixed resource block is present if $N_{\text{cs}}^{(1)}=0$. At most one resource block in each slot supports a mix of formats 1/1a/1b and 2/2a/2b.
Resources used for transmission of PUCCH formats 1/1a/1b, 2/2a/2b, 3, 4, and 5 are represented by the non-negative indices $n_{\text{PUCCH}}^{(1,\tilde{p})}$, $n_{\text{PUCCH}}^{(2,\tilde{p})}<N_{\text{RB}}^{(2)}N_{\text{sc}}^{\text{RB}}+\left\lceil\frac{N_{\text{cs}}^{(1)}}{8}\right\rceil\cdot(N_{\text{sc}}^{\text{RB}}-N_{\text{cs}}^{(1)}-2)$, $n_{\text{PUCCH}}^{(3,\tilde{p})}$, $n_{\text{PUCCH}}^{(4)}$ and $n_{\text{PUCCH}}^{(5)}$, respectively.

5.4.1 PUCCH formats 1, 1a and 1b

For PUCCH format 1, information is carried by the presence/absence of transmission of PUCCH from the UE.
In the remainder of this clause, $d(0)=1$ shall be assumed for PUCCH format 1.

For PUCCH formats 1a and 1b, one or two explicit bits are transmitted, respectively. The block of bits $b(0),...,b(M_{\text{bit}}-1)$ shall be modulated as described in Table 5.4.1-1, resulting in a complex-valued symbol $d(0)$.
The modulation schemes for the different PUCCH formats are given by Table 5.4-1.

The complex-valued symbol $d(0)$ shall be multiplied with a cyclically shifted length $N_{\text{seq}}^{\text{PUCCH}}=12$ sequence $r_{u,v}^{(\alpha_{\tilde{p}})}(n)$ for each of the P antenna ports used for PUCCH transmission according to

$$y^{(\tilde{p},\delta)}(n)=\frac{1}{\sqrt{P}}d(0)\cdot r_{u,v}^{(\alpha_{\tilde{p}},\delta)}(n),\qquad n=0,1,...,N_{\text{seq}}^{\text{PUCCH}}-1$$

where $r_{u,v}^{(\alpha_{\tilde{p}},\delta)}(n)$ is defined by clause 5.5.1 with $M_{\text{sc}}^{\text{RS}}=N_{\text{seq}}^{\text{PUCCH}}$ and $\delta=0$. The antenna-port specific cyclic shift $\alpha_{\tilde{p}}$ varies between symbols and slots as defined below.

The block of complex-valued symbols $y^{(\tilde{p})}(0),...,y^{(\tilde{p})}(N_{\text{seq}}^{\text{PUCCH}}-1)$ shall be scrambled by $S(n_s)$ and block-wise spread with the antenna-port specific orthogonal sequence $w_{n_{\text{oc}}^{(\tilde{p})}}(i)$ according to

$$z^{(\tilde{p})}\left(m'\cdot N_{\text{SF}}^{\text{PUCCH}}\cdot N_{\text{seq}}^{\text{PUCCH}}+m\cdot N_{\text{seq}}^{\text{PUCCH}}+n\right)=S(n_{\text{s}})\cdot w_{n_{\text{oc}}^{(\tilde{p})}}(m)\cdot y^{(\tilde{p})}(n)$$

where

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

and

$$S(n_s)=\begin{cases}1 & \text{if } n'_{\tilde{p}}(n_s) \bmod 2 = 0\\ e^{j\pi/2} & \text{otherwise}\end{cases}$$

with $N_{\mathrm{SF}}^{\mathrm{PUCCH}}$ for the two slots in a subframe given by Table 5.4.1-1a. The sequence $w_{n_{\mathrm{oc}}^{(\tilde{p})}}(i)$ is given by Table 5.4.1-2 and Table 5.4.1-3 and $n'_{\tilde{p}}(n_s)$ is defined below.

Resources used for transmission of PUCCH format 1, 1a and 1b are identified by a resource index $n_{\mathrm{PUCCH}}^{(1,\tilde{p})}$ from which the orthogonal sequence index $n_{\mathrm{oc}}^{(\tilde{p})}(n_s)$ and the cyclic shift $\alpha_{\tilde{p}}(n_s,l)$ are determined according to

$$n_{\mathrm{oc}}^{(\tilde{p})}(n_s)=\begin{cases}\left\lfloor n'_{\tilde{p}}(n_s)\cdot\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\big/N'\right\rfloor & \text{for normal cyclic prefix}\\ 2\cdot\left\lfloor n'_{\tilde{p}}(n_s)\cdot\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\big/N'\right\rfloor & \text{for extended cyclic prefix}\end{cases}$$

$$\alpha_{\tilde{p}}(n_s,l)=2\pi\cdot n_{\mathrm{cs}}^{(\tilde{p})}(n_s,l)\big/N_{\mathrm{sc}}^{\mathrm{RB}}$$

$$n_{\mathrm{cs}}^{(\tilde{p})}(n_s,l)=\begin{cases}\left[n_{\mathrm{cs}}^{\mathrm{cell}}(n_s,l)+\left(n'_{\tilde{p}}(n_s)\cdot\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}+\left(n_{\mathrm{oc}}^{(\tilde{p})}(n_s)\bmod\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\right)\right)\bmod N'\right]\bmod N_{\mathrm{sc}}^{\mathrm{RB}} & \text{for normal cyclic prefix}\\ \left[n_{\mathrm{cs}}^{\mathrm{cell}}(n_s,l)+\left(n'_{\tilde{p}}(n_s)\cdot\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}+n_{\mathrm{oc}}^{(\tilde{p})}(n_s)/2\right)\bmod N'\right]\bmod N_{\mathrm{sc}}^{\mathrm{RB}} & \text{for extended cyclic prefix}\end{cases}$$

where

$$N'=\begin{cases}N_{\mathrm{cs}}^{(1)} & \text{if } n_{\mathrm{PUCCH}}^{(1,\tilde{p})}<c\cdot N_{\mathrm{cs}}^{(1)}\big/\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\\ N_{\mathrm{sc}}^{\mathrm{RB}} & \text{otherwise}\end{cases}$$

$$c=\begin{cases}3 & \text{normal cyclic prefix}\\ 2 & \text{extended cyclic prefix}\end{cases}$$

The resource indices within the two resource blocks in the two slots of a subframe to which the PUCCH is mapped are given by

$$n'_{\tilde{p}}(n_s)=\begin{cases}n_{\mathrm{PUCCH}}^{(1,\tilde{p})} & \text{if } n_{\mathrm{PUCCH}}^{(1,\tilde{p})}<c\cdot N_{\mathrm{cs}}^{(1)}\big/\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\\ \left(n_{\mathrm{PUCCH}}^{(1,\tilde{p})}-c\cdot N_{\mathrm{cs}}^{(1)}\big/\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\right)\bmod\left(c\cdot N_{\mathrm{sc}}^{\mathrm{RB}}\big/\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\right) & \text{otherwise}\end{cases}$$

for $n_s \bmod 2 = 0$ and by

$$n'_{\tilde{p}}(n_s)=\begin{cases}\left[c\left(n'_{\tilde{p}}(n_s-1)+1\right)\right]\bmod\left(cN_{\mathrm{sc}}^{\mathrm{RB}}\big/\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}+1\right)-1 & n_{\mathrm{PUCCH}}^{(1,\tilde{p})}\geq c\cdot N_{\mathrm{cs}}^{(1)}\big/\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\\ \left\lfloor h_{\tilde{p}}/c\right\rfloor+\left(h_{\tilde{p}}\bmod c\right)N'/\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}} & \text{otherwise}\end{cases}$$

for $n_s \bmod 2 = 1$, where $h_{\tilde{p}}=\left(n'_{\tilde{p}}(n_s-1)+d\right)\bmod\left(cN'/\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\right)$, with $d=2$ for normal CP and $d=0$ for extended CP.

The parameter *deltaPUCCH-Shift* $\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}$ is provided by higher layers.

Table 5.4.1-1: Modulation symbol $d(0)$ for PUCCH formats 1a and 1b

PUCCH format	$b(0),...,b(M_{\mathrm{bit}}-1)$	$d(0)$
1a	0	1
	1	-1
1b	00	1
	01	$-j$
	10	j
	11	-1

Table 5.4.1-1a: The quantity $N_{\mathrm{SF}}^{\mathrm{PUCCH}}$ for PUCCH formats 1a and 1b

PUCCH format	$N_{\mathrm{SF}}^{\mathrm{PUCCH}}$	
	first slot	second slot
normal 1/1a/1b	4	4
shortened 1/1a/1b	4	3

Table 5.4.1-2: Orthogonal sequences $\begin{bmatrix} w(0) & \cdots & w(N_{\mathrm{SF}}^{\mathrm{PUCCH}}-1) \end{bmatrix}$ for $N_{\mathrm{SF}}^{\mathrm{PUCCH}}=4$

Sequence index $n_{\mathrm{oc}}^{(\tilde{p})}(n_{\mathrm{s}})$	Orthogonal sequences $\begin{bmatrix} w(0) & \cdots & w(N_{\mathrm{SF}}^{\mathrm{PUCCH}}-1) \end{bmatrix}$
0	$\begin{bmatrix} +1 & +1 & +1 & +1 \end{bmatrix}$
1	$\begin{bmatrix} +1 & -1 & +1 & -1 \end{bmatrix}$
2	$\begin{bmatrix} +1 & -1 & -1 & +1 \end{bmatrix}$

Table 5.4.1-3: Orthogonal sequences $\begin{bmatrix} w(0) & \cdots & w(N_{\mathrm{SF}}^{\mathrm{PUCCH}}-1) \end{bmatrix}$ for $N_{\mathrm{SF}}^{\mathrm{PUCCH}}=3$

Sequence index $n_{\mathrm{oc}}^{(\tilde{p})}(n_{\mathrm{s}})$	Orthogonal sequences $\begin{bmatrix} w(0) & \cdots & w(N_{\mathrm{SF}}^{\mathrm{PUCCH}}-1) \end{bmatrix}$
0	$\begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$
1	$\begin{bmatrix} 1 & e^{j2\pi/3} & e^{j4\pi/3} \end{bmatrix}$
2	$\begin{bmatrix} 1 & e^{j4\pi/3} & e^{j2\pi/3} \end{bmatrix}$

5.4.2 PUCCH formats 2, 2a and 2b

The block of bits $b(0),...,b(19)$ shall be scrambled with a UE-specific scrambling sequence, resulting in a block of scrambled bits $\tilde{b}(0),...,\tilde{b}(19)$ according to

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

where the scrambling sequence $c(i)$ is given by clause 7.2. The scrambling sequence generator shall be initialised with $c_{\text{init}} = \left(\lfloor n_{\text{s}}/2 \rfloor + 1\right) \cdot \left(2N_{\text{ID}}^{\text{cell}} + 1\right) \cdot 2^{16} + n_{\text{RNTI}}$ at the start of each subframe where n_{RNTI} is C-RNTI.

The block of scrambled bits $\tilde{b}(0),...,\tilde{b}(19)$ shall be QPSK modulated as described in clause 7.1, resulting in a block of complex-valued modulation symbols $d(0),...,d(9)$.

Each complex-valued symbol $d(0),...,d(9)$ shall be multiplied with a cyclically shifted length $N_{\text{seq}}^{\text{PUCCH}} = 12$ sequence $r_{u,v}^{(\alpha_{\tilde{p}},\delta)}(n)$ for each of the P antenna ports used for PUCCH transmission according to

$$\begin{gathered} z^{(\tilde{p})}(N_{\text{seq}}^{\text{PUCCH}} \cdot n + i) = \frac{1}{\sqrt{P}} d(n) \cdot r_{u,v}^{(\alpha_{\tilde{p}},\delta)}(i) \\ n = 0,1,...,9 \\ i = 0,1,...,N_{\text{sc}}^{\text{RB}} - 1 \end{gathered}$$

where $r_{u,v}^{(\alpha_{\tilde{p}},\delta)}(i)$ is defined by clause 5.5.1 with $M_{\text{sc}}^{\text{RS}} = N_{\text{seq}}^{\text{PUCCH}}$ and $\delta = 0$.

Resources used for transmission of PUCCH formats 2/2a/2b are identified by a resource index $n_{\text{PUCCH}}^{(2,\tilde{p})}$ from which the cyclic shift $\alpha_{\tilde{p}}(n_{\text{s}},l)$ is determined according to

$$\alpha_{\tilde{p}}(n_{\text{s}},l) = 2\pi \cdot n_{\text{cs}}^{(\tilde{p})}(n_{\text{s}},l) / N_{\text{sc}}^{\text{RB}}$$

where

$$n_{\text{cs}}^{(\tilde{p})}(n_{\text{s}},l) = \left(n_{\text{cs}}^{\text{cell}}(n_{\text{s}},l) + n'_{\tilde{p}}(n_{\text{s}})\right) \bmod N_{\text{sc}}^{\text{RB}}$$

and

$$n'_{\tilde{p}}(n_{\text{s}}) = \begin{cases} n_{\text{PUCCH}}^{(2,\tilde{p})} \bmod N_{\text{sc}}^{\text{RB}} & \text{if } n_{\text{PUCCH}}^{(2,\tilde{p})} < N_{\text{sc}}^{\text{RB}} N_{\text{RB}}^{(2)} \\ \left(n_{\text{PUCCH}}^{(2,\tilde{p})} + N_{\text{cs}}^{(1)} + 1\right) \bmod N_{\text{sc}}^{\text{RB}} & \text{otherwise} \end{cases}$$

for $n_{\text{s}} \bmod 2 = 0$ and by

$$n'_{\tilde{p}}(n_{\text{s}}) = \begin{cases} \left[N_{\text{sc}}^{\text{RB}}\left(n'_{\tilde{p}}(n_{\text{s}} - 1) + 1\right)\right] \bmod \left(N_{\text{sc}}^{\text{RB}} + 1\right) - 1 & \text{if } n_{\text{PUCCH}}^{(2,\tilde{p})} < N_{\text{sc}}^{\text{RB}} N_{\text{RB}}^{(2)} \\ \left(N_{\text{sc}}^{\text{RB}} - 2 - n_{\text{PUCCH}}^{(2,\tilde{p})}\right) \bmod N_{\text{sc}}^{\text{RB}} & \text{otherwise} \end{cases}$$

for $n_{\text{s}} \bmod 2 = 1$.

For PUCCH formats 2a and 2b, supported for normal cyclic prefix only, the bit(s) $b(20),...,b(M_{\text{bit}} - 1)$ shall be modulated as described in Table 5.4.2-1 resulting in a single modulation symbol $d(10)$ used in the generation of the reference-signal for PUCCH format 2a and 2b as described in clause 5.5.2.2.1.

Table 5.4.2-1: Modulation symbol $d(10)$ for PUCCH formats 2a and 2b

PUCCH format	$b(20),...,b(M_{\text{bit}}-1)$	$d(10)$
2a	0	1
	1	-1
2b	00	1
	01	$-j$
	10	j
	11	-1

5.4.2A PUCCH format 3

The block of bits $b(0),...,b(M_{\text{bit}}-1)$ shall be scrambled with a UE-specific scrambling sequence, 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 7.2. The scrambling sequence generator shall be initialised with $c_{\text{init}} = \left(\lfloor n_{\text{s}}/2 \rfloor + 1\right) \cdot \left(2N_{\text{ID}}^{\text{cell}} + 1\right) \cdot 2^{16} + n_{\text{RNTI}}$ at the start of each subframe where n_{RNTI} is the C-RNTI.

The block of scrambled bits $\tilde{b}(0),...,\tilde{b}(M_{\text{bit}}-1)$ shall be QPSK modulated as described in Subclause 7.1, resulting in a block of complex-valued modulation symbols $d(0),...,d(M_{\text{symb}}-1)$ where $M_{\text{symb}} = M_{\text{bit}}/2 = 2N_{\text{sc}}^{\text{RB}}$.

The complex-valued symbols $d(0),...,d(M_{\text{symb}}-1)$ shall be block-wise spread with the orthogonal sequences $w_{n_{oc,0}^{(\tilde{p})}}(i)$ and $w_{n_{oc,1}^{(\tilde{p})}}(i)$ resulting in $N_{\text{SF},0}^{\text{PUCCH}} + N_{\text{SF},1}^{\text{PUCCH}}$ sets of $N_{\text{sc}}^{\text{RB}}$ values each according to

$$y_n^{(\tilde{p})}(i) = \begin{cases} w_{n_{oc,0}^{(\tilde{p})}}(\overline{n}) \cdot e^{j\pi \left\lfloor n_{\text{cs}}^{\text{cell}}(n_{\text{s}},l)/64 \right\rfloor /2} \cdot d(i) & n < N_{\text{SF},0}^{\text{PUCCH}} \\ w_{n_{oc,1}^{(\tilde{p})}}(\overline{n}) \cdot e^{j\pi \left\lfloor n_{\text{cs}}^{\text{cell}}(n_{\text{s}},l)/64 \right\rfloor /2} \cdot d(N_{\text{sc}}^{\text{RB}} + i) & \text{otherwise} \end{cases}$$
$$\overline{n} = n \bmod N_{\text{SF},0}^{\text{PUCCH}}$$
$$n = 0,..., N_{\text{SF},0}^{\text{PUCCH}} + N_{\text{SF},1}^{\text{PUCCH}} - 1$$
$$i = 0,1,..., N_{\text{sc}}^{\text{RB}} - 1$$

where $N_{\text{SF},0}^{\text{PUCCH}} = N_{\text{SF},1}^{\text{PUCCH}} = 5$ for both slots in a subframe using normal PUCCH format 3 and $N_{\text{SF},0}^{\text{PUCCH}} = 5$, $N_{\text{SF},1}^{\text{PUCCH}} = 4$ holds for the first and second slot, respectively, in a subframe using shortened PUCCH format 3. The orthogonal sequences $w_{n_{oc,0}^{(\tilde{p})}}(i)$ and $w_{n_{oc,1}^{(\tilde{p})}}(i)$ are given by Table 5.4.2A-1. Resources used for transmission of PUCCH format 3 are identified by a resource index $n_{\text{PUCCH}}^{(3,\tilde{p})}$ from which the quantities $n_{\text{oc},0}^{(\tilde{p})}$ and $n_{\text{oc},1}^{(\tilde{p})}$ are derived according to

$$n_{\text{oc},0}^{(\tilde{p})} = n_{\text{PUCCH}}^{(3,\tilde{p})} \bmod N_{\text{SF},1}^{\text{PUCCH}}$$
$$n_{\text{oc},1}^{(\tilde{p})} = \begin{cases} \left(3n_{\text{oc},0}^{(\tilde{p})}\right) \bmod N_{\text{SF},1}^{\text{PUCCH}} & \text{if } N_{\text{SF},1}^{\text{PUCCH}} = 5 \\ n_{\text{oc},0}^{(\tilde{p})} \bmod N_{\text{SF},1}^{\text{PUCCH}} & \text{otherwise} \end{cases}$$

Each set of complex-valued symbols shall be cyclically shifted according to

$$\tilde{y}_n^{(\tilde{p})}(i) = y_n^{(\tilde{p})}\left(\left(i + n_{\text{cs}}^{\text{cell}}(n_{\text{s}},l)\right) \bmod N_{\text{sc}}^{\text{RB}}\right)$$

where $n_{\text{cs}}^{\text{cell}}(n_{\text{s}},l)$ is given by Subclause 5.4, n_{s} is the slot number within a radio frame and l is the SC-FDMA symbol number within a slot.

The shifted sets of complex-valued symbols shall be transform precoded according to

$$z^{(\tilde{p})}(n \cdot N_{\mathrm{sc}}^{\mathrm{RB}} + k) = \frac{1}{\sqrt{P}} \frac{1}{\sqrt{N_{\mathrm{sc}}^{\mathrm{RB}}}} \sum_{i=0}^{N_{\mathrm{sc}}^{\mathrm{RB}}-1} \tilde{y}_n^{(\tilde{p})}(i) e^{-j\frac{2\pi i k}{N_{\mathrm{sc}}^{\mathrm{RB}}}}$$

$$k = 0,\ldots,N_{\mathrm{sc}}^{\mathrm{RB}} - 1$$

$$n = 0,\ldots,N_{\mathrm{SF},0}^{\mathrm{PUCCH}} + N_{\mathrm{SF},1}^{\mathrm{PUCCH}} - 1$$

where P is the number of antenna ports used for PUCCH transmission, resulting in a block of complex-valued symbols $z^{(\tilde{p})}(0),\ldots,z^{(\tilde{p})}\left(\left(N_{\mathrm{SF},0}^{\mathrm{PUCCH}} + N_{\mathrm{SF},1}^{\mathrm{PUCCH}}\right)N_{\mathrm{sc}}^{\mathrm{RB}} - 1\right)$.

Table 5.4.2A-1: The orthogonal sequence $w_{n_{\mathrm{oc}}}(i)$

Sequence index n_{oc}	**Orthogonal sequence** $\left[w_{n_{\mathrm{oc}}}(0) \quad \cdots \quad w_{n_{\mathrm{oc}}}(N_{\mathrm{SF}}^{\mathrm{PUCCH}}-1)\right]$	
	$N_{\mathrm{SF}}^{\mathrm{PUCCH}} = 5$	$N_{\mathrm{SF}}^{\mathrm{PUCCH}} = 4$
0	$\left[1 \quad 1 \quad 1 \quad 1 \quad 1\right]$	$\left[+1 \quad +1 \quad +1 \quad +1\right]$
1	$\left[1 \quad e^{j2\pi/5} \quad e^{j4\pi/5} \quad e^{j6\pi/5} \quad e^{j8\pi/5}\right]$	$\left[+1 \quad -1 \quad +1 \quad -1\right]$
2	$\left[1 \quad e^{j4\pi/5} \quad e^{j8\pi/5} \quad e^{j2\pi/5} \quad e^{j6\pi/5}\right]$	$\left[+1 \quad +1 \quad -1 \quad -1\right]$
3	$\left[1 \quad e^{j6\pi/5} \quad e^{j2\pi/5} \quad e^{j8\pi/5} \quad e^{j4\pi/5}\right]$	$\left[+1 \quad -1 \quad -1 \quad +1\right]$
4	$\left[1 \quad e^{j8\pi/5} \quad e^{j6\pi/5} \quad e^{j4\pi/5} \quad e^{j2\pi/5}\right]$	-

5.4.2B PUCCH format 4

The block of bits $b(0),...,b(M_{\mathrm{bit}}-1)$ shall be scrambled with a UE-specific scrambling sequence, 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 7.2. The scrambling sequence generator shall be initialised with $c_{\mathrm{init}}=\left(\lfloor n_{\mathrm{s}}/2\rfloor+1\right)\cdot\left(2N_{\mathrm{ID}}^{\mathrm{cell}}+1\right)\cdot 2^{16}+n_{\mathrm{RNTI}}$ at the start of each subframe where n_{RNTI} is the C-RNTI.

The block of scrambled bits $\tilde{b}(0),...,\tilde{b}(M_{\mathrm{bit}}-1)$ shall be QPSK modulated as described in Subclause 7.1, resulting in a block of complex-valued modulation symbols $d(0),...,d(M_{\mathrm{symb}}-1)$ where $M_{\mathrm{symb}}=M_{\mathrm{bit}}/2$.

The block of complex-valued symbols $d(0),...,d(M_{\mathrm{symb}}-1)$ is divided into $N_0^{\mathrm{PUCCH}}+N_1^{\mathrm{PUCCH}}$ sets, each corresponding to one SC-FDMA symbol. Transform precoding shall be applied according to

$$\begin{aligned}
z^{(\tilde{p})}(l\cdot M_{\mathrm{sc}}^{\mathrm{PUCCH4}}+k)&=\frac{1}{\sqrt{M_{\mathrm{sc}}^{\mathrm{PUCCH4}}}}\sum_{i=0}^{M_{\mathrm{sc}}^{\mathrm{PUCCH4}}-1}d(l\cdot M_{\mathrm{sc}}^{\mathrm{PUCCH4}}+i)e^{-j\frac{2\pi ik}{M_{\mathrm{sc}}^{\mathrm{PUCCH4}}}}\\
k&=0,...,M_{\mathrm{sc}}^{\mathrm{PUCCH4}}-1\\
l&=0,...,N_0^{\mathrm{PUCCH}}+N_1^{\mathrm{PUCCH}}-1
\end{aligned}$$

where $\tilde{p}=0$, N_0^{PUCCH} and N_1^{PUCCH} are given by Table 5.4.2C-1 for normal PUCCH format 4 and shortened PUCCH format 4, resulting in a block of complex-valued symbols $z^{(\tilde{p})}(0),...,z^{(\tilde{p})}(M_{\mathrm{symb}}-1)$. The variable $M_{\mathrm{sc}}^{\mathrm{PUCCH4}}=M_{\mathrm{RB}}^{\mathrm{PUCCH4}}\cdot N_{\mathrm{sc}}^{\mathrm{RB}}$, where $M_{\mathrm{RB}}^{\mathrm{PUCCH4}}$ represents the bandwidth of the PUCCH format 4 in terms of resource blocks, shall fulfil

$$M_{\mathrm{RB}}^{\mathrm{PUCCH4}}=2^{\alpha_2}\cdot 3^{\alpha_3}\cdot 5^{\alpha_5}\le N_{\mathrm{RB}}^{\mathrm{UL}}$$

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

5.4.2C PUCCH format 5

The block of bits $b(0),...,b(M_{\mathrm{bit}}-1)$ shall be scrambled with a UE-specific scrambling sequence, 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 7.2. The scrambling sequence generator shall be initialised with $c_{\mathrm{init}}=\left(\lfloor n_{\mathrm{s}}/2\rfloor+1\right)\cdot\left(2N_{\mathrm{ID}}^{\mathrm{cell}}+1\right)\cdot 2^{16}+n_{\mathrm{RNTI}}$ at the start of each subframe where n_{RNTI} is the C-RNTI.

The block of scrambled bits $\tilde{b}(0),...,\tilde{b}(M_{\mathrm{bit}}-1)$ shall be QPSK modulated as described in Subclause 7.1, resulting in a block of complex-valued modulation symbols $d(0),...,d(M_{\mathrm{symb}}-1)$ where $M_{\mathrm{symb}}=M_{\mathrm{bit}}/2$.

The complex-valued symbols $d(0),...,d(M_{\mathrm{symb}}-1)$ shall be divided into $N_0^{\mathrm{PUCCH}}+N_1^{\mathrm{PUCCH}}$ sets, each corresponding to one SC-FDMA symbol. Block-wise spreading shall be applied according to

$$\begin{aligned}
y_n(i)&=w_{n_{\mathrm{oc}}}(i)\cdot d\left(i\bmod N_{\mathrm{sc}}^{\mathrm{RB}}/N_{\mathrm{SF}}^{\mathrm{PUCCH}}+n\cdot N_{\mathrm{sc}}^{\mathrm{RB}}/N_{\mathrm{SF}}^{\mathrm{PUCCH}}\right)\\
n&=0,...,N_0^{\mathrm{PUCCH}}+N_1^{\mathrm{PUCCH}}-1\\
i&=0,1,...,N_{\mathrm{sc}}^{\mathrm{RB}}-1
\end{aligned}$$

where $N_{\mathrm{SF}}^{\mathrm{PUCCH}}=2$, N_0^{PUCCH} and N_1^{PUCCH} are given by Table 5.4.2C-1 for normal PUCCH format 5 and shortened PUCCH format 5, and $w_{n_{\mathrm{oc}}}(i)$ is given by Table 5.4.2C-2 with n_{oc} provided by higher layers.

The block-wise spread complex-valued symbols shall be transform precoded according to

$$z^{(\tilde{p})}(n\cdot N_{\mathrm{sc}}^{\mathrm{RB}}+k)=\frac{1}{\sqrt{N_{\mathrm{sc}}^{\mathrm{RB}}}}\sum_{i=0}^{N_{\mathrm{sc}}^{\mathrm{RB}}-1}y_n(i)e^{-j\frac{2\pi ik}{N_{\mathrm{sc}}^{\mathrm{RB}}}}$$
$$k=0,...,N_{\mathrm{sc}}^{\mathrm{RB}}-1$$
$$n=0,...,N_0^{\mathrm{PUCCH}}+N_1^{\mathrm{PUCCH}}-1$$

where $\tilde{p}=0$, resulting in a block of complex-valued symbols $z^{(\tilde{p})}(0),...,z^{(\tilde{p})}\left(\left(N_0^{\mathrm{PUCCH}}+N_1^{\mathrm{PUCCH}}\right)N_{\mathrm{sc}}^{\mathrm{RB}}-1\right)$.

Table 5.4.2C-1: The quantities N_0^{PUCCH} and N_1^{PUCCH}

PUCCH format type	Normal cyclic prefix		Extended cyclic prefix	
	N_0^{PUCCH}	N_1^{PUCCH}	N_0^{PUCCH}	N_1^{PUCCH}
Normal PUCCH format	6	6	5	5
Shortened PUCCH format	6	5	5	4

Table 5.4.2C-2: Orthogonal sequences $w_{n_{\mathrm{oc}}}(i)$

n_{oc}	Orthogonal sequences $\left[w_{n_{CDM}}(0)\ \cdots\ w_{n_{CDM}}\left(N_{sc}^{RB}-1\right)\right]$
0	$[+1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1]$
1	$[+1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ -1\ \ -1\ \ -1\ \ -1\ \ -1\ \ -1]$

5.4.3 Mapping to physical resources

The block of complex-valued symbols $z^{(\tilde{p})}(i)$ shall be multiplied with the amplitude scaling factor β_{PUCCH} in order to conform to the transmit power P_{PUCCH} specified in Subclause 5.1.2.1 in 3GPP TS 36.213 [4], and mapped in sequence starting with $z^{(\tilde{p})}(0)$ to resource elements. PUCCH uses one or more resource block in each of the two slots in a subframe. Within the physical resource block(s) used for transmission, the mapping of $z^{(\tilde{p})}(i)$ to resource elements (k,l) on antenna port p and not used for transmission of reference signals shall be in increasing order of first k, then l and finally the slot number, starting with the first slot in the subframe. The relation between the index $\tilde{p}$ and the antenna port number p is given by Table 5.2.1-1.

For non-BL/CE UEs, except for PUCCH format 4, the physical resource blocks to be used for transmission of PUCCH in slot n_{s} are given by

$$n_{\mathrm{PRB}}=\begin{cases}\left\lfloor \frac{m}{2}\right\rfloor & \text{if } (m+n_{\mathrm{s}} \bmod 2)\bmod 2=0\\ N_{\mathrm{RB}}^{\mathrm{UL}}-1-\left\lfloor \frac{m}{2}\right\rfloor & \text{if } (m+n_{\mathrm{s}} \bmod 2)\bmod 2=1\end{cases}$$

For BL/CE UEs, PUCCH is transmitted with $N_{\mathrm{rep}}^{\mathrm{PUCCH}}\geq 1$ repetitions. The PUCCH transmission spans $N_{\mathrm{abs}}^{\mathrm{PUCCH}}\geq N_{\mathrm{rep}}^{\mathrm{PUCCH}}$ consecutive subframes, including non-BL/CE UL subframes where the UE postpones the PUCCH transmission if $N_{\mathrm{rep}}^{\mathrm{PUCCH}}>1$. The quantity $N_{\mathrm{rep}}^{\mathrm{PUCCH}}$ is given

- by the higher layer parameter *pucch-NumRepetitionCE-Format1* for PUCCH format 1/1a and *pucch-NumRepetitionCE-Format2* for PUCCH format 2/2a/2b, if configured. Otherwise

- by the higher-layer parameter *pucch-NumRepetitionCE-Msg4-Level0-r13, pucch-NumRepetitionCE-Msg4-Level1-r13, pucch-NumRepetitionCE-Msg4-Level2-r13* or *pucch-NumRepetitionCE-Msg4-Level3-r13*.

The physical resource blocks to be used for transmission of PUCCH in subframe i within the $N_{\text{abs}}^{\text{PUCCH}}$ consecutive subframes are given by

$$n_{\text{PRB}}(i) = \begin{cases} m'(j)/2 & \text{if } m'(j) \bmod 2 = 0 \\ N_{\text{RB}}^{\text{UL}} - 1 - \lfloor m'(j)/2 \rfloor & \text{if } m'(j) \bmod 2 = 1 \end{cases}$$

$$m'(j) = \begin{cases} m & \text{if } j \bmod 2 = 0 \\ m+1 & \text{if } j \bmod 2 = 1 \text{ and } m \bmod 2 = 0 \\ m-1 & \text{if } j \bmod 2 = 1 \text{ and } m \bmod 2 = 1 \end{cases}$$

$$j = \left\lfloor \frac{i}{N_{\text{NB}}^{\text{ch,UL}}} \right\rfloor$$

$$i_0 \le i \le i_0 + N_{\text{abs}}^{\text{PUCCH}} - 1$$

where i_0 is the absolute subframe number of the first uplink subframe intended for PUCCH.

The variable m depends on the PUCCH format.

- Formats 1, 1a and 1b:

$$m = \begin{cases} N_{\text{RB}}^{(2)} & \text{if } n_{\text{PUCCH}}^{(1,\tilde{p})} < c \cdot N_{\text{cs}}^{(1)} / \Delta_{\text{shift}}^{\text{PUCCH}} \\ \left\lfloor \dfrac{n_{\text{PUCCH}}^{(1,\tilde{p})} - c \cdot N_{\text{cs}}^{(1)} / \Delta_{\text{shift}}^{\text{PUCCH}}}{c \cdot N_{\text{sc}}^{\text{RB}} / \Delta_{\text{shift}}^{\text{PUCCH}}} \right\rfloor + N_{\text{RB}}^{(2)} + \left\lceil \dfrac{N_{\text{cs}}^{(1)}}{8} \right\rceil & \text{otherwise} \end{cases}$$

$$c = \begin{cases} 3 & \text{normal cyclic prefix} \\ 2 & \text{extended cyclic prefix} \end{cases}$$

- Formats 2, 2a and 2b:

$$m = \left\lfloor n_{\text{PUCCH}}^{(2,\tilde{p})} / N_{\text{sc}}^{\text{RB}} \right\rfloor$$

- Format 3:

$$m = \left\lfloor n_{\text{PUCCH}}^{(3,\tilde{p})} / N_{\text{SF,0}}^{\text{PUCCH}} \right\rfloor$$

- Format 5 (non-BL/CE UEs only):

$$m = n_{\text{PUCCH}}^{(5)}$$

For non-BL/CE UEs, for PUCCH format 4, the physical resource blocks to be used for transmission of PUCCH in slot n_{s} are given by

$$n_{\text{PRB}} = \begin{cases} m & \text{if } n_{\text{s}} \bmod 2 = 0 \\ N_{\text{RB}}^{\text{UL}} - 1 - m & \text{if } n_{\text{s}} \bmod 2 = 1 \end{cases}$$

$$m = n_{\text{PUCCH}}^{(4)}, n_{\text{PUCCH}}^{(4)} + 1, \ldots, n_{\text{PUCCH}}^{(4)} + M_{\text{RB}}^{\text{PUCCH4}} - 1$$

where $M_{\text{RB}}^{\text{PUCCH4}}$ is obtained from [4].

Mapping of modulation symbols for the physical uplink control channel for PUCCH formats 1 – 3 is illustrated in Figure 5.4.3-1.

In case of simultaneous transmission of sounding reference signal and PUCCH format 1, 1a, 1b, 3, 4 or 5 when there is one serving cell configured, the shortened PUCCH format shall be used where the last SC-FDMA symbol in the second slot of a subframe shall be left empty.

In case of guard period for narrowband or wideband retuning for BL/CE UEs, if an SC-FDMA symbol is left empty due to guard period, the SC-FDMA symbol shall be counted in the PUCCH mapping but not used for transmission of the PUCCH. The SC-FDMA symbol affected by the guard period can be the first SC-FDMA symbol in the first slot of a subframe and/or the last SC-FDMA symbol in the second slot of a subframe.

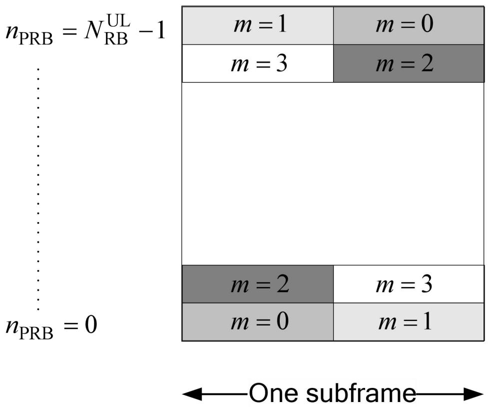

Figure 5.4.3-1: Mapping to physical resource blocks for PUCCH formats 1 – 3 for non-BL/CE UEs.

5.4A Short Physical Uplink Control Channel

5.4A.1 General

The short physical uplink control channel, SPUCCH, carries uplink control information. Simultaneous transmission of SPUCCH and PUSCH from the same UE where both SPUCCH and PUSCH is using either slot or subslot transmission is supported if enabled by higher layers (see *simultaneousPUCCH-PUSCH* in 3GPP TS 36.331 [9]). For frame structure type 2 and in UpPTS, transmission of SPUCCH is not supported.

SPUCCH supports multiple formats as shown in Table 5.4A-1 and Table 5.4A-2 with different number of bits carried by each SPUCCH.

Table 5.4A-1: SPUCCH formats for slot transmission

SPUCCH format	Modulation scheme	Number of bits per slot, M_{bit}
1	N/A	N/A
1a	BPSK	1
1b	QPSK	2
3	QPSK	24
4	QPSK	$M_{\text{RB}}^{\text{SPUCCH4}} \cdot N_{\text{sc}}^{\text{RB}} \cdot N_{\text{slot}}^{\text{SPUCCH}} \cdot 2$

Table 5.4A-2: SPUCCH formats for subslot transmission

SPUCCH format	Modulation scheme	Number of bits per subslot, M_{bit}
1	N/A	N/A
1a	N/A	1
1b	N/A	2
4	QPSK	$M_{\text{RB}}^{\text{SPUCCH4}} \cdot N_{\text{sc}}^{\text{RB}} \cdot N_{\text{subslot}}^{\text{SPUCCH}} \cdot 2$

The quantity $M_{\text{RB}}^{\text{SPUCCH4}}$ represents the bandwidth of the SPUCCH format 4 as defined by subclause 5.4A.4.1, and $N_{\text{slot}}^{\text{SPUCCH}}$ and $N_{\text{subslot}}^{\text{SPUCCH}}$ are defined in Table 5.4A.4.1-1 and Table 5.4A.4.2-1, respectively.

SPUCCH formats 1/1a/1b use a cyclic shift, $n_{\text{cs}}^{\text{cell}}(n_{\text{s}}, l)$, which varies with the symbol number l and the slot number n_{s} as described in subclause 5.4.

5.4A.2 SPUCCH formats 1,1a,1b

5.4A.2.1 Slot-SPUCCH

Slot-SPUCCH format 1, 1a, 1b can be configured by higher layers to either have frequency hopping enabled or disabled (see *n1SlotSPUCCH-FH-AN-List* and *n1SlotSPUCCH-NoFH-AN-List* in 3GPP TS 36.331 [9]).

In case slot-SPUCCH format 1, 1a, 1b and frequency hopping is enabled, the scrambled and block-wise spread complex-valued symbols $z^{(\tilde{p})}$ are generated as described in subclause 5.4.1 for PUCCH format 1/1a/1b where $S(n_s)=1$, $m'=0$ and $w(m)=+1$.

In case slot-SPUCCH format 1, 1a, 1b and frequency hopping is disabled, the scrambled and block-wise spread complex-valued symbols $z^{(\tilde{p})}$ are generated as described in subclause 5.4.1 for PUCCH format 1/1a/1b where $m'=0$.

Irrespective of frequency hopping being enabled or disabled, $N_{\text{SF}}^{\text{PUCCH}}$ is applied as described in subclause 5.4.1 for the slot in which the slot-SPUCCH is transmitted in, i.e. either in the first or the second slot of the subframe.

Resources used for transmission of slot-SPUCCH format 1, 1a and 1b are identified by a resource index $n_{\mathrm{SPUCCH}}^{(1,\tilde{p})}$ from which the cyclic shift $\alpha_{\tilde{p}}(n_{\mathrm{s}},l)$ is derived:

$$\alpha_{\tilde{p}}(n_{\mathrm{s}},l) = 2\pi \cdot n_{\mathrm{cs}}^{(\tilde{p})}(n_{\mathrm{s}},l) \big/ N_{\mathrm{sc}}^{\mathrm{RB}} ,$$

In case frequency hopping is enabled, the cyclic shift is determined as described in subclause 5.4.2, assuming the condition $n_{\mathrm{PUCCH}}^{(2,\tilde{p})} < N_{\mathrm{sc}}^{\mathrm{RB}} N_{\mathrm{RB}}^{(2)}$ is fulfilled.

In case frequency hopping is disabled, the resource index $n_{\mathrm{SPUCCH}}^{(1,\tilde{p})}$ also indicates the orthogonal sequence index $n_{\mathrm{oc}}^{(\tilde{p})}(n_{\mathrm{s}})$. Both the cyclic shift and the orthogonal sequence index is in this case determined as described in subclause 5.4.1.

5.4A.2.2 Subslot-SPUCCH

For subslot-SPUCCH formats 1a and 1b, one or two bits are communicated by SPUCCH resource selection. The resource set available for selection are configured by higher layers (see *n1SubslotSPUCCH-AN-List* and *sr-SubslotSPUCCH-ResourceList* in 3GPP TS 36.331 [9]). For subslot-SPUCCH format 1, information is carried by the presence/absence of transmission of subslot-SPUCCH from the UE.

The sequence $y^{(\tilde{p},\delta)}(n)$ is generated as described in subclause 5.4.1, assuming $d(0)=1$.

The block of complex-valued symbols $y^{(\tilde{p})}(0),...,y^{(\tilde{p})}(N_{\mathrm{seq}}^{\mathrm{PUCCH}}-1)$ shall be scrambled by $S(n_s)=1$ as described in subclause 5.4.1 assuming $w_{n_{\mathrm{oc}}^{(\tilde{p})}}(i)=1$, $m'=0$, and with $N_{\mathrm{SF}}^{\mathrm{PUCCH}}$ replaced by $N_{\mathrm{SF}}^{\mathrm{SPUCCH}}$, defined in Table 5.4A.2.2-1.

Table 5.4A.2.2-1: The quantity $N_{\mathrm{SF}}^{\mathrm{SPUCCH}}$ for subslot-SPUCCH formats 1a and 1b

SPUCCH format type	Subslot number in subframe	$N_{\mathrm{SF}}^{\mathrm{SPUCCH}}$
Normal SPUCCH format	1,2,3,4	2
Normal SPUCCH format	0,5	3
Shortened SPUCCH format	5	2

Resources used for transmission of SPUCCH format 1, 1a and 1b are identified by a resource index $n_{\mathrm{SPUCCH,i}}^{(1,\tilde{p})}$ from which the cyclic shift $\alpha_{\tilde{p}}(n_{\mathrm{s}},l)$ is determined, as described in subclause 5.4.2, assuming the condition $n_{\mathrm{PUCCH}}^{(2,\tilde{p})} < N_{\mathrm{sc}}^{\mathrm{RB}} N_{\mathrm{RB}}^{(2)}$ is fulfilled.The resource set for subslot-SPUCCH format 1/1a/1b is configured by higher layers (see *n1SubslotSPUCCH-AN-List* in 3GPP TS 36.331 [9]):

- subslot-SPUCCH format 1: $n_{\mathrm{SPUCCH,i}}^{(1,\tilde{p})}, i \in \{0\}$
- subslot-SPUCCH format 1a: $n_{\mathrm{SPUCCH,i}}^{(1,\tilde{p})}, i \in \{0,1\}$
- subslot-SPUCCH format 1b: $n_{\mathrm{SPUCCH,i}}^{(1,\tilde{p})}, i \in \{0,1,2,3\}$

Each resource indicates (a) bit state(s) as defined by Table 5.4A.2.2-2.

Table 5.4A.2.2-2: Subslot-SPUCCH resource for formats 1a and 1b

PUCCH format	$b(0),...,b(M_{\text{bit}}-1)$	$n_{\text{SPUCCH},i}^{(1,\tilde{p})}$
1	-	$n_{\text{SPUCCH},0}^{(1,\tilde{p})}$
1a	0	$n_{\text{SPUCCH},0}^{(1,\tilde{p})}$
	1	$n_{\text{SPUCCH},1}^{(1,\tilde{p})}$
1b	00	$n_{\text{SPUCCH},0}^{(1,\tilde{p})}$
	10	$n_{\text{SPUCCH},1}^{(1,\tilde{p})}$
	01	$n_{\text{SPUCCH},2}^{(1,\tilde{p})}$
	11	$n_{\text{SPUCCH},3}^{(1,\tilde{p})}$

5.4A.3 SPUCCH format 3

5.4A.3.1 Slot-SPUCCH

The complex-valued modulation symbols $d(0),...,d(M_{\text{symb}}-1)$ shall be generated as described in subclause 5.4.2A.

Depending on if the slot-SPUCCH is transmitted in the first or the second slot of the subframe, different block-wise spreading with the orthogonal sequences $w_{n_{oc,0}^{(\tilde{p})}}(i)$ or $w_{n_{oc,1}^{(\tilde{p})}}(i)$ is applied. Each spreading results in $N_{\text{SF}}^{\text{SPUCCH}}$ sets of $N_{\text{sc}}^{\text{RB}}$ values each according to:

$$y_n^{(\tilde{p})}(i) = \begin{cases} w_{n_{oc,0}^{(\tilde{p})}}(n) \cdot e^{j\pi \left\lfloor n_{\text{cs}}^{\text{cell}}(n_s,l)/64 \right\rfloor /2} \cdot d(i) & \text{if } n_s \bmod 2 = 0 \\ w_{n_{oc,1}^{(\tilde{p})}}(n) \cdot e^{j\pi \left\lfloor n_{\text{cs}}^{\text{cell}}(n_s,l)/64 \right\rfloor /2} \cdot d(i) & \text{otherwise} \end{cases}$$
$$n = 0,...,N_{\text{SF}}^{\text{SPUCCH}}-1$$
$$i = 0,1,...,N_{\text{sc}}^{\text{RB}}-1$$

where

- $N_{\text{SF}}^{\text{SPUCCH}} = N_{\text{SF},0}^{\text{PUCCH}}$ (see subclause 5.4.2A) if transmitted in the first slot, and $N_{\text{SF}}^{\text{SPUCCH}} = N_{\text{SF},1}^{\text{PUCCH}}$ (see subclause 5.4.2A), if transmitted in the second slot.
- The orthogonal sequences $w_{n_{oc,0}^{(\tilde{p})}}(i)$ and $w_{n_{oc,1}^{(\tilde{p})}}(i)$ are given by Table 5.4.2A-1

Resources used for transmission of SPUCCH format 3 are identified by a resource index $n_{\text{SPUCCH}}^{(3,\tilde{p})}$ from which the quantities $n_{\text{oc},0}^{(\tilde{p})}$ and $n_{\text{oc},1}^{(\tilde{p})}$ are derived according to subclause 5.4A.3 by replacing $n_{\text{PUCCH}}^{(3,\tilde{p})}$ with $n_{\text{SPUCCH}}^{(3,\tilde{p})}$.

Each set of complex-valued symbols shall be cyclically shifted and transform precoded according to subclause 5.4.2A with $N_{\text{SF},0}^{\text{PUCCH}} + N_{\text{SF},1}^{\text{PUCCH}}$ replaced by $N_{\text{SF}}^{\text{SPUCCH}}$ in the transform precoding.

5.4A.4 SPUCCH format 4

5.4A.4.1 Slot-SPUCCH

The block of bits $b(0),...,b(M_{\text{bit}}-1)$ shall be scrambled according to subclause 5.4.2B.

The block of scrambled bits $\tilde{b}(0),...,\tilde{b}(M_{\text{bit}}-1)$ shall be QPSK modulated as described in Subclause 7.1, resulting in a block of complex-valued modulation symbols $d(0),...,d(M_{\text{symb}}-1)$ where $M_{\text{symb}} = M_{\text{bit}}/2$.

The block of complex-valued symbols $d(0),...,d(M_{\text{symb}}-1)$ is divided into $N_{\text{slot}}^{\text{SPUCCH}}$ (defined in Table 5.4A.4.1-1) sets, each corresponding to one SC-FDMA symbol. Transform precoding shall be applied according to subclause 5.4.2B replacing $M_{\text{sc}}^{\text{PUCCH4}}$ with $M_{\text{sc}}^{\text{SPUCCH4}}$ and replacing $N_0^{\text{PUCCH}} + N_1^{\text{PUCCH}}$ with $N_{\text{slot}}^{\text{SPUCCH}}$.

The variable $M_{\text{sc}}^{\text{SPUCCH4}} = M_{\text{RB}}^{\text{SPUCCH4}} \cdot N_{\text{sc}}^{\text{RB}}$, where $M_{\text{RB}}^{\text{SPUCCH4}}$ represents the bandwidth of the SPUCCH format 4 in terms of resource blocks in the frequency domain, and is determined by higher layer signalling (*n4numberOfPRB-r15*, see 3GPP TS 36.213 [4, Table 10.1.1-2] and 3GPP TS 36.331 [9]), and shall fulfil

$$M_{\text{RB}}^{\text{SPUCCH4}} = 2^{\alpha_2} \cdot 3^{\alpha_3} \cdot 5^{\alpha_5} \le N_{\text{RB}}^{\text{UL}},$$

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

Table 5.4A.4.1-1: The quantity $N_{\text{slot}}^{\text{SPUCCH}}$.

SPUCCH format type	$N_{\text{slot}}^{\text{SPUCCH}}$
Normal SPUCCH format	5
Shortened SPUCCH format	4

5.4A.4.2 Subslot-SPUCCH

For subslot-SPUCCH the procedure of slot-SPUCCH in subclause 5.4A.4.1 is followed except that:

- the block of complex-valued symbols $d(0),...,d(M_{\text{symb}}-1)$ is divided into $N_{\text{subslot}}^{\text{SPUCCH}}$ (defined in Table 5.4A.4.2-1) sets, instead of $N_{\text{slot}}^{\text{SPUCCH}}$ sets, and,
- $N_{\text{slot}}^{\text{SPUCCH}}$ is replaced by $N_{\text{subslot}}^{\text{SPUCCH}}$, in the transform precoding.

Table 5.4A.4.2-1: The quantity $N_{\text{subslot}}^{\text{SPUCCH}}$.

SPUCCH format type	Subslot number in subframe	$N_{\text{subslot}}^{\text{SPUCCH}}$
Normal SPUCCH format	1,2,3,4	1
Normal SPUCCH format	0,5	2
Shortened SPUCCH format	5	1

5.4A.5 Mapping to physical resources

The block of complex-valued symbols $z^{(\tilde{p})}(i)$ shall be multiplied with the amplitude scaling factor β_{SPUCCH} in order to conform to the transmit power P_{SPUCCH} specified in Subclause 5.1.2.1 of 3GPP TS 36.213 [4], and mapped in sequence starting with $z^{(\tilde{p})}(0)$ to resource elements.

SPUCCH uses one or more resource block in the frequency domain and is mapped to either a slot or a subslot in the time domain. Within the physical resource block(s) used for transmission, the mapping of $z^{(\tilde{p})}(i)$ to resource elements (k,l) on antenna port p and not used for transmission of reference signals shall be in increasing order of first k, then l.

The starting symbol l for each subslot number is provided by Table 5.4A.4.5-1 for subslot-SPUCCH.

For slot-SPUCCH the starting symbol is $l = 0$ for the slot the SPUCCH is transmitted in.

Table 5.4A.5-1: Starting symbol for subslot-SPUCCH mapping

	Subslot number					
	0	**1**	**2**	**3**	**4**	**5**
Format 1/1a/1b	0	3	5	0	2	4
Format 4	1	4	6	1	3	5

The relation between the index $\tilde{p}$ and the antenna port number p is given by Table 5.2.1-1.

The physical resource blocks (n_{PRB}) within which the transmission of SPUCCH is carried out in slot n_{s} depends on the SPUCCH format and whether frequency hopping is enabled or not.

In case of slot-SPUCCH format 1, 1a, 1b and frequency hopping disabled, the PRB used is determined as described in subclause 5.4.3 for PUCCH format 1, 1a, 1b.

In case of slot-SPUCCH format 3, the PRB used is given by

$$n_{\text{PRB}} = \begin{cases} \left\lfloor \dfrac{m}{2} \right\rfloor & \text{if } (m + n_{\text{s}} \bmod 2) \bmod 2 = 0 \\ N_{\text{RB}}^{\text{UL}} - 1 - \left\lfloor \dfrac{m}{2} \right\rfloor & \text{if } (m + n_{\text{s}} \bmod 2) \bmod 2 = 1 \end{cases}$$

For the other SPUCCH formats, it is determined by Table 5.4A.5-2, Table 5.4A.5-3 and Table 5.4A.5-4.

Table 5.4A.5-2: n_{PRB} for slot-SPUCCH format 1, 1a, 1b with frequency hopping enabled

Slot number	Slot-SPUCCH format
	Format 1/1a/1b with frequency hopping enabled
$n_{\mathrm{s}} \bmod 2 = 0$	$\left\lfloor \frac{m}{2} \right\rfloor$ for $l = 0,1$ or 2 $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor$ for $l = 3,4,5$ or 6 for $(m + n_{\mathrm{s}} \bmod 2) \bmod 2 = 0$ $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor$ for $l = 0,1$ or 2 $\left\lfloor \frac{m}{2} \right\rfloor$ for $l = 3,4,5$ or 6 for $(m + n_{\mathrm{s}} \bmod 2) \bmod 2 = 1$
$n_{\mathrm{s}} \bmod 2 = 1$	$\left\lfloor \frac{m}{2} \right\rfloor$ for $l = 0,1,2$ or 3 $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor$ for $l = 4,5$ or 6 for $(m + n_{\mathrm{s}} \bmod 2) \bmod 2 = 0$ $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor$ for $l = 0,1,2$ or 3 $\left\lfloor \frac{m}{2} \right\rfloor$ for $l = 4,5$ or 6 for $(m + n_{\mathrm{s}} \bmod 2) \bmod 2 = 1$

Table 5.4A.5-3: n_{PRB} for slot-SPUCCH format 4

Slot number	Slot-SPUCCH format
	Format 4
$n_{\mathrm{s}} \bmod 2 = 0$	m for $l = 0,1$ or 2 $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - m$ for $l = 3,4,5$ or 6
$n_{\mathrm{s}} \bmod 2 = 1$	m for $l = 4,5$ or 6 $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - m$ for $l = 0,1,2$ or 3

Table 5.4A.5-4: n_{PRB} for subslot-SPUCCH format 1, 1a, 1b, 4

Subslot number	SPUCCH format	
	Format 1/1a/1b	Format 4
0	$\left\lfloor \frac{m}{2} \right\rfloor$ for $l = 0$ $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor$ for $l = 1,2$ for $(m + n_{\mathrm{s}} \bmod 2) \bmod 2 = 0$ $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor$ for $l = 0$ $\left\lfloor \frac{m}{2} \right\rfloor$ for $l = 1,2$ for $(m + n_{\mathrm{s}} \bmod 2) \bmod 2 = 1$	m for $l = 1,2$
1	$\left\lfloor \frac{m}{2} \right\rfloor$ for $l = 4$ $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor$ for $l = 3$ for $(m + n_{\mathrm{s}} \bmod 2) \bmod 2 = 0$ $N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \frac{m}{2} \right\rfloor$ for $l = 4$ $\left\lfloor \frac{m}{2} \right\rfloor$ for $l = 3$ for $(m + n_{\mathrm{s}} \bmod 2) \bmod 2 = 1$	m for $l = 4$

2	$\begin{cases} \left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=5 \\ N_{\text{RB}}^{\text{UL}}-1-\left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=6 \end{cases}$ for $(m+n_{\text{s}} \bmod 2) \bmod 2 = 0$ $\begin{cases} N_{\text{RB}}^{\text{UL}}-1-\left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=5 \\ \left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=6 \end{cases}$ for $(m+n_{\text{s}} \bmod 2) \bmod 2 = 1$	m for $l=6$
3	$\begin{cases} \left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=1 \\ N_{\text{RB}}^{\text{UL}}-1-\left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=0 \end{cases}$ for $(m+n_{\text{s}} \bmod 2) \bmod 2 = 0$ $\begin{cases} N_{\text{RB}}^{\text{UL}}-1-\left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=1 \\ \left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=0 \end{cases}$ for $(m+n_{\text{s}} \bmod 2) \bmod 2 = 1$	m for $l=1$
4	$\begin{cases} \left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=2 \\ N_{\text{RB}}^{\text{UL}}-1-\left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=3 \end{cases}$ for $(m+n_{\text{s}} \bmod 2) \bmod 2 = 0$ $\begin{cases} N_{\text{RB}}^{\text{UL}}-1-\left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=2 \\ \left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=3 \end{cases}$ for $(m+n_{\text{s}} \bmod 2) \bmod 2 = 1$	m for $l=3$
5	$\begin{cases} \left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=5,6 \\ N_{\text{RB}}^{\text{UL}}-1-\left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=4 \end{cases}$ for $(m+n_{\text{s}} \bmod 2) \bmod 2 = 0$ $\begin{cases} N_{\text{RB}}^{\text{UL}}-1-\left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=5,6 \\ \left\lfloor \frac{m}{2} \right\rfloor & \text{for } l=4 \end{cases}$ for $(m+n_{\text{s}} \bmod 2) \bmod 2 = 1$	m for $l=5,6$

The variable m depends on the SPUCCH format as defined in Table 5.4A.5-5.

Table 5.4A.5-5: m for SPUCCH

SPUCCH Format		m
Slot	Format 1, 1a, 1b	Frequency hopping disabled: see derivation of m for PUCCH format 1, 1a, 1b in subclause 5.4.3 replacing $n_{\mathrm{PUCCH}}^{(1,\tilde{p})}$ with $n_{\mathrm{SPUCCH}}^{(1,\tilde{p})}$ Frequency hopping enabled: see derivation of m for PUCCH format 2, 2a, 2b in subclause 5.4.3 replacing $n_{\mathrm{PUCCH}}^{(2,\tilde{p})}$ with $n_{\mathrm{SPUCCH}}^{(1,\tilde{p})}$
	Format 3	$\left\lfloor n_{\mathrm{SPUCCH}}^{(3,\tilde{p})} \big/ N_{\mathrm{SF,0}}^{\mathrm{PUCCH}} \right\rfloor$
	Format 4	$m = n_{\mathrm{SPUCCH}}^{(4)}, n_{\mathrm{SPUCCH}}^{(4)} + 1, \ldots, n_{\mathrm{SPUCCH}}^{(4)} + M_{\mathrm{RB}}^{\mathrm{SPUCCH4}} - 1$
Subslot	Format 1, 1a, 1b	see derivation of m for PUCCH format 2, 2a, 2b in subclause 5.4.3 replacing $n_{\mathrm{PUCCH}}^{(2,\tilde{p})}$ with $n_{\mathrm{SPUCCH,i}}^{(1,\tilde{p})}$
	Format 4	$m = n_{\mathrm{SPUCCH}}^{(4)}, n_{\mathrm{SPUCCH}}^{(4)} + 1, \ldots, n_{\mathrm{SPUCCH}}^{(4)} + M_{\mathrm{RB}}^{\mathrm{SPUCCH4}} - 1$

In case of subslot-SPUCCH, there is a configuration restriction that each SPUCCH resource in the resource set, of up to four resources, $n_{\mathrm{SPUCCH,i}}^{(1,\tilde{p})}, i \in \{0,1,2,3\}$, shall map to the same pair of PRBs (n_{PRB}) This restriction applies separately to each of *n1SubslotSPUCCH-AN-List* and *sr-SubslotSPUCCH-Resource* in 3GPP TS 36.331 [9].

In case of simultaneous transmission of sounding reference signal and SPUCCH when there is one serving cell configured, the shortened SPUCCH format shall be used where the last SC-FDMA symbol in the second slot of a subframe shall be left empty.

5.5 Reference signals

Two types of uplink reference signals are supported:

- Demodulation reference signal, associated with transmission of PUSCH or (S)PUCCH
- Sounding reference signal, not associated with transmission of PUSCH or (S)PUCCH

The same set of base sequences is used for demodulation and sounding reference signals.

5.5.1 Generation of the reference signal sequence

Reference signal 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

$$r_{u,v}^{(\alpha,\delta)}(n) = e^{j\alpha\left(n + \delta\frac{\varpi \bmod 2}{2}\right)} \bar{r}_{u,v}(n), \quad 0 \le n < M_{\mathrm{sc}}^{\mathrm{RS}}$$

where

- $M_{\mathrm{sc}}^{\mathrm{RS}} = m N_{\mathrm{sc}}^{\mathrm{RB}} \big/ 2^{\delta}$ is the length of the reference signal sequence, $1 \le m \le N_{\mathrm{RB}}^{\mathrm{max,UL}}$, ϖ is defined in subclause 5.5.2.1.2, and,
- $\delta = 1$ when either
  - the higher-layer parameter *ul-DMRS-IFDMA* is set and the most recent uplink-related DCI contains the *Cyclic Shift Field mapping table for DMRS bit* field which indicates the use of Table 5.5.2.1.1-3, or,
  - the *Cyclic Shift Field mapping table for DMRS bit* is set in the most recent uplink-related DCI format 7 which indicates the use of Table 5.5.2.1.1-4, and
- $\delta = 0$ otherwise.

Multiple reference signal sequences are defined from a single base sequence through different values of α .

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 $M_{\mathrm{sc}}^{\mathrm{RS}} = mN_{\mathrm{sc}}^{\mathrm{RB}}$, $1 \le m \le 5$ and two base sequences ($v = 0,1$) of each length $M_{\mathrm{sc}}^{\mathrm{RS}} = mN_{\mathrm{sc}}^{\mathrm{RB}}$, $6 \le m \le N_{\mathrm{RB}}^{\mathrm{max,UL}}$. The sequence group number u and the number v within the group may vary in time as described in clauses 5.5.1.3 and 5.5.1.4, respectively. The definition of the base sequence $\bar{r}_{u,v}(0),...,\bar{r}_{u,v}(M_{\mathrm{sc}}^{\mathrm{RS}}-1)$ depends on the sequence length $M_{\mathrm{sc}}^{\mathrm{RS}}$.

5.5.1.1 Base sequences of length $3N_{\mathrm{sc}}^{\mathrm{RB}}$ or larger

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

$$\bar{r}_{u,v}(n) = x_q(n \bmod N_{\mathrm{ZC}}^{\mathrm{RS}}), \quad 0 \le n < M_{\mathrm{sc}}^{\mathrm{RS}}$$

where the q^{th} root Zadoff-Chu sequence is defined by

$$x_q(m) = e^{-j\frac{\pi q m(m+1)}{N_{\mathrm{ZC}}^{\mathrm{RS}}}}, \quad 0 \le m \le N_{\mathrm{ZC}}^{\mathrm{RS}} - 1$$

with q given by

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

The length $N_{\mathrm{ZC}}^{\mathrm{RS}}$ of the Zadoff-Chu sequence is given by the largest prime number such that $N_{\mathrm{ZC}}^{\mathrm{RS}} < M_{\mathrm{sc}}^{\mathrm{RS}}$.

5.5.1.2 Base sequences of length less than $3N_{\mathrm{sc}}^{\mathrm{RB}}$

For $M_{\mathrm{sc}}^{\mathrm{RS}} = N_{\mathrm{sc}}^{\mathrm{RB}}$, $M_{\mathrm{sc}}^{\mathrm{RS}} = 2N_{\mathrm{sc}}^{\mathrm{RB}}$, $M_{\mathrm{sc}}^{\mathrm{RS}} = N_{\mathrm{sc}}^{\mathrm{RB}}/2$, and $M_{\mathrm{sc}}^{\mathrm{RS}} = 3N_{\mathrm{sc}}^{\mathrm{RB}}/2$, the base sequence is given by

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

where the value of $\varphi(n)$ is given by Table 5.5.1.2-1, Table 5.5.1.2-2, Table 5.5.1.2-3, and Table 5.5.1.2-4 for $M_{\mathrm{sc}}^{\mathrm{RS}} = N_{\mathrm{sc}}^{\mathrm{RB}}$, $M_{\mathrm{sc}}^{\mathrm{RS}} = 2N_{\mathrm{sc}}^{\mathrm{RB}}$, $M_{\mathrm{sc}}^{\mathrm{RS}} = N_{\mathrm{sc}}^{\mathrm{RB}}/2$, and $M_{\mathrm{sc}}^{\mathrm{RS}} = 3N_{\mathrm{sc}}^{\mathrm{RB}}/2$, respectively. For $M_{\mathrm{sc}}^{\mathrm{RS}} = 5N_{\mathrm{sc}}^{\mathrm{RB}}/2$, the base sequence $\bar{r}_{u,v}(0),...,\bar{r}_{u,v}(M_{\mathrm{sc}}^{\mathrm{RS}} - 1)$ is given by

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

Table 5.5.1.2-1: Definition of $\varphi(n)$ for $M_{\mathrm{sc}}^{\mathrm{RS}} = N_{\mathrm{sc}}^{\mathrm{RB}}$.

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

Table 5.5.1.2-2: Definition of $\varphi(n)$ for $M_{\mathrm{sc}}^{\mathrm{RS}} = 2N_{\mathrm{sc}}^{\mathrm{RB}}$

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

Table 5.5.1.2-3: Definition of $\varphi(n)$ for $M_{\text{sc}}^{\text{RS}} = N_{\text{sc}}^{\text{RB}}/2$

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

Table 5.5.1.2-4: Definition of $\varphi(n)$ for $M_{\mathrm{sc}}^{\mathrm{RS}} = 3N_{\mathrm{sc}}^{\mathrm{RB}}/2$

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

5.5.1.3 Group hopping

The sequence-group number u in slot n_s is defined by a group hopping pattern $f_{gh}(n_s)$ and a sequence-shift pattern f_{ss} according to

$$u = \left(f_{gh}(n_s) + f_{ss}\right) \bmod 30$$

There are 17 different hopping patterns and 30 different sequence-shift patterns. Sequence-group hopping can be enabled or disabled by means of the cell-specific parameter *Group-hopping-enabled* provided by higher layers. Sequence-group hopping for PUSCH can be disabled for a certain UE through the higher-layer parameter *Disable-sequence-group-hopping* despite being enabled on a cell basis unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure.

The group-hopping pattern $f_{gh}(n_s)$ may be different for PUSCH, (S)PUCCH and SRS and is given by

$$f_{gh}(n_s) = \begin{cases} 0 & \text{if group hopping is disabled} \\ \left(\sum_{i=0}^{7} c(8n_s + i) \cdot 2^i\right) \bmod 30 & \text{if group hopping is enabled} \end{cases}$$

where the pseudo-random sequence $c(i)$ is defined by clause 7.2. The pseudo-random sequence generator shall be initialized with $c_{init} = \left\lfloor \frac{n_{ID}^{RS}}{30} \right\rfloor$ at the beginning of each radio frame where n_{ID}^{RS} is given by clause 5.5.1.5.

The sequence-shift pattern f_{ss} definition differs between PUCCH, PUSCH and SRS.

For SPUCCH/PUCCH, the sequence-shift pattern f_{ss}^{PUCCH} is given by $f_{ss}^{PUCCH} = n_{ID}^{RS} \bmod 30$ where n_{ID}^{RS} is given by clause 5.5.1.5.

For PUSCH, the sequence-shift pattern f_{ss}^{PUSCH} is given by $f_{ss}^{PUSCH} = \left(N_{ID}^{cell} + \Delta_{ss}\right) \bmod 30$, where $\Delta_{ss} \in \{0,1,...,29\}$ is configured by higher layers, if no value for n_{ID}^{PUSCH} is provided by higher layers or if the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, otherwise it is given by $f_{ss}^{PUSCH} = n_{ID}^{RS} \bmod 30$ with n_{ID}^{RS} given by clause 5.5.1.5.

For SRS, the sequence-shift pattern f_{ss}^{SRS} is given by $f_{ss}^{SRS} = n_{ID}^{RS} \bmod 30$ where n_{ID}^{RS} is given by clause 5.5.1.5.

5.5.1.4 Sequence hopping

Sequence hopping only applies for reference-signals of length $M_{\mathrm{sc}}^{\mathrm{RS}} \geq 6N_{\mathrm{sc}}^{\mathrm{RB}}$.

For reference-signals of length $M_{\mathrm{sc}}^{\mathrm{RS}} < 6N_{\mathrm{sc}}^{\mathrm{RB}}$, the base sequence number v within the base sequence group is given by $v = 0$.

For reference-signals of length $M_{\mathrm{sc}}^{\mathrm{RS}} \geq 6N_{\mathrm{sc}}^{\mathrm{RB}}$, the base sequence number v within the base sequence group in slot n_{s} is defined by

$$v = \begin{cases} c(n_{\mathrm{s}}) & \text{if group hopping is disabled and sequence hopping is enabled} \\ 0 & \text{otherwise} \end{cases}$$

where the pseudo-random sequence $c(i)$ is given by clause 7.2. The parameter *Sequence-hopping-enabled* provided by higher layers determines if sequence hopping is enabled or not. Sequence hopping for PUSCH can be disabled for a certain UE through the higher-layer parameter *Disable-sequence-group-hopping* despite being enabled on a cell basis unless the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure.

For PUSCH or SPUCCH/PUCCH format 4 transmission with $\geq$ 6 RBs, the pseudo-random sequence generator shall be initialized with $c_{\mathrm{init}} = \left\lfloor \frac{n_{\mathrm{ID}}^{\mathrm{RS}}}{30} \right\rfloor \cdot 2^5 + f_{\mathrm{ss}}^{\mathrm{PUSCH}}$ at the beginning of each radio frame where $n_{\mathrm{ID}}^{\mathrm{RS}}$ is given by clause 5.5.1.5.

For SRS, the pseudo-random sequence generator shall be initialized with $c_{\mathrm{init}} = \left\lfloor \frac{n_{\mathrm{ID}}^{\mathrm{RS}}}{30} \right\rfloor \cdot 2^5 + \left(n_{\mathrm{ID}}^{\mathrm{RS}} + \Delta_{\mathrm{ss}}\right) \bmod 30$ at the beginning of each radio frame where $n_{\mathrm{ID}}^{\mathrm{RS}}$ is given by clause 5.5.1.5 and Δ_{ss} is given by clause 5.5.1.3.

5.5.1.5 Determining virtual cell identity for sequence generation

The definition of $n_{\mathrm{ID}}^{\mathrm{RS}}$ depends on the type of transmission.

Transmissions associated with PUSCH:

- $n_{\mathrm{ID}}^{\mathrm{RS}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ if no value for $n_{\mathrm{ID}}^{\mathrm{PUSCH}}$ is configured by higher layers or if the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure,
- $n_{\mathrm{ID}}^{\mathrm{RS}} = n_{\mathrm{ID}}^{\mathrm{PUSCH}}$ otherwise.

Transmissions associated with SPUCCH/PUCCH:

- $n_{\mathrm{ID}}^{\mathrm{RS}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ if no value for $n_{\mathrm{ID}}^{\mathrm{PUCCH}}$ is configured by higher layers,
- $n_{\mathrm{ID}}^{\mathrm{RS}} = n_{\mathrm{ID}}^{\mathrm{PUCCH}}$ otherwise.

Sounding reference signals:

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

5.5.2 Demodulation reference signal

5.5.2.1 Demodulation reference signal for PUSCH

5.5.2.1.1 Reference signal sequence

The PUSCH demodulation reference signal sequence $r_{\mathrm{PUSCH}}^{(\lambda)}(\cdot)$ associated with layer $\lambda \in \{0,1,...,\upsilon-1\}$ is defined by

$$r_{\mathrm{PUSCH}}^{(\lambda)}\left(m \cdot M_{\mathrm{sc}}^{\mathrm{RS}} + n\right) = w^{(\lambda)}(m) r_{u,v}^{(\alpha_\lambda,\delta)}(n)$$

where

$$m = \begin{cases} 0 & \text{for special subframe and (sub)slot - PUSCH} \\ 0,1 & \text{otherwise} \end{cases}$$
$$n = 0,...,M_{\mathrm{sc}}^{\mathrm{RS}} - 1$$

and $M_{\mathrm{sc}}^{\mathrm{RS}} = M_{\mathrm{sc}}^{\mathrm{PUSCH}} / 2$ if

- the higher-layer parameter *ul-DMRS-IFDMA* is set and the most recent uplink-related DCI contains the *Cyclic Shift Field mapping table for DMRS bit* field which indicates the use of Table 5.5.2.1.1-3, or,
- the *Cyclic Shift Field mapping table for DMRS bit* field is set in the most recent uplink-related DCI format 7 which indicates the use of Table 5.5.2.1.1-4, or,
- subslot-PUSCH/slot-PUSCH for the transport block is semi-persistently scheduled (i.e. higher layer parameter *sps-ConfigUL-STTI* is configured, see 3GPP TS 36.331 [9]), and *ifdma-Config-SPS* is set.

In all other cases, $M_{\mathrm{sc}}^{\mathrm{RS}} = M_{\mathrm{sc}}^{\mathrm{PUSCH}}$.

Subclause 5.5.1 defines the sequence $r_{u,v}^{(\alpha_\lambda,\delta)}(0),...,r_{u,v}^{(\alpha_\lambda,\delta)}(M_{\mathrm{sc}}^{\mathrm{RS}}-1)$ where, for PUSCH demodulation reference signal sequence, $\delta = 1$ when

- the higher-layer parameter *ul-DMRS-IFDMA* is set and the most recent uplink-related DCI contains the *Cyclic Shift Field mapping table for DMRS bit* field which indicates the use of Table 5.5.2.1.1-3, or,
- the *Cyclic Shift Field mapping table for DMRS bit* field is set in the most recent uplink-related DCI format 7 which indicates the use of Table 5.5.2.1.1-4, or,
- subslot-PUSCH/slot-PUSCH for the transport block is semi-persistently scheduled (i.e. higher layer parameter *sps-ConfigUL-STTI* is configured, see 3GPP TS 36.331 [9]), and *ifdma-Config-SPS* is set.

In all other cases, $\delta = 0$.

The orthogonal sequence $w^{(\lambda)}(m)$ is given by $w^{(\lambda)}(m) = 1$ for subslot-PUSCH/slot-PUSCH. In all other cases, it is given by $\left[w^{\lambda}(0) \quad w^{\lambda}(1)\right] = \left[1 \quad 1\right]$ for DCI format 0 if the higher-layer parameter *Activate-DMRS-with OCC* is not set or if the temporary C-RNTI was used to transmit the most recent uplink-related DCI for the transport block associated with the corresponding PUSCH transmission. Otherwise,

- if higher-layer parameter *ul-DMRS-IFDMA* is not set, $w^{(\lambda)}(m)$ is given by Table 5.5.2.1.1-1 using the cyclic shift field in the most recent uplink-related DCI [3],
- if higher-layer parameter *ul-DMRS-IFDMA* is set and the *Cyclic Shift Field mapping table for DMRS bit* field is not present in the most recent uplink-related DCI, $w^{(\lambda)}(m)$ is given by Table 5.5.2.1.1-1 using the cyclic shift field in the most recent uplink-related DCI,
- if higher-layer parameter *ul-DMRS-IFDMA* is set and the *Cyclic Shift Field mapping table for DMRS bit* field is present in the most recent uplink-related DCI, $w^{(\lambda)}(m)$ is given by Table 5.5.2.1.1-1 using the cyclic shift field

in the most recent uplink-related DCI when the *Cyclic Shift Field mapping table for DMRS bit* field indicates the use of Table 5.5.2.1.1-1, and

- if higher-layer parameter *ul-DMRS-IFDMA* is set and the *Cyclic Shift Field mapping table for DMRS bit* field is present in the most recent uplink-related DCI, $w^{(\lambda)}(m)$ is given by Table 5.5.2.1.1-3 using the cyclic shift field in the most recent uplink-related DCI when the *Cyclic Shift Field mapping table for DMRS bit* field indicates the use of Table 5.5.2.1.1-3.

The cyclic shift α_λ in a slot n_s is given as $\alpha_\lambda = 0$ if the ul-V-SPS-RNTI-r14 was used to transmit the most recent uplink-related DCI for the transport block associated with the corresponding PUSCH transmission.

Otherwise, the cyclic shift α_λ in a slot n_s is given as $\alpha_\lambda = 2\pi n_{\mathrm{cs},\lambda}/12$ with

$$n_{\mathrm{cs},\lambda} = \left(n_{\mathrm{DMRS}}^{(1)} + n_{\mathrm{DMRS},\lambda}^{(2)} + (1+\delta)n_{\mathrm{PN}}(n_\mathrm{s})\right)\mathrm{mod}\,12$$

where the value of $n_{\mathrm{DMRS}}^{(1)}$ is given by Table 5.5.2.1.1-2 according to the parameter *cyclicShift* provided by higher layers. For non-BL/CE UEs $n_{\mathrm{DMRS},\lambda}^{(2)}$ is given using the most recent uplink-related DCI 3GPP TS 36.212 [3] for the transport block associated with the corresponding PUSCH transmission, except for subslot-PUSCH/slot-PUSCH, as follows:

- if the higher-layer parameter *ul-DMRS-IFDMA* is not set, $n_{\mathrm{DMRS},\lambda}^{(2)}$ is given by Table 5.5.2.1.1-1 using the cyclic shift field in the most recent uplink-related DCI,
- if higher-layer parameter *ul-DMRS-IFDMA* is set and the *Cyclic Shift Field mapping table for DMRS bit* field is not present in the most recent uplink-related DCI, $n_{\mathrm{DMRS},\lambda}^{(2)}$ is given by Table 5.5.2.1.1-1 using the cyclic shift field in the most recent uplink-related DCI,
- if higher-layer parameter *ul-DMRS-IFDMA* is set and the *Cyclic Shift Field mapping table for DMRS bit* field is present in the most recent uplink-related DCI, $n_{\mathrm{DMRS},\lambda}^{(2)}$ is given by Table 5.5.2.1.1-1 using the cyclic shift field in the most recent uplink-related DCI when the *Cyclic Shift Field mapping table for DMRS bit* field indicates the use of Table 5.5.2.1.1-1, and
- if higher-layer parameter *ul-DMRS-IFDMA* is set and the *Cyclic Shift Field mapping table for DMRS bit* field is present in the most recent uplink-related DCI, $n_{\mathrm{DMRS},\lambda}^{(2)}$ is given by Table 5.5.2.1.1-3 using the cyclic shift field in the most recent uplink-related DCI when the *Cyclic Shift Field mapping table for DMRS bit* field indicates the use of Table 5.5.2.1.1-3.

For subslot-PUSCH/slot-PUSCH for non-BL/CE UEs, $n_{\mathrm{DMRS},\lambda}^{(2)}$ is given by Table 5.5.2.1.1-4, using the cyclic shift field in the most recent uplink-related DCI. If the *Cyclic Shift Field mapping table for DMRS bit* field is not set, ϖ in Table 5.5.2.1.1-4 is ignored. If the *Cyclic Shift Field mapping table for DMRS bit* field is set, both $n_{\mathrm{DMRS},\lambda}^{(2)}$ and ϖ are given by Table 5.5.2.1.1-4.

For BL/CE UEs, a cyclic shift field of '000' shall be assumed when determining $n_{\mathrm{DMRS},\lambda}^{(2)}$ from Table 5.5.2.1.1-1.

For subframe-based PUSCH transmission, the first row of Table 5.5.2.1.1-1 shall be used to obtain $n_{\mathrm{DMRS},0}^{(2)}$ and $w^{(\lambda)}(m)$ if there is no uplink-related DCI for the same transport block associated with the corresponding PUSCH transmission, and

- if the initial PUSCH for the same transport block is semi-persistently scheduled and *cyclicShiftSPS* is not configured, or
- if the initial PUSCH for the same transport block is scheduled by the random-access response grant.

An exception applies if subframe-based PUSCH for the transport block is semi-persistently scheduled and the higher-layer parameter *cyclicShiftSPS* is configured. In this case, the value of $n_{\mathrm{DMRS},0}^{(2)}$ is given by Table 5.5.2.1.1-1 according to the higher-layer parameter *cyclicShiftSPS*.

An exception applies if subslot-PUSCH/slot-PUSCH for the transport block is semi-persistently scheduled (see 3GPP TS 36.331, *sps-ConfigUL-sTTI*). In this case:

- $n_{\text{DMRS},0}^{(2)}$ is given by Table 5.5.2.1.1-1 according to the higher-layer parameter *cyclicShiftSPS-STTI* if the higher layer parameter *ifdma-Config-SPS* is not set, and,

- $n_{\text{DMRS},0}^{(2)}$ and ϖ are given by Table 5.5.2.1.1-3 according to the higher-layer parameter *cyclicShiftSPS-STTI* if the higher layer parameter *ifdma-Config-SPS* is set.

The quantity $n_{\text{PN}}(n_\text{s})$ is given by

$$n_{\text{PN}}(n_\text{s}) = \sum_{i=0}^{7} c(8N_{\text{symb}}^{\text{UL}} \cdot n_\text{s} + i) \cdot 2^i$$

where the pseudo-random sequence $c(i)$ is defined by clause 7.2. The application of $c(i)$ is cell-specific. The pseudo-random sequence generator shall be initialized with c_init at the beginning of each radio frame. The quantity c_init is given by $c_\text{init} = \left\lfloor \frac{N_\text{ID}^\text{cell}}{30} \right\rfloor \cdot 2^5 + \left(\left(N_\text{ID}^\text{cell} + \Delta_\text{ss}\right) \bmod 30 \right)$ if no value for $N_\text{ID}^\text{csh\_DMRS}$ is configured by higher layers for PUSCH/(S)PUCCH format 4/PUCCH format 5 or the PUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure, otherwise it is given by $c_\text{init} = \left\lfloor \frac{N_\text{ID}^\text{csh\_DMRS}}{30} \right\rfloor \cdot 2^5 + \left(N_\text{ID}^\text{csh\_DMRS} \bmod 30 \right)$.

The vector of reference signals shall be precoded according to

$$\begin{bmatrix} \tilde{r}_\text{PUSCH}^{(0)} \\ \vdots \\ \tilde{r}_\text{PUSCH}^{(P-1)} \end{bmatrix} = W \begin{bmatrix} r_\text{PUSCH}^{(0)} \\ \vdots \\ r_\text{PUSCH}^{(\upsilon-1)} \end{bmatrix}$$

where P is the number of antenna ports used for PUSCH transmission.

For PUSCH transmission using a single antenna port, $P = 1$, $W = 1$ and $\upsilon = 1$.

For spatial multiplexing, $P = 2$ or $P = 4$ and the precoding matrix W shall be identical to the precoding matrix used in clause 5.3.3A.2 for precoding of the PUSCH in the same subframe.

Table 5.5.2.1.1-1: Mapping of Cyclic Shift Field in uplink-related DCI format to $n_{\text{DMRS},\lambda}^{(2)}$ and $\left[w^{(\lambda)}(0) \quad w^{(\lambda)}(1) \right]$

Cyclic Shift Field in uplink-related DCI format [3]	$n_{\text{DMRS},\lambda}^{(2)}$				$\left[w^{(\lambda)}(0) \quad w^{(\lambda)}(1) \right]$			
	$\lambda = 0$	$\lambda = 1$	$\lambda = 2$	$\lambda = 3$	$\lambda = 0$	$\lambda = 1$	$\lambda = 2$	$\lambda = 3$

000	0	6	3	9	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ -1]$	$[1\ \ -1]$
001	6	0	9	3	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ 1]$	$[1\ \ 1]$
010	3	9	6	0	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ 1]$	$[1\ \ 1]$
011	4	10	7	1	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ 1]$
100	2	8	5	11	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ 1]$
101	8	2	11	5	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ -1]$
110	10	4	1	7	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ -1]$
111	9	3	0	6	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ -1]$	$[1\ \ -1]$

Table 5.5.2.1.1-2: Mapping of *cyclicShift* to $n_{\mathrm{DMRS}}^{(1)}$ values

cyclicShift	$n_{\mathrm{DMRS}}^{(1)}$
0	0
1	2
2	3
3	4
4	6
5	8
6	9
7	10

Table 5.5.2.1.1-3: Mapping of Cyclic Shift Field in uplink-related DCI format to $n_{\mathrm{DMRS},\lambda}^{(2)}$, ϖ, and $\left[w^{(\lambda)}(0)\quad w^{(\lambda)}(1)\right]$

Cyclic Shift Field in uplink-related DCI format [3]	ϖ	$n_{\mathrm{DMRS},\lambda}^{(2)}$				$\left[w^{(\lambda)}(0)\quad w^{(\lambda)}(1)\right]$			
		$\lambda=0$	$\lambda=1$	$\lambda=2$	$\lambda=3$	$\lambda=0$	$\lambda=1$	$\lambda=2$	$\lambda=3$
000	1	0	6	3	9	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ -1]$	$[1\ \ -1]$
001	1	6	0	9	3	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ 1]$	$[1\ \ 1]$
010	1	3	9	6	0	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ 1]$	$[1\ \ 1]$
011	0	4	10	7	1	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ 1]$
100	0	2	8	5	11	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ 1]$
101	0	8	2	11	5	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ -1]$
110	0	10	4	1	7	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ -1]$	$[1\ \ -1]$
111	1	9	3	0	6	$[1\ \ 1]$	$[1\ \ 1]$	$[1\ \ -1]$	$[1\ \ -1]$

Table 5.5.2.1.1-4: $n_{\mathrm{DMRS},\lambda}^{(2)}$ for subslot-PUSCH/slot-PUSCH

Cyclic Shift Field in uplink-related DCI format [3]	$n_{\mathrm{DMRS},\lambda}^{(2)}$				ϖ			
	$\lambda=0$	$\lambda=1$	$\lambda=2$	$\lambda=3$	$\lambda=0$	$\lambda=1$	$\lambda=2$	$\lambda=3$
0	0	6	3	9	0	0	1	1
1	6	0	9	3	1	1	0	0

5.5.2.1.2 Mapping to physical resources

For each antenna port used for transmission of the PUSCH, the sequence $\tilde{r}^{(\tilde{p})}_{\mathrm{PUSCH}}(\cdot)$ shall be multiplied with the amplitude scaling factor $\sqrt{1+\delta}\,\beta_{\mathrm{PUSCH}}$ and mapped in sequence starting with $\tilde{r}^{(\tilde{p})}_{\mathrm{PUSCH}}(0)$ to the resource blocks.

- $\delta=1$ when either
  - the higher-layer parameter *ul-DMRS-IFDMA* is set and the most recent uplink-related DCI contains the *Cyclic Shift Field mapping table for DMRS bit* field which indicates the use of Table 5.5.2.1.1-3, or
  - the *Cyclic Shift Field mapping table for DMRS bit* field is set in the most recent uplink-related DCI format 7 which indicates the use of Table 5.5.2.1.1-4, and
- $\delta=0$ otherwise.

If higher-layer parameter *ul-DMRS-IFDMA* is set and the most recent uplink-related DCI contains the *Cyclic Shift Field mapping table for DMRS bit* field which indicates the use of Table 5.5.2.1.1-3, the mapping to resource elements (k,l), with $l=3$ for normal cyclic prefix and $l=2$ for extended cyclic prefix, in the subframe shall be in increasing order of first k for all values of k satisfying $k \bmod 2 = \varpi$, then the slot number. The quantity ϖ is given by Table 5.5.2.1.1-3 using the cyclic shift field in the most recent uplink-related DCI.

In case of slot-PUSCH, the mapping to resource elements (k,l), with $l=3$ for normal cyclic prefix, in the slot of the subframe where slot-PUSCH is transmitted shall be in increasing order of first k for all values of k, except if the *Cyclic Shift Field mapping table for DMRS bit* field is set in the most recent uplink-related DCI format 7, which indicates the use of Table 5.5.2.1.1-4. In this case the mapping to resource element shall be in increasing order of first k only for values of k satisfying $k \bmod 2 = \varpi$.

In case of subslot-PUSCH, the mapping to resource elements (k,l), in the subframe shall be in increasing order of first k for all values of k, except if the *Cyclic Shift Field mapping table for DMRS bit* field is set in the most recent uplink-related DCI format 7, which indicates the use of Table 5.5.2.1.1-4. In this case the mapping to resource element shall be in increasing order of first k only for values of k satisfying $k \bmod 2 = \varpi$. The value of l depends on the uplink subslot number and the *DMRS-pattern* field in the most recent uplink-related DCI, according to Table 5.5.2.1.2-1, or according to Table 5.5.2.1.2-2 in case of semi-persistent scheduling of subslot-PUSCH (i.e. higher layer patameter *sps-ConfigUL-sTTI-r15* is configured, se 3GPP TS 36.331 [9]) and with a configured periodicity of 1 subslot (i.e. *semiPersistSchedIntervalUL-STTI-r15* set to *sTTI1*). In case of subslot-PUSCH and semi-persistent scheduling with a configured periodicity longer than 1 subslot, the mapping shall start at symbol l according to the first row of Table 5.5.2.1.2-2 (i.e. equivalent to a signalling of *DMRS-pattern* field set to '00'). In case no value of l is defined for the uplink subslot number, and in case no valid starting symbol index (see table 5.3.4-1), no reference signal is transmitted associated with the uplink-related DCI format.

Table 5.5.2.1.2-1: The quantity l for subslot-PUSCH

***DMRS-pattern* field in uplink-related DCI format [3]**	**Uplink subslot number**					
	#0	**#1**	**#2**	**#3**	**#4**	**#5**
00	0	3	5	0	2	4
01	2	4	-	1	3	-
10	-	-	-	2	-	-
11	-	5	-	-	4	-

Table 5.5.2.1.2-2: The quantity l for subslot-PUSCH for semi-persistent scheduling

***DMRS-pattern* field in uplink-related DCI format [3]**	**Uplink subslot number**					
	#0	**#1**	**#2**	**#3**	**#4**	**#5**
00	0	3	5	0	2	4
10	0	5	5	2	2	4

For all other cases, the set of physical resource blocks used in the mapping process and the relation between the index $\tilde{p}$ and the antenna port number p shall be identical to the corresponding PUSCH transmission as defined in clause 5.3.4.

The mapping to resource elements (k,l), with $l=3$, or with l according to Table 5.5.2.1.2-1 for subslot-PUSCH, for normal cyclic prefix and $l=2$ for extended cyclic prefix, in the subframe shall be in increasing order of first k, then the slot number, except for slot-PUSCH and subslot-PUSCH where the reference signal is only mapped to the slot where the slot-PUSCH/subslot-PUSCH is transmitted). No DM-RS shall be transmitted in UpPTS if *dmrsLess-UpPts* is set to true.

5.5.2.1A Demodulation reference signal for PUSCH with sub-PRB allocations

5.5.2.1A.1 Reference signal sequence using modulation schemes other than π/2-BPSK

The reference signal sequence $r_{\text{PUSCH}}(n)$ for $M_{\text{sc}}^{\text{RU}} > 1$ is defined by a cyclic shift α of a base sequence according to

$$r_{\text{PUSCH}}(n) = e^{j\alpha n} e^{j\phi(n)\pi/4}$$
$$0 \le n < M_{\text{sc}}^{\text{RU}},$$

where $\phi(n)$ is given by Tables 5.5.2.1A.1-1 and 5.5.2.1A.1-2 for $M_{\text{sc}}^{\text{RU}}=3$ and $M_{\text{sc}}^{\text{RU}}=6$, respectively. The cyclic shift α is derived from higher layer parameters *ce-pusch-subPrb-threeTone-CyclicShift* and *ce-pusch-subPrb-sixTone-CyclicShift*, respectively, as defined in Table 5.5.2.1A.1-3.

If group hopping is enabled, the base sequence index u is given by clause 5.5.2.1A.3.

If group hopping is not enabled, the base sequence index u is given by

- $N_{\text{ID}}^{\text{cell}} \bmod 12$ for $M_{\text{sc}}^{\text{RU}}=3$
- $N_{\text{ID}}^{\text{cell}} \bmod 14$ for $M_{\text{sc}}^{\text{RU}}=6$

Table 5.5.2.1A.1-1: Definition of $\phi(n)$ for $M_{\text{sc}}^{\text{RU}}=3$

u	$\phi(0),...,\phi(3)$		
0	1	-3	-3
1	1	-3	-1
2	1	-3	3
3	1	-1	-1
4	1	-1	1
5	1	-1	3
6	1	1	-3
7	1	1	-1
8	1	1	3
9	1	3	-1
10	1	3	1
11	1	3	3

Table 5.5.2.1A.1-2: Definition of $\phi(n)$ for $M_{sc}^{RU}=6$

u	$\phi(0),...,\phi(5)$					
0	1	1	1	1	3	-3
1	1	1	3	1	-3	3
2	1	-1	-1	-1	1	-3
3	1	-1	3	-3	-1	-1
4	1	3	1	-1	-1	3
5	1	-3	-3	1	3	1
6	-1	-1	1	-3	-3	-1
7	-1	-1	-1	3	-3	-1
8	3	-1	1	-3	-3	3
9	3	-1	3	-3	-1	1
10	3	-3	3	-1	3	3
11	-3	1	3	1	-3	-1
12	-3	1	-3	3	-3	-1
13	-3	3	-3	1	1	-3

Table 5.5.2.1A.1-3: Definition of α

$M_{sc}^{RU}=3$		$M_{sc}^{RU}=6$	
ce-pusch-subPrb-threeTone-CyclicShift	α	**ce-pusch-subPrb-sixTone-CyclicShift**	α
0	0	0	0
1	$2\pi/3$	1	$2\pi/6$
2	$4\pi/3$	2	$4\pi/6$
-	-	3	$8\pi/6$

5.5.2.1A.2 Reference signal sequence using π/2-BPSK modulation scheme

For $M_{sc}^{RU}=3$ using π/2-BPSK modulation scheme, $N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 2$ is used to determine which 2 of 3 subcarriers will be used:

- 0 indicates that the two subcarriers having the lowest indices among the three allocated are utilized.
- 1 indicates that the two subcarriers having the highest indices among the three allocated are utilized.

The reference signal sequences $\bar{r}_{u1}(n)$ and $\bar{r}_{u2}(n)$ for $M_{sc}^{RU}=3$ using 2 out of 3 subcarriers are defined by

$$\bar{r}_{u1}(n)=\frac{1}{\sqrt{2}}(1+j)\big(1-2c(n)\big)w(n \bmod 16),\quad 0\le n< N_{\mathrm{rep}}^{\mathrm{PUSCH}} M_{\mathrm{slots}}^{\mathrm{UL}} M_{\mathrm{RU}}$$

$$\bar{r}_{u2}(n)=-1^{n+(N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 2)}\left(\frac{1}{\sqrt{2}}(1+j)\big(1-2c(n)\big)w(n \bmod 16)\right),\quad 0\le n< N_{\mathrm{rep}}^{\mathrm{PUSCH}} M_{\mathrm{slots}}^{\mathrm{UL}} M_{\mathrm{RU}}$$

where the binary sequence $c(n)$ is defined by clause 7.2 and shall be initialised with $c_{\mathrm{init}}=35$ at the start of the PUSCH transmission using sub-PRB allocations for BL/CE UEs. The quantity $w(n)$ is given by Table 5.5.2.1A.2-1 where $u=N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 16$ if group hopping is not enabled, and by clause 5.5.2.1A.3 if group hopping is enabled for PUSCH using sub-PRB allocations for BL/CE UEs.

Table 5.5.2.1A.2-1: Definition of $w(n)$

u	$w(0),\ldots,w(15)$															
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	1	-1	1	-1	1	-1	1	-1
2	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1
3	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1
4	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1
5	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
6	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1
7	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1
8	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1
9	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1
10	1	1	-1	-1	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1
11	1	-1	-1	1	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1
12	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1
13	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1
14	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1
15	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1

The reference signal sequences for PUSCH using sub-PRB allocations for BL/CE UEs is given by clause 5.3.3, where $\bar{r}_{u1}(n)$ and $\bar{r}_{u2}(n)$ correspond to the complex-valued symbols at the input of the transform precoding. The resulting complex-valued symbols at the output of the transform precoding correspond to the sequence $r(\cdot)$ which is mapped to physical resources as described in clause 5.5.2.1A.4.

5.5.2.1A.3 Group hopping

For the reference signal for PUSCH transmission using sub-PRB allocations for BL/CE UEs, sequence-group hopping can be enabled where the sequence-group number u in slot n_s is defined by a group hopping pattern $f_\mathrm{gh}(n_\mathrm{s})$ and a sequence-shift pattern f_ss according to

$$u = \left(f_{gh}(n_s) + f_{ss}\right) \mathrm{mod} M_\mathrm{seq}^\mathrm{RU}$$

where the number of reference signal sequences available for each resource unit size, $M_\mathrm{seq}^\mathrm{RU}$ is given by Table 5.5.2.1A.3-1.

Table 5.5.2.1A.3-1: Definition of $M_\mathrm{seq}^\mathrm{RU}$

Modulation Scheme	$M_\mathrm{sc}^\mathrm{RU}$	$M_\mathrm{seq}^\mathrm{RU}$
π/2-BPSK	3	16
QPSK	3	12
	6	14

Sequence-group hopping can be enabled or disabled as described in clause 5.5.1.3.

The group-hopping pattern $f_\mathrm{gh}(n_\mathrm{s})$ is given by

$$f_{gh}(n_s) = \left(\sum_{i=0}^{7} c(8n'_s + i) \cdot 2^i\right) \mathrm{mod} M_\mathrm{seq}^\mathrm{RU}$$

where $n'_\mathrm{s} = n_\mathrm{s}$ for $M_\mathrm{sc}^\mathrm{RU} > 1$ using QPSK modulation scheme and n'_s is the slot number of the first slot of the resource unit for $M_\mathrm{sc}^\mathrm{RU} = 3$ using π/2-BPSK modulation scheme. The pseudo-random sequence $c(i)$ is defined by clause 7.2. The pseudo-random sequence generator shall be initialized with $c_\mathrm{init} = \left\lfloor N_\mathrm{ID}^\mathrm{cell} / M_\mathrm{seq}^\mathrm{RU} \right\rfloor$ at the beginning of the resource unit for $M_\mathrm{sc}^\mathrm{RU} = 3$ using π/2-BPSK modulation scheme and in every even slot for $M_\mathrm{sc}^\mathrm{RU} > 1$ using QPSK modulation scheme.

The sequence-shift pattern f_{ss} is given by

$$f_{ss}(n_s) = (N_{\mathrm{ID}}^{\mathrm{cell}} + \Delta_{ss}) \bmod M_{\mathrm{seq}}^{\mathrm{RU}}$$

where $\Delta_{\mathrm{ss}} = 0$.

5.5.2.1A.4 Mapping to physical resources

The sequence $r(\cdot)$ shall be multiplied with the amplitude scaling factor β_{PUSCH} and mapped in sequence starting with $r(0)$ to the sub-carriers.

The set of sub-carriers used in the mapping process shall be identical to the corresponding PUSCH transmissions using sub-PRB allocations for BL/CE UEs as defined in clause 5.3.4.

The mapping to resource elements (k,l) shall be in increasing order of first k, then l, and finally the slot number. The value of the symbol index l in a slot is 3.

5.5.2.2 Demodulation reference signal for PUCCH

5.5.2.2.1 Reference signal sequence

The PUCCH demodulation reference signal sequence $r_{\mathrm{PUCCH}}^{(\widetilde{p})}(\cdot)$ for PUCCH formats 1, 1a, 1b, 2, 2a, 2b, and 3 is defined by

$$r_{\mathrm{PUCCH}}^{(\widetilde{p})}\left(m' N_{\mathrm{RS}}^{\mathrm{PUCCH}} M_{\mathrm{sc}}^{\mathrm{RS}} + m M_{\mathrm{sc}}^{\mathrm{RS}} + n\right) = \frac{1}{\sqrt{P}} \overline{w}^{(\widetilde{p})}(m) z(m) r_{u,v}^{(\alpha_{\widetilde{p}},\delta)}(n)$$

where

$$\begin{aligned} m &= 0,\ldots,N_{\mathrm{RS}}^{\mathrm{PUCCH}} - 1 \\ n &= 0,\ldots,M_{\mathrm{sc}}^{\mathrm{RS}} - 1 \\ m' &= 0,1 \end{aligned}$$

and P is the number of antenna ports used for PUCCH transmission. For PUCCH formats 2a and 2b, $z(m)$ equals $d(10)$ for $m = 1$, where $d(10)$ is defined in clause 5.4.2. For all other cases, $z(m) = 1$.

The sequence $r_{u,v}^{(\alpha_{\widetilde{p}})}(n)$ is given by clause 5.5.1 with $M_{\mathrm{sc}}^{\mathrm{RS}} = 12$ and $\delta = 0$ where the expression for the cyclic shift $\alpha_{\widetilde{p}}$ is determined by the PUCCH format.

For PUCCH formats 1, 1a and 1b, $\alpha_{\widetilde{p}}(n_{\mathrm{s}},l)$ is given by

$$\overline{n}_{\mathrm{oc}}^{(\widetilde{p})}(n_{\mathrm{s}}) = \left\lfloor n'_{\widetilde{p}}(n_{\mathrm{s}}) \cdot \Delta_{\mathrm{shift}}^{\mathrm{PUCCH}} \big/ N' \right\rfloor$$

$$\alpha_{\widetilde{p}}(n_{\mathrm{s}},l) = 2\pi \cdot \overline{n}_{\mathrm{cs}}^{(\widetilde{p})}(n_{\mathrm{s}},l) \big/ N_{\mathrm{sc}}^{\mathrm{RB}}$$

$$\overline{n}_{\mathrm{cs}}^{(\widetilde{p})}(n_{\mathrm{s}},l) = \begin{cases} \left[n_{\mathrm{cs}}^{\mathrm{cell}}(n_{\mathrm{s}},l) + \left(n'_{\widetilde{p}}(n_{\mathrm{s}}) \cdot \Delta_{\mathrm{shift}}^{\mathrm{PUCCH}} + \left(\overline{n}_{\mathrm{oc}}^{(\widetilde{p})}(n_{\mathrm{s}}) \bmod \Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}\right)\right) \bmod N'\right] \bmod N_{\mathrm{sc}}^{\mathrm{RB}} & \text{for normal cyclic prefix} \\ \left[n_{\mathrm{cs}}^{\mathrm{cell}}(n_{\mathrm{s}},l) + \left(n'_{\widetilde{p}}(n_{\mathrm{s}}) \cdot \Delta_{\mathrm{shift}}^{\mathrm{PUCCH}} + \overline{n}_{\mathrm{oc}}^{(\widetilde{p})}(n_{\mathrm{s}})\right) \bmod N'\right] \bmod N_{\mathrm{sc}}^{\mathrm{RB}} & \text{for extended cyclic prefix} \end{cases}$$

where $n'_{\widetilde{p}}(n_{\mathrm{s}})$, N' , $\Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}$ and $n_{\mathrm{cs}}^{\mathrm{cell}}(n_s,l)$ are defined by clause 5.4.1. The number of reference symbols per slot $N_{\mathrm{RS}}^{\mathrm{PUCCH}}$ and the sequence $\overline{w}(n)$ are given by Table 5.5.2.2.1-1 and 5.5.2.2.1-2, respectively.

For PUCCH formats 2, 2a and 2b, $\alpha_{\tilde{p}}(n_s,l)$ is defined by clause 5.4.2. The number of reference symbols per slot N_{RS}^{PUCCH} and the sequence $\overline{w}^{(\tilde{p})}(n)$ are given by Table 5.5.2.2.1-1 and 5.5.2.2.1-3, respectively.

For PUCCH format 3, $\alpha_{\tilde{p}}(n_s,l)$ is given by

$$\alpha_{\tilde{p}}(n_s,l) = 2\pi \cdot n_{cs}^{(\tilde{p})}(n_s,l) / N_{sc}^{RB}$$
$$n_{cs}^{(\tilde{p})}(n_s,l) = \left(n_{cs}^{cell}(n_s,l) + n'_{\tilde{p}}(n_s)\right) \bmod N_{sc}^{RB}$$

where $n'_{\tilde{p}}(n_s)$ is given by Table 5.5.2.2.1-4 and $n_{oc,0}^{(\tilde{p})}$ and $n_{oc,1}^{(\tilde{p})}$ for the first and second slot in a subframe, respectively, are obtained from clause 5.4.2A. The number of reference symbols per slot N_{RS}^{PUCCH} and the sequence $\overline{w}(n)$ are given by Table 5.5.2.2.1-1 and 5.5.2.2.1-3, respectively.

Table 5.5.2.2.1-1: Number of PUCCH demodulation reference symbols per slot N_{RS}^{PUCCH}

PUCCH format	Normal cyclic prefix	Extended cyclic prefix
1, 1a, 1b	3	2
2, 3	2	1
2a, 2b	2	N/A

Table 5.5.2.2.1-2: Orthogonal sequences $\left[\overline{w}^{(\tilde{p})}(0) \quad \cdots \quad \overline{w}^{(\tilde{p})}(N_{RS}^{PUCCH}-1)\right]$ for PUCCH formats 1, 1a and 1b

Sequence index $\overline{n}_{oc}^{(\tilde{p})}(n_s)$	Normal cyclic prefix	Extended cyclic prefix
0	$\begin{bmatrix}1 & 1 & 1\end{bmatrix}$	$\begin{bmatrix}1 & 1\end{bmatrix}$
1	$\begin{bmatrix}1 & e^{j2\pi/3} & e^{j4\pi/3}\end{bmatrix}$	$\begin{bmatrix}1 & -1\end{bmatrix}$
2	$\begin{bmatrix}1 & e^{j4\pi/3} & e^{j2\pi/3}\end{bmatrix}$	N/A

Table 5.5.2.2.1-3: Orthogonal sequences $\left[\overline{w}^{(\tilde{p})}(0) \quad \cdots \quad \overline{w}^{(\tilde{p})}(N_{RS}^{PUCCH}-1)\right]$ for PUCCH formats 2, 2a, 2b and 3.

Normal cyclic prefix	Extended cyclic prefix
$\begin{bmatrix}1 & 1\end{bmatrix}$	$\begin{bmatrix}1\end{bmatrix}$

Table 5.5.2.2.1-4: Relation between $n_{oc}^{(\tilde{p})}$ and $n'_{\tilde{p}}(n_s)$ for PUCCH format 3.

$n_{oc}^{(\tilde{p})}$	$n'_{\tilde{p}}(n_s)$	
	$N_{SF,1}=5$	$N_{SF,1}=4$
0	0	0
1	3	3
2	6	6
3	8	9
4	10	N/A

The PUCCH demodulation reference signal sequence $r_{PUCCH}^{(\tilde{p})}(\cdot)$ for PUCCH formats 4 and 5 is defined by

$$r_{\mathrm{PUCCH}}^{(\widetilde{p})}\left(m \cdot M_{\mathrm{sc}}^{\mathrm{RS}} + n\right) = r_{u,v}^{(\alpha,\delta)}(n)$$

where

$$\widetilde{p} = 0$$
$$m = 0,1$$
$$n = 0,\ldots,M_{\mathrm{sc}}^{\mathrm{RS}} - 1$$

and

$$M_{\mathrm{sc}}^{\mathrm{RS}} = \begin{cases} M_{\mathrm{sc}}^{\mathrm{PUCCH4}} & \text{for PUCCH format 4} \\ N_{\mathrm{sc}}^{\mathrm{RB}} & \text{for PUCCH format 5} \end{cases}$$

Subclause 5.5.1 defines the sequence $r_{u,v}^{(\alpha_\lambda,\delta)}(0),\ldots,r_{u,v}^{(\alpha_\lambda,\delta)}(M_{\mathrm{sc}}^{\mathrm{RS}}-1)$ where $\delta = 0$.

The cyclic shift α_λ in a slot n_{s} is given as $\alpha_\lambda = 2\pi n_{\mathrm{cs},\lambda}/12$ with

$$n_{\mathrm{cs},\lambda} = \left(n_{\mathrm{DMRS}}^{(1)} + n_{\mathrm{DMRS}}^{(2)} + n_{\mathrm{PN}}(n_{\mathrm{s}})\right) \bmod 12$$

where the values of $n_{\mathrm{DMRS}}^{(1)}$ and $n_{\mathrm{PN}}(n_{\mathrm{s}})$ are given by Subclause 5.5.2.1.1 and

$$n_{\mathrm{DMRS}}^{(2)} = \begin{cases} 0 & \text{PUCCH format 4} \\ 0 & \text{PUCCH format 5 with } n_{\mathrm{oc}} = 0 \\ 6 & \text{PUCCH format 5 with } n_{\mathrm{oc}} = 1 \end{cases}$$

with n_{oc} obtained as described in clause 5.4.2C.

5.5.2.2.2 Mapping to physical resources

The sequence $r_{\mathrm{PUCCH}}^{(\widetilde{p})}(\cdot)$ shall be multiplied with the amplitude scaling factor β_{PUCCH} and mapped in sequence starting with $r_{\mathrm{PUCCH}}^{(\widetilde{p})}(0)$ to resource elements (k,l) on antenna port p. The mapping shall be in increasing order of first k, then l and finally the slot number. The set of values for k and the relation between the index $\widetilde{p}$ and the antenna port number p shall be identical to the values used for the corresponding PUCCH transmission. The values of the symbol index l in a slot are given by Table 5.5.2.2.2-1.

Table 5.5.2.2.2-1: Demodulation reference signal location for different PUCCH formats.

PUCCH format	Set of values for l	
	Normal cyclic prefix	Extended cyclic prefix
1, 1a, 1b	2, 3, 4	2, 3
2, 3	1, 5	3
2a, 2b	1, 5	N/A
4,5	3	2

5.5.2.3 Demodulation reference signal for SPUCCH

5.5.2.3.1 Reference signal sequence

The SPUCCH demodulation reference signal sequence $r_{\mathrm{SPUCCH}}^{(\widetilde{p})}(\cdot)$ for subslot-SPUCCH format 4, and, slot- SPUCCH formats 1, 1a, 1b, 3 and 4 is as defined for $r_{\mathrm{PUCCH}}^{(\widetilde{p})}(\cdot)$ in subclause 5.5.2.2.1 for PUCCH format 1, 1a, 1b, 2, 2a, 2b and 3, using the parameter settings in Table 5.5.2.3.1-1, and with the number of reference symbols $N_{\mathrm{RS}}^{\mathrm{PUCCH}}$ replaced by $N_{\mathrm{RS}}^{\mathrm{SPUCCH}}$ and given by Table 5.5.2.3.1-2.

NOTE: Subslot-SPUCCH format 1/1a/1b does not employ a reference signal based design.

The sequence $r_{u,v}^{(\alpha_{\tilde{p}})}(n)$ is given by clause 5.5.1 with $\delta = 0$, where the expression for the cyclic shift α is determined depending on the SPUCCH format, see table 5.5.2.3.1-3.

Table 5.5.2.3.1-1: Parameters for SPUCCH demodulation reference signal

SPUCCH format		Frequency hopping	m'	$M_{\mathrm{sc}}^{\mathrm{RS}}$	$\overline{w}^{(\tilde{p})}(m)$	$z(m)$
Slot	1, 1a, 1b	Disabled	0	12	See Table 5.5.2.2.1-2 for normal cyclic prefix	1
		Enabled	0	12	1	1
	3	Disabled	0	12	See subclause 5.5.2.2.2	1
	4	Enabled	0	$M_{\mathrm{sc}}^{\mathrm{SPUCCH4}}$	1	1
Subslot	4	Disabled	0	$M_{\mathrm{sc}}^{\mathrm{SPUCCH4}}$	1	1

Table 5.5.2.3.1-2: Number of SPUCCH demodulation reference symbols $N_{\mathrm{RS}}^{\mathrm{SPUCCH}}$ per slot or per subslot

SPUCCH format		Frequency hopping	$N_{\mathrm{RS}}^{\mathrm{SPUCCH}}$
Slot	1, 1a, 1b	Enabled or disabled	3
	3	Disabled	2
	4	Enabled	2
Subslot	4	Disabled	1

Table 5.5.2.3.1-3: α

SPUCCH format		Frequency hopping	α
Slot	1, 1a, 1b	Enabled or disabled	see $\alpha_{\tilde{p}}$ in subclause 5.4A.2
	3	Disabled	see $\alpha_{\tilde{p}}$ for PUCCH format 3 in subclause 5.5.2.2.1 and determining $n_{\mathrm{oc},0}^{(\tilde{p})}$ and $n_{\mathrm{oc},1}^{(\tilde{p})}$ in subclause 5.4A.3.1
	4	Enabled	see α_{λ} for PUCCH format 4 in subclause 5.5.2.2.1
Subslot	4	Disabled	see α_{λ} for PUCCH format 4 in subclause 5.5.2.2.1

5.5.2.3.2 Mapping to physical resources

The sequence $r_{\mathrm{PSUCCH}}^{(\tilde{p})}(\cdot)$ shall be multiplied with the amplitude scaling factor β_{SPUCCH} and mapped in sequence starting with $r_{\mathrm{SPUCCH}}^{(\tilde{p})}(0)$ to resource elements (k,l) on antenna port p. The mapping shall be in increasing order of first k, then l. The set of values for k and the relation between the index $\tilde{p}$ and the antenna port number p shall be identical to the values used for the corresponding SPUCCH transmission. The values of the symbol index l in a slot and a subslot are given by Table 5.5.2.3.2-1 and Table 5.5.2.3.2-2 respectively.

Table 5.5.2.3.2-1: Demodulation reference signal location for different slot-SPUCCH formats

SPUCCH format	Frequency hopping	Slot	Set of values for l
1, 1a, 1b	Enabled	1st	1, 4, 5
		2nd	1, 2, 5
	Disabled	1st and 2nd	2, 3, 4
3	Disabled	1st and 2nd	1, 5
4	Enabled	1st and 2nd	1, 5

Table 5.5.2.3.2-2: Demodulation reference signal location for different subslot-SPUCCH formats

SPUCCH format	Subslot number in subframe	Slot	l
4	0	1^{st}	0
	1	1^{st}	3
	2	1^{st}	5
	3	2^{nd}	0
	4	2^{nd}	2
	5	2^{nd}	4

5.5.3 Sounding reference signal

5.5.3.1 Sequence generation

The sounding reference signal sequence $r_{\mathrm{SRS}}^{(\tilde{p})}(n)=r_{u,v}^{(\alpha_{\tilde{p}},\delta)}(n)$ is defined by clause 5.5.1, where u is the sequence-group number defined in clause 5.5.1.3, v is the base sequence number defined in clause 5.5.1.4, and $\delta=0$. The cyclic shift $\alpha_{\tilde{p}}$ of the sounding reference signal is given as

$$\alpha_{\tilde{p}}=2\pi\frac{n_{\mathrm{SRS}}^{\mathrm{cs},\tilde{p}}}{n_{\mathrm{SRS}}^{\mathrm{cs,max}}}$$
$$n_{\mathrm{SRS}}^{\mathrm{cs},\tilde{p}}=\left(n_{\mathrm{SRS}}^{\mathrm{cs}}+\frac{n_{\mathrm{SRS}}^{\mathrm{cs,max}}\tilde{p}}{N_{\mathrm{ap}}}\right)\bmod n_{\mathrm{SRS}}^{\mathrm{cs,max}},$$
$$\tilde{p}\in\{0,1,...,N_{\mathrm{ap}}-1\}$$

where $n_{\mathrm{SRS}}^{\mathrm{cs}}=\{0,1,...,n_{\mathrm{SRS}}^{\mathrm{cs,max}}-1\}$ is configured separately for periodic and each configuration of aperiodic sounding by the higher-layer parameters *cyclicShift* and *cyclicShift-ap*, respectively, for each UE and N_{ap} is the number of antenna ports used for sounding reference signal transmission. The parameter $n_{\mathrm{SRS}}^{\mathrm{cs,max}}=8$ if $K_{\mathrm{TC}}=2$, otherwise $n_{\mathrm{SRS}}^{\mathrm{cs,max}}=12$. The parameter K_{TC} is given by the higher layer parameter *transmissionCombNum* if configured, otherwise $K_{\mathrm{TC}}=2$.

5.5.3.2 Mapping to physical resources

The sequence shall be multiplied with the amplitude scaling factor β_{SRS} in order to conform to the transmit power P_{SRS} specified in clause 5.1.3.1 in 3GPP TS 36.213 [4], and mapped in sequence starting with $r_{\mathrm{SRS}}^{(\tilde{p})}(0)$ to resource elements (k,l) on antenna port p according to

$$a_{K_{\mathrm{TC}}k'+k_0^{(p)},l}^{(p)}=\begin{cases}\frac{1}{\sqrt{N_{\mathrm{ap}}}}\beta_{\mathrm{SRS}}r_{SRS}^{(\tilde{p})}(k') & k'=0,1,\ldots,M_{\mathrm{sc},b}^{\mathrm{RS}}-1\\ 0 & \text{otherwise}\end{cases}$$

where N_{ap} is the number of antenna ports used for sounding reference signal transmission and the relation between the index $\tilde{p}$ and the antenna port p is given by Table 5.2.1-1. The set of antenna ports used for sounding reference signal transmission is configured independently for periodic and each configuration of aperiodic sounding. The quantity $k_0^{(p)}$ is the frequency-domain starting position of the sounding reference signal and for $b=B_{\mathrm{SRS}}$ and $M_{\mathrm{sc},b}^{\mathrm{RS}}$ is the length of the sounding reference signal sequence defined as

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

where $m_{\mathrm{SRS},b}$ is given by Table 5.5.3.2-1 through Table 5.5.3.2-4 for each uplink bandwidth $N_{\mathrm{RB}}^{\mathrm{UL}}$. The cell-specific parameter *srs-BandwidthConfig,* $C_{\mathrm{SRS}}\in\{0,1,2,3,4,5,6,7\}$ and the UE-specific parameter *srs-Bandwidth,* $B_{\mathrm{SRS}}\in\{0,1,2,3\}$ are given by higher layers. For UpPTS, $m_{\mathrm{SRS},0}$ shall be reconfigured to $m_{\mathrm{SRS},0}^{\max}=\max_{c\in C_{\mathrm{SRS}}}\{m_{\mathrm{SRS},0}^{c}\}\le\left(N_{\mathrm{RB}}^{\mathrm{UL}}-6N_{\mathrm{RA}}\right)$ if this reconfiguration is enabled by the cell-specific parameter *srsMaxUpPts* given by higher layers, otherwise if the reconfiguration is disabled $m_{\mathrm{SRS},0}^{\max}=m_{\mathrm{SRS},0}$,where c is a SRS BW configuration and C_{SRS} is the set of SRS BW configurations from the Tables 5.5.3.2-1 to 5.5.3.2-4 for each uplink bandwidth $N_{\mathrm{RB}}^{\mathrm{UL}}$, N_{RA} is the number of format 4 PRACH in the addressed UpPTS and derived from Table 5.7.1-4.

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

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

where for normal uplink subframes $\bar{k}_0^{(p)}$ is defined by

$$\bar{k}_0^{(p)} = \left(\left\lfloor N_{\mathrm{RB}}^{\mathrm{UL}}/2 \right\rfloor - m_{\mathrm{SRS},0}/2\right) N_{\mathrm{SC}}^{\mathrm{RB}} + k_{\mathrm{TC}}^{(p)}$$

and for UpPTS by

$$\bar{k}_0^{(p)} = \begin{cases} (N_{\mathrm{RB}}^{\mathrm{UL}} - m_{\mathrm{SRS},0}^{\max}) N_{\mathrm{sc}}^{\mathrm{RB}} + k_{\mathrm{TC}}^{(p)} & \text{if } \left((n_{\mathrm{f}} \bmod 2) \cdot (2 - N_{\mathrm{SP}}) + n_{\mathrm{hf}}\right) \bmod 2 = 0 \\ k_{\mathrm{TC}}^{(p)} & \text{otherwise} \end{cases}$$

The quantity $k_{\mathrm{TC}}^{(p)} \in \{0,1,...,K_{\mathrm{TC}}-1\}$ is given by

$$k_{\mathrm{TC}}^{(p)} = \begin{cases} 1 - \bar{k}_{\mathrm{TC}} & \text{if } n_{\mathrm{SRS}}^{\mathrm{cs}} \in \{4,5,6,7\} \text{ and } \tilde{p} \in \{1,3\} \text{ and } N_{\mathrm{ap}} = 4 \\ \bar{k}_{\mathrm{TC}} & \text{otherwise} \end{cases}$$

where the relation between the index $\tilde{p}$ and the antenna port p is given by Table 5.2.1-1, $\bar{k}_{\mathrm{TC}} \in \{0,1,...,K_{\mathrm{TC}}-1\}$ is given by the UE-specific parameter *transmissionComb* or *transmissionComb-ap* for periodic and each configuration of aperiodic transmission, respectively, provided by higher layers for the UE, and n_b is frequency position index. The variable n_{hf} is equal to 0 for UpPTS in the first half frame and equal to 1 for UpPTS in the second half frame of a radio frame.

The frequency hopping of the sounding reference signal is configured by the parameter $b_{\mathrm{hop}} \in \{0,1,2,3\}$, provided by higher-layer parameter *srs-HoppingBandwidth.* Frequency hopping is not supported for aperiodic transmission. If frequency hopping of the sounding reference signal is not enabled (i.e., $b_{\mathrm{hop}} \geq B_{\mathrm{SRS}}$), the frequency position index n_b remains constant (unless re-configured) and is defined by $n_{\mathrm{b}} = \left\lfloor 4 n_{\mathrm{RRC}} / m_{\mathrm{SRS},b} \right\rfloor \bmod N_{\mathrm{b}}$ where the parameter n_{RRC} is given by higher-layer parameters *freqDomainPosition* and *freqDomainPosition-ap* for periodic and each configuration of aperiodic transmission, respectively. If frequency hopping of the sounding reference signal is enabled (i.e., $b_{\mathrm{hop}} < B_{\mathrm{SRS}}$), the frequency position indexes n_b are defined by

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

where N_b is given by Table 5.5.3.2-1 through Table 5.5.3.2-4 for each uplink bandwidth $N_{\mathrm{RB}}^{\mathrm{UL}}$,

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

where $N_{b_{\mathrm{hop}}} = 1$ regardless of the N_b value on Table 5.5.3.2-1 through Table 5.5.3.2-4, and

$$n_{\mathrm{SRS}} = \begin{cases} 2 N_{\mathrm{SP}} n_{\mathrm{f}} + 2(N_{\mathrm{SP}} - 1) \left\lfloor \dfrac{n_{\mathrm{s}}}{10} \right\rfloor + \left\lfloor \dfrac{T_{\mathrm{offset}}}{T_{\mathrm{offset\_max}}} \right\rfloor, & \text{for 2 ms SRS periodicity of frame structure type 2} \\ \left\lfloor (n_{\mathrm{f}} \times 10 + \left\lfloor n_{\mathrm{s}}/2 \right\rfloor) / T_{\mathrm{SRS}} \right\rfloor, & \text{otherwise} \end{cases}$$

counts the number of UE-specific SRS transmissions, where T_{SRS} is UE-specific periodicity of SRS transmission defined in clause 8.2 of 3GPP TS 36.213 [4], T_{offset} is SRS subframe offset defined in Table 8.2-2 of 3GPP TS 36.213 [4] and $T_{\mathrm{offset\_max}}$ is the maximum value of T_{offset} for a certain configuration of SRS subframe offset.

The sounding reference signal shall be transmitted in the last symbol of the uplink subframe.

Table 5.5.3.2-1: $m_{\text{SRS},b}$ and N_b, $b = 0,1,2,3$, values for the uplink bandwidth of $6 \le N_{\text{RB}}^{\text{UL}} \le 40$

SRS bandwidth configuration C_{SRS}	SRS-Bandwidth $B_{\text{SRS}} = 0$		SRS-Bandwidth $B_{\text{SRS}} = 1$		SRS-Bandwidth $B_{\text{SRS}} = 2$		SRS-Bandwidth $B_{\text{SRS}} = 3$	
	$m_{\text{SRS},0}$	N_0	$m_{\text{SRS},1}$	N_1	$m_{\text{SRS},2}$	N_2	$m_{\text{SRS},3}$	N_3
0	36	1	12	3	4	3	4	1
1	32	1	16	2	8	2	4	2
2	24	1	4	6	4	1	4	1
3	20	1	4	5	4	1	4	1
4	16	1	4	4	4	1	4	1
5	12	1	4	3	4	1	4	1
6	8	1	4	2	4	1	4	1
7	4	1	4	1	4	1	4	1

Table 5.5.3.2-2: $m_{\text{SRS},b}$ and N_b, $b = 0,1,2,3$, values for the uplink bandwidth of $40 < N_{\text{RB}}^{\text{UL}} \le 60$

SRS bandwidth configuration C_{SRS}	SRS-Bandwidth $B_{\text{SRS}} = 0$		SRS-Bandwidth $B_{\text{SRS}} = 1$		SRS-Bandwidth $B_{\text{SRS}} = 2$		SRS-Bandwidth $B_{\text{SRS}} = 3$	
	$m_{\text{SRS},0}$	N_0	$m_{\text{SRS},1}$	N_1	$m_{\text{SRS},2}$	N_2	$m_{\text{SRS},3}$	N_3
0	48	1	24	2	12	2	4	3
1	48	1	16	3	8	2	4	2
2	40	1	20	2	4	5	4	1
3	36	1	12	3	4	3	4	1
4	32	1	16	2	8	2	4	2
5	24	1	4	6	4	1	4	1
6	20	1	4	5	4	1	4	1
7	16	1	4	4	4	1	4	1

Table 5.5.3.2-3: $m_{\text{SRS},b}$ and N_b, $b = 0,1,2,3$, values for the uplink bandwidth of $60 < N_{\text{RB}}^{\text{UL}} \le 80$

SRS bandwidth configuration C_{SRS}	SRS-Bandwidth $B_{\text{SRS}} = 0$		SRS-Bandwidth $B_{\text{SRS}} = 1$		SRS-Bandwidth $B_{\text{SRS}} = 2$		SRS-Bandwidth $B_{\text{SRS}} = 3$	
	$m_{\text{SRS},0}$	N_0	$m_{\text{SRS},1}$	N_1	$m_{\text{SRS},2}$	N_2	$m_{\text{SRS},3}$	N_3
0	72	1	24	3	12	2	4	3
1	64	1	32	2	16	2	4	4
2	60	1	20	3	4	5	4	1
3	48	1	24	2	12	2	4	3
4	48	1	16	3	8	2	4	2
5	40	1	20	2	4	5	4	1
6	36	1	12	3	4	3	4	1
7	32	1	16	2	8	2	4	2

Table 5.5.3.2-4: $m_{\text{SRS},b}$ and N_b, $b = 0,1,2,3$, values for the uplink bandwidth of $80 < N_{\text{RB}}^{\text{UL}} \le 110$

SRS bandwidth configuration C_{SRS}	SRS-Bandwidth $B_{\text{SRS}} = 0$		SRS-Bandwidth $B_{\text{SRS}} = 1$		SRS-Bandwidth $B_{\text{SRS}} = 2$		SRS-Bandwidth $B_{\text{SRS}} = 3$	
	$m_{\text{SRS},0}$	N_0	$m_{\text{SRS},1}$	N_1	$m_{\text{SRS},2}$	N_2	$m_{\text{SRS},3}$	N_3
0	96	1	48	2	24	2	4	6
1	96	1	32	3	16	2	4	4
2	80	1	40	2	20	2	4	5
3	72	1	24	3	12	2	4	3
4	64	1	32	2	16	2	4	4
5	60	1	20	3	4	5	4	1
6	48	1	24	2	12	2	4	3
7	48	1	16	3	8	2	4	2

5.5.3.3 Sounding reference signal subframe configuration

The cell-specific subframe configuration period T_{SFC} and the cell-specific subframe offset Δ_{SFC} for the transmission of sounding reference signals are listed in Tables 5.5.3.3-1 and 5.5.3.3-2, for frame structures type 1 and 2 respectively, where the parameter *srs-SubframeConfig* is provided by higher layers. Sounding reference signal subframes are the subframes satisfying $\lfloor n_{\mathrm{s}}/2 \rfloor \bmod T_{\mathrm{SFC}} \in \Delta_{\mathrm{SFC}}$. For frame structure type 2, a sounding reference signal is transmitted only in uplink subframes or UpPTS.

Table 5.5.3.3-1: Frame structure type 1 sounding reference signal subframe configuration

srs-SubframeConfig	Binary	Configuration Period T_{SFC} (subframes)	Transmission offset Δ_{SFC} (subframes)
0	0000	1	{0}
1	0001	2	{0}
2	0010	2	{1}
3	0011	5	{0}
4	0100	5	{1}
5	0101	5	{2}
6	0110	5	{3}
7	0111	5	{0,1}
8	1000	5	{2,3}
9	1001	10	{0}
10	1010	10	{1}
11	1011	10	{2}
12	1100	10	{3}
13	1101	10	{0,1,2,3,4,6,8}
14	1110	10	{0,1,2,3,4,5,6,8}
15	1111	reserved	reserved

Table 5.5.3.3-2: Frame structure type 2 sounding reference signal subframe configuration

srs-SubframeConfig	Binary	Configuration Period T_{SFC} (subframes)	Transmission offset Δ_{SFC} (subframes)
0	0000	5	{1}
1	0001	5	{1, 2}
2	0010	5	{1, 3}
3	0011	5	{1, 4}
4	0100	5	{1, 2, 3}
5	0101	5	{1, 2, 4}
6	0110	5	{1, 3, 4}
7	0111	5	{1, 2, 3, 4}
8	1000	10	{1, 2, 6}
9	1001	10	{1, 3, 6}
10	1010	10	{1, 6, 7}
11	1011	10	{1, 2, 6, 8}
12	1100	10	{1, 3, 6, 9}
13	1101	10	{1, 4, 6, 7}
14	1110	reserved	reserved
15	1111	reserved	reserved

5.6 SC-FDMA baseband signal generation

This clause applies to all uplink physical signals and uplink physical channels except the physical random access channel and PUSCH using sub-PRB allocations for BL/CE UEs.

The time-continuous signal $s_l^{(p)}(t)$ for antenna port p in SC-FDMA symbol l in an uplink slot is defined by

$$s_l^{(p)}(t)=\sum_{k=-\lfloor N_{\mathrm{RB}}^{\mathrm{UL}}N_{\mathrm{sc}}^{\mathrm{RB}}/2\rfloor}^{\lceil N_{\mathrm{RB}}^{\mathrm{UL}}N_{\mathrm{sc}}^{\mathrm{RB}}/2\rceil-1} a_{k^{(-)},l}^{(p)}\cdot e^{j2\pi(k+1/2)\Delta f\left(t-N_{\mathrm{CP},l}T_{\mathrm{s}}\right)}$$

for $0\le t<\left(N_{\mathrm{CP},l}+N\right)\times T_{\mathrm{s}}$ where $k^{(-)}=k+\lfloor N_{RB}^{UL}N_{sc}^{RB}/2\rfloor$, $N=2048$, $\Delta f=15\,\mathrm{kHz}$ and $a_{k,l}^{(p)}$ is the content of resource element (k,l) on antenna port p.

For frame structure type 3, if the associated DCI indicates PUSCH starting position other than '00' or if 'autonomous PUSCH' is configured, $s_l^{(p)}(t), l=0$ is given by

$$s_0^{(p)}(t)=\begin{cases}0 & 0\le t<N_{\mathrm{start}}^{\mathrm{FS3}}T_{\mathrm{s}}\\ -s_1^{(p)}\left(t-N_{\mathrm{CP},0}T_{\mathrm{s}}\right) & N_{\mathrm{start}}^{\mathrm{FS3}}T_{\mathrm{s}}\le t<\left(N_{\mathrm{CP},0}+N\right)T_{\mathrm{s}}\end{cases}$$

where

$$N_{\mathrm{start}}^{\mathrm{FS3}}=\begin{cases}768 & \text{if the associated DCI indicates PUSCH starting position '01'}\\ 768+N_{\mathrm{TA}} & \text{if the associated DCI indicates PUSCH starting position '10'}\\ N_{\mathrm{CP},0}+N & \text{if the associated DCI indicates PUSCH starting position '11'}\end{cases}$$

and were $N_{\mathrm{start}}^{\mathrm{FS3}}$ is given by TS36.213 [4] if 'autonomous PUSCH' is configured.

The quantity N_{TA} is given by clause 8.1. The UE behaviour if $N_{\mathrm{start}}^{\mathrm{FS3}}>N_{\mathrm{CP},0}+N$ is undefined.

The SC-FDMA symbols in a slot shall be transmitted in increasing order of l, starting with $l=0$, where SC-FDMA symbol $l>0$ starts at time $\sum_{l'=0}^{l-1}(N_{\mathrm{CP},l'}+N)T_{\mathrm{s}}$ within the slot.

Table 5.6-1 lists the values of $N_{\mathrm{CP},l}$ that shall be used.

Table 5.6-1: SC-FDMA parameters

Configuration	Cyclic prefix length $N_{\mathrm{CP},l}$
Normal cyclic prefix	160 for $l=0$ 144 for $l=1,2,...,6$
Extended cyclic prefix	512 for $l=0,1,...,5$

5.6A SC-FDMA baseband signal generation for PUSCH using sub-PRB allocations

5.6A.1 Modulation schemes other than π/2-BPSK

For $M_{\mathrm{sc}}^{\mathrm{RU}} > 1$, the time-continuous signal $s_l^{(p)}(t)$ for antenna port p in SC-FDMA symbol l in an uplink slot is defined by clause 5.6 with $N_{\mathrm{RB}}^{\mathrm{UL}} N_{\mathrm{sc}}^{\mathrm{RB}}$ replaced by $M_{\mathrm{sc}}^{\mathrm{UL}}$.

5.6A.2 Modulation scheme π/2-BPSK

For $M_{\mathrm{sc}}^{\mathrm{RU}} = 3$ and π/2-BPSK modulation only 2-of-3 adjacent subcarriers are selected as described in 5.5.2.1A.2. The time-continuous signal $s_{k,l}(t)$ in SC-FDMA symbol l in an uplink slot is defined by

$$
\begin{aligned}
s_{k,l}(t) &= s_{\mathrm{sc1}}(t) + s_{\mathrm{sc2}}(t) \\
s_{\mathrm{sc1}}(t) &= a_{k^{(-)},l}\, e^{j\phi_{k,l}} e^{j2\pi(k+1/2)\Delta f(t-N_{\mathrm{CP},l}T_{\mathrm{s}})} \\
s_{\mathrm{sc2}}(t) &= a_{k^{(-)}+1,l}\, e^{j\phi_{k,l}} e^{j2\pi(k+3/2)\Delta f(t-N_{\mathrm{CP},l}T_{\mathrm{s}})} \\
k^{(-)} &= k + \left\lfloor M_{\mathrm{sc}}^{\mathrm{UL}} / 2 \right\rfloor
\end{aligned}
$$

for $0 \le t < \left(N_{\mathrm{CP},l} + N\right) T_{\mathrm{s}}$ where $N = 2048$, $\Delta f = 15\ \mathrm{kHz}$, $N_{\mathrm{CP},l}$ is given by Table 5.6-1, and $a_{k^{(-)},l}$ and $a_{k^{(-)}+1,l}$ are respectively the modulation value for subcarrier index $k^{(-)}$ and $k^{(-)}+1$ for symbol l, and the values of k used on $s_{\mathrm{sc1}}(t)$ and $s_{\mathrm{sc2}}(t)$ are respectively obtained by subtracting $\left\lfloor M_{\mathrm{sc}}^{\mathrm{UL}} / 2 \right\rfloor$ from the resulting set of allocated subcarriers as described in Table 8.1.6-1 of [4], and $k^{(-)}$ represents the lower subcarrier index among the selected subcarriers and $k^{(-)}+1$ is the subcarrier index adjacent to it. The phase rotation ϕ is given by

$$
\begin{aligned}
\phi &= \frac{\pi}{2}\left(\tilde{l} \bmod 2\right) + \varphi_{\mathrm{avg}_k}\left(\tilde{l}\right) \\
\varphi_{\mathrm{avg}_k}\left(\tilde{l}\right) &= \varphi_{\mathrm{avg}_k}\left(\tilde{l}-1\right) + 2\pi\Delta f\,(k+1)\left(N + N_{\mathrm{CP},\,l}\right)T_{\mathrm{s}} \ \text{ when } \tilde{l} > 0 \\
\varphi_{\mathrm{avg}_k}(0) &= 0 \\
\tilde{l} &= 0,1,\ldots,N_{\mathrm{rep}}^{\mathrm{PUSCH}} M_{\mathrm{RU}} M_{\mathrm{slots}}^{\mathrm{UL}} M_{\mathrm{symb}}^{\mathrm{UL}} - 1 \\
l &= \tilde{l} \bmod M_{\mathrm{symb}}^{\mathrm{UL}}
\end{aligned}
$$

where $\tilde{l}$ is a symbol counter that is reset at the start of a transmission and incremented for each symbol during the transmission.

The SC-FDMA symbols in a slot shall be transmitted in increasing order of l, starting with $l = 0$, where SC-FDMA symbol $l > 0$ starts at time $\sum_{l'=0}^{l-1} (N_{\mathrm{CP},l'} + N) T_{\mathrm{s}}$ within the slot.

5.7 Physical random access channel

5.7.1 Time and frequency structure

The physical layer random access preamble, illustrated in Figure 5.7.1-1, consists of a cyclic prefix of length T_{CP} and a sequence part of length T_{SEQ}. The parameter values are listed in Table 5.7.1-1 and depend on the frame structure and the random access configuration. Higher layers control the preamble format.

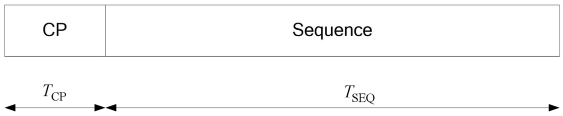

Figure 5.7.1-1: Random access preamble format

Table 5.7.1-1: Random access preamble parameters

Preamble format	T_{CP}	T_{SEQ}
0	$3168 \cdot T_{\mathrm{s}}$	$24576 \cdot T_{\mathrm{s}}$
1	$21024 \cdot T_{\mathrm{s}}$	$24576 \cdot T_{\mathrm{s}}$
2	$6240 \cdot T_{\mathrm{s}}$	$2 \cdot 24576 \cdot T_{\mathrm{s}}$
3	$21024 \cdot T_{\mathrm{s}}$	$2 \cdot 24576 \cdot T_{\mathrm{s}}$
4 (see Note)	$448 \cdot T_{\mathrm{s}}$	$4096 \cdot T_{\mathrm{s}}$
NOTE: Frame structure type 2 and special subframe configurations with UpPTS lengths $4384 \cdot T_{\mathrm{s}}$ and $5120 \cdot T_{\mathrm{s}}$ only assuming that the number of additional SC-FDMA symbols in UpPTS X in Table 4.2-1 is 0.		

The transmission of a random access preamble, if triggered by the MAC layer, is restricted to certain time and frequency resources. These resources are enumerated in increasing order of the subframe number within the radio frame and the physical resource blocks in the frequency domain such that index 0 correspond to the lowest numbered physical resource block and subframe within the radio frame. PRACH resources within the radio frame are indicated by a PRACH configuration index, where the indexing is in the order of appearance in Table 5.7.1-2 and Table 5.7.1-4.

For non-BL/CE UEs there are up to two PRACH configurations in a cell. The first PRACH configuration is configured by higher layers with a PRACH configuration index (*prach-ConfigurationIndex*) and a PRACH frequency offset $n_{\mathrm{PRB\,offset}}^{\mathrm{RA}}$ (*prach-FrequencyOffset*). The second PRACH configuration (if any) is configured by higher layers with a PRACH configuration index (*prach-ConfigurationIndexHighSpeed*) and a PRACH frequency offset $n_{\mathrm{PRB\,offset}}^{\mathrm{RA}}$ (*prach-FrequencyOffsetHighSpeed*).

For BL/CE UEs, for each PRACH coverage enhancement level, there is a PRACH configuration configured by higher layers with a PRACH configuration index (*prach-ConfigurationIndex*), a PRACH frequency offset $\overline{n}_{\mathrm{PRBoffset}}^{\mathrm{RA}}$ (*prach-FrequencyOffset*), a number of PRACH repetitions per attempt $N_{\mathrm{rep}}^{\mathrm{PRACH}}$ (*numRepetitionPerPreambleAttempt*) and optionally a PRACH starting subframe periodicity $N_{\mathrm{start}}^{\mathrm{PRACH}}$ (*prach-StartingSubframe*). PRACH of preamble format 0-3 is transmitted $N_{\mathrm{rep}}^{\mathrm{PRACH}} \geq 1$ times, whereas PRACH of preamble format 4 is transmitted one time only.

For BL/CE UEs and for each PRACH coverage enhancement level, if frequency hopping is enabled for a PRACH configuration by the higher-layer parameter *prach-HoppingConfig*, the value of the parameter $n_{\mathrm{PRB\,offset}}^{\mathrm{RA}}$ depends on the SFN and the PRACH configuration index and is given by

- In case the PRACH configuration index is such that a PRACH resource occurs in every radio frame when calculated as below from Table 5.7.1-2 or Table 5.7.1-4,

$$n_{\text{PRB offset}}^{\text{RA}} = \begin{cases} \bar{n}_{\text{PRB offset}}^{\text{RA}} & \text{if } \mathrm{n_f} \bmod 2 = 0 \\ \left(\bar{n}_{\text{PRB offset}}^{\text{RA}} + f_{\text{PRB,hop}}^{\text{PRACH}}\right) \bmod N_{\text{RB}}^{\text{UL}} & \text{if } \mathrm{n_f} \bmod 2 = 1 \end{cases}$$

- otherwise

$$n_{\text{PRB offset}}^{\text{RA}} = \begin{cases} \bar{n}_{\text{PRB offset}}^{\text{RA}} & \text{if } \left\lfloor \frac{\mathrm{n_f} \bmod 4}{2} \right\rfloor = 0 \\ \left(\bar{n}_{\text{PRB offset}}^{\text{RA}} + f_{\text{PRB,hop}}^{\text{PRACH}}\right) \bmod N_{\text{RB}}^{\text{UL}} & \text{if } \left\lfloor \frac{\mathrm{n_f} \bmod 4}{2} \right\rfloor = 1 \end{cases}$$

where n_{f} is the system frame number corresponding to the first subframe for each PRACH repetition, $f_{\text{PRB,hop}}^{\text{PRACH}}$ corresponds to a cell-specific higher-layer parameter *prach-HoppingOffset*. If frequency hopping is not enabled for the PRACH configuration then $n_{\text{PRB offset}}^{\text{RA}} = \bar{n}_{\text{PRB offset}}^{\text{RA}}$.

For frame structure type 1 with preamble format 0-3, for each of the PRACH configurations there is at most one random access resource per subframe.
Table 5.7.1-2 lists the preamble formats according to Table 5.7.1-1 and the subframes in which random access preamble transmission is allowed for a given configuration in frame structure type 1. The start of the random access preamble shall be aligned with the start of the corresponding uplink subframe at the UE assuming $N_{\text{TA}} = 0$, where N_{TA} is defined in clause 8.1. For PRACH configurations 0, 1, 2, 15, 16, 17, 18, 31, 32, 33, 34, 47, 48, 49, 50 and 63 the UE may for handover purposes assume an absolute value of the relative time difference between radio frame i in the current cell and the target cell of less than $153600 \cdot T_{\text{s}}$.

The first physical resource block $n_{\text{PRB}}^{\text{RA}}$ allocated to the PRACH opportunity considered for preamble formats 0, 1, 2 and 3 is defined as $n_{\text{PRB}}^{\text{RA}} = n_{\text{PRB offset}}^{\text{RA}}$.

Table 5.7.1-2: Frame structure type 1 random access configuration for preamble formats 0-3

PRACH Configuration Index	Preamble Format	System frame number	Subframe number	PRACH Configuration Index	Preamble Format	System frame number	Subframe number
0	0	Even	1	32	2	Even	1
1	0	Even	4	33	2	Even	4
2	0	Even	7	34	2	Even	7
3	0	Any	1	35	2	Any	1
4	0	Any	4	36	2	Any	4
5	0	Any	7	37	2	Any	7
6	0	Any	1, 6	38	2	Any	1, 6
7	0	Any	2 ,7	39	2	Any	2 ,7
8	0	Any	3, 8	40	2	Any	3, 8
9	0	Any	1, 4, 7	41	2	Any	1, 4, 7
10	0	Any	2, 5, 8	42	2	Any	2, 5, 8
11	0	Any	3, 6, 9	43	2	Any	3, 6, 9
12	0	Any	0, 2, 4, 6, 8	44	2	Any	0, 2, 4, 6, 8
13	0	Any	1, 3, 5, 7, 9	45	2	Any	1, 3, 5, 7, 9
14	0	Any	0, 1, 2, 3, 4, 5, 6, 7, 8, 9	46	N/A	N/A	N/A
15	0	Even	9	47	2	Even	9
16	1	Even	1	48	3	Even	1
17	1	Even	4	49	3	Even	4
18	1	Even	7	50	3	Even	7
19	1	Any	1	51	3	Any	1
20	1	Any	4	52	3	Any	4
21	1	Any	7	53	3	Any	7
22	1	Any	1, 6	54	3	Any	1, 6
23	1	Any	2 ,7	55	3	Any	2 ,7
24	1	Any	3, 8	56	3	Any	3, 8
25	1	Any	1, 4, 7	57	3	Any	1, 4, 7
26	1	Any	2, 5, 8	58	3	Any	2, 5, 8
27	1	Any	3, 6, 9	59	3	Any	3, 6, 9
28	1	Any	0, 2, 4, 6, 8	60	N/A	N/A	N/A
29	1	Any	1, 3, 5, 7, 9	61	N/A	N/A	N/A
30	N/A	N/A	N/A	62	N/A	N/A	N/A
31	1	Even	9	63	3	Even	9

For frame structure type 2 with preamble formats 0-4, for each of the PRACH configurations there might be multiple random access resources in an UL subframe (or UpPTS for preamble format 4) depending on the UL/DL configuration [see table 4.2-2]. Table 5.7.1-3 lists PRACH configurations allowed for frame structure type 2 where the configuration index corresponds to a certain combination of preamble format, PRACH density value, D_{RA} and version index, r_{RA}. For frame structure type 2 with PRACH configuration indices 0, 1, 2, 20, 21, 22, 30, 31, 32, 40, 41, 42, 48, 49, 50, or with PRACH configuration indices 51, 53, 54, 55, 56, 57 in UL/DL configuration 3, 4, 5, the UE may for handover purposes assume an absolute value of the relative time difference between radio frame i in the current cell and the target cell is less than $153600 \cdot T_{\mathrm{s}}$.

Table 5.7.1-3: Frame structure type 2 random access configurations for preamble formats 0-4

PRACH configuration Index	Preamble Format	Density Per 10 ms D_{RA}	Version r_{RA}	PRACH configuration Index	Preamble Format	Density Per 10 ms D_{RA}	Version r_{RA}
0	0	0.5	0	32	2	0.5	2
1	0	0.5	1	33	2	1	0
2	0	0.5	2	34	2	1	1
3	0	1	0	35	2	2	0
4	0	1	1	36	2	3	0
5	0	1	2	37	2	4	0
6	0	2	0	38	2	5	0
7	0	2	1	39	2	6	0
8	0	2	2	40	3	0.5	0
9	0	3	0	41	3	0.5	1
10	0	3	1	42	3	0.5	2
11	0	3	2	43	3	1	0
12	0	4	0	44	3	1	1
13	0	4	1	45	3	2	0
14	0	4	2	46	3	3	0
15	0	5	0	47	3	4	0
16	0	5	1	48	4	0.5	0
17	0	5	2	49	4	0.5	1
18	0	6	0	50	4	0.5	2
19	0	6	1	51	4	1	0
20	1	0.5	0	52	4	1	1
21	1	0.5	1	53	4	2	0
22	1	0.5	2	54	4	3	0
23	1	1	0	55	4	4	0
24	1	1	1	56	4	5	0
25	1	2	0	57	4	6	0
26	1	3	0	58	N/A	N/A	N/A
27	1	4	0	59	N/A	N/A	N/A
28	1	5	0	60	N/A	N/A	N/A
29	1	6	0	61	N/A	N/A	N/A
30	2	0.5	0	62	N/A	N/A	N/A
31	2	0.5	1	63	N/A	N/A	N/A

Table 5.7.1-4 lists the mapping to physical resources for the different random access opportunities needed for a certain PRACH density value, D_{RA}. Each quadruple of the format $(f_{\mathrm{RA}}, t_{\mathrm{RA}}^{(0)}, t_{\mathrm{RA}}^{(1)}, t_{\mathrm{RA}}^{(2)})$ indicates the location of a specific random access resource, where f_{RA} is a frequency resource index within the considered time instance, $t_{\mathrm{RA}}^{(0)} = 0,1,2$ indicates whether the resource is reoccurring in all radio frames, in even radio frames, or in odd radio frames, respectively, $t_{\mathrm{RA}}^{(1)} = 0,1$ indicates whether the random access resource is located in first half frame or in second half frame, respectively, and where $t_{\mathrm{RA}}^{(2)}$ is the uplink subframe number where the preamble starts, counting from 0 at the first uplink subframe between 2 consecutive downlink-to-uplink switch points, with the exception of preamble format 4 where $t_{\mathrm{RA}}^{(2)}$ is denoted as (*). The start of the random access preamble formats 0-3 shall be aligned with the start of the corresponding uplink subframe at the UE assuming $N_{\mathrm{TA}} = 0$ and the random access preamble format 4 shall start $4832 \cdot T_{\mathrm{s}}$ before the end of the UpPTS at the UE, where the UpPTS is referenced to the UE's uplink frame timing assuming $N_{\mathrm{TA}} = 0$.

The random access opportunities for each PRACH configuration shall be allocated in time first and then in frequency if and only if time multiplexing is not sufficient to hold all opportunities of a PRACH configuration needed for a certain density value D_{RA} without overlap in time. For preamble format 0-3, the frequency multiplexing shall be done according to

$$n_{\text{PRB}}^{\text{RA}} = \begin{cases} n_{\text{PRB offset}}^{\text{RA}} + 6\left\lfloor \dfrac{f_{\text{RA}}}{2} \right\rfloor, & \text{if } f_{\text{RA}} \bmod 2 = 0 \\ N_{\text{RB}}^{\text{UL}} - 6 - n_{\text{PRB offset}}^{\text{RA}} - 6\left\lfloor \dfrac{f_{\text{RA}}}{2} \right\rfloor, & \text{otherwise} \end{cases}$$

where $N_{\text{RB}}^{\text{UL}}$ is the number of uplink resource blocks, $n_{\text{PRB}}^{\text{RA}}$ is the first physical resource block allocated to the PRACH opportunity considered and where $n_{\text{PRB offset}}^{\text{RA}}$ is the first physical resource block available for PRACH.

For preamble format 4, the frequency multiplexing shall be done according to

$$n_{\text{PRB}}^{\text{RA}} = \begin{cases} 6 f_{\text{RA}}, & \text{if } \left((n_{\text{f}} \bmod 2) \times (2 - N_{\text{SP}}) + t_{\text{RA}}^{(1)}\right) \bmod 2 = 0 \\ N_{\text{RB}}^{\text{UL}} - 6(f_{\text{RA}} + 1), & \text{otherwise} \end{cases}$$

where n_{f} is the system frame number and where N_{SP} is the number of DL to UL switch points within the radio frame.

For BL/CE UEs, only a subset of the subframes allowed for preamble transmission are allowed as starting subframes for the $N_{\text{rep}}^{\text{PRACH}}$ repetitions. The allowed starting subframes for a PRACH configuration are determined as follows:

- Enumerate the subframes that are allowed for preamble transmission for the PRACH configuration as $n_{\text{sf}}^{\text{RA}} = 0, \ldots N_{\text{sf}}^{\text{RA}} - 1$ where $n_{\text{sf}}^{\text{RA}} = 0$ and $n_{\text{sf}}^{\text{RA}} = N_{\text{sf}}^{\text{RA}} - 1$ correspond to the two subframes allowed for preamble transmission with the smallest and the largest absolute subframe number $n_{\text{sf}}^{\text{abs}}$, respectively.

- If a PRACH starting subframe periodicity $N_{\text{start}}^{\text{PRACH}}$ is not provided by higher layers, the periodicity of the allowed starting subframes in terms of subframes allowed for preamble transmission is $N_{\text{rep}}^{\text{PRACH}}$. The allowed starting subframes defined over $n_{\text{sf}}^{\text{RA}} = 0, \ldots N_{\text{sf}}^{\text{RA}} - 1$ are given by $j N_{\text{rep}}^{\text{PRACH}}$ where $j = 0, 1, 2, \ldots$

- If a PRACH starting subframe periodicity $N_{\text{start}}^{\text{PRACH}}$ is provided by higher layers, it indicates the periodicity of the allowed starting subframes in terms of subframes allowed for preamble transmission. The allowed starting subframes defined over $n_{\text{sf}}^{\text{RA}} = 0, \ldots N_{\text{sf}}^{\text{RA}} - 1$ are given by $j N_{\text{start}}^{\text{PRACH}} + N_{\text{rep}}^{\text{PRACH}}$ where $j = 0, 1, 2, \ldots$

- No starting subframe defined over $n_{\text{sf}}^{\text{RA}} = 0, \ldots N_{\text{sf}}^{\text{RA}} - 1$ such that $n_{\text{sf}}^{\text{RA}} > N_{\text{sf}}^{\text{RA}} - N_{\text{rep}}^{\text{PRACH}}$ is allowed.

Each random access preamble occupies a bandwidth corresponding to 6 consecutive resource blocks for both frame structures.

Table 5.7.1-4: Frame structure type 2 random access preamble mapping in time and frequency

PRACH configuration Index (See Table 5.7.1-3)	UL/DL configuration (See Table 4.2-2)						
	0	1	2	3	4	5	6
0	(0,1,0,2)	(0,1,0,1)	(0,1,0,0)	(0,1,0,2)	(0,1,0,1)	(0,1,0,0)	(0,1,0,2)
1	(0,2,0,2)	(0,2,0,1)	(0,2,0,0)	(0,2,0,2)	(0,2,0,1)	(0,2,0,0)	(0,2,0,2)
2	(0,1,1,2)	(0,1,1,1)	(0,1,1,0)	(0,1,0,1)	(0,1,0,0)	N/A	(0,1,1,1)
3	(0,0,0,2)	(0,0,0,1)	(0,0,0,0)	(0,0,0,2)	(0,0,0,1)	(0,0,0,0)	(0,0,0,2)
4	(0,0,1,2)	(0,0,1,1)	(0,0,1,0)	(0,0,0,1)	(0,0,0,0)	N/A	(0,0,1,1)
5	(0,0,0,1)	(0,0,0,0)	N/A	(0,0,0,0)	N/A	N/A	(0,0,0,1)
6	(0,0,0,2) (0,0,1,2)	(0,0,0,1) (0,0,1,1)	(0,0,0,0) (0,0,1,0)	(0,0,0,1) (0,0,0,2)	(0,0,0,0) (0,0,0,1)	(0,0,0,0) (1,0,0,0)	(0,0,0,2) (0,0,1,1)
7	(0,0,0,1) (0,0,1,1)	(0,0,0,0) (0,0,1,0)	N/A	(0,0,0,0) (0,0,0,2)	N/A	N/A	(0,0,0,1) (0,0,1,0)
8	(0,0,0,0) (0,0,1,0)	N/A	N/A	(0,0,0,0) (0,0,0,1)	N/A	N/A	(0,0,0,0) (0,0,1,1)
9	(0,0,0,1) (0,0,0,2) (0,0,1,2)	(0,0,0,0) (0,0,0,1) (0,0,1,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0)	(0,0,0,0) (0,0,0,1) (0,0,0,2)	(0,0,0,0) (0,0,0,1) (1,0,0,1)	(0,0,0,0) (1,0,0,0) (2,0,0,0)	(0,0,0,1) (0,0,0,2) (0,0,1,1)
10	(0,0,0,0) (0,0,1,0) (0,0,1,1)	(0,0,0,1) (0,0,1,0) (0,0,1,1)	(0,0,0,0) (0,0,1,0) (1,0,1,0)	N/A	(0,0,0,0) (0,0,0,1) (1,0,0,0)	N/A	(0,0,0,0) (0,0,0,2) (0,0,1,0)
11	N/A	(0,0,0,0) (0,0,0,1) (0,0,1,0)	N/A	N/A	N/A	N/A	(0,0,0,1) (0,0,1,0) (0,0,1,1)
12	(0,0,0,1) (0,0,0,2) (0,0,1,1) (0,0,1,2)	(0,0,0,0) (0,0,0,1) (0,0,1,0) (0,0,1,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0) (1,0,1,0)	(0,0,0,0) (0,0,0,1) (0,0,0,2) (1,0,0,2)	(0,0,0,0) (0,0,0,1) (1,0,0,0) (1,0,0,1)	(0,0,0,0) (1,0,0,0) (2,0,0,0) (3,0,0,0)	(0,0,0,1) (0,0,0,2) (0,0,1,0) (0,0,1,1)
13	(0,0,0,0) (0,0,0,2) (0,0,1,0) (0,0,1,2)	N/A	N/A	(0,0,0,0) (0,0,0,1) (0,0,0,2) (1,0,0,1)	N/A	N/A	(0,0,0,0) (0,0,0,1) (0,0,0,2) (0,0,1,1)
14	(0,0,0,0) (0,0,0,1) (0,0,1,0) (0,0,1,1)	N/A	N/A	(0,0,0,0) (0,0,0,1) (0,0,0,2) (1,0,0,0)	N/A	N/A	(0,0,0,0) (0,0,0,2) (0,0,1,0) (0,0,1,1)
15	(0,0,0,0) (0,0,0,1) (0,0,0,2) (0,0,1,1) (0,0,1,2)	(0,0,0,0) (0,0,0,1) (0,0,1,0) (0,0,1,1) (1,0,0,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0) (1,0,1,0) (2,0,0,0)	(0,0,0,0) (0,0,0,1) (0,0,0,2) (1,0,0,1) (1,0,0,2)	(0,0,0,0) (0,0,0,1) (1,0,0,0) (1,0,0,1) (2,0,0,1)	(0,0,0,0) (1,0,0,0) (2,0,0,0) (3,0,0,0) (4,0,0,0)	(0,0,0,0) (0,0,0,1) (0,0,0,2) (0,0,1,0) (0,0,1,1)
16	(0,0,0,1) (0,0,0,2) (0,0,1,0) (0,0,1,1) (0,0,1,2)	(0,0,0,0) (0,0,0,1) (0,0,1,0) (0,0,1,1) (1,0,1,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0) (1,0,1,0) (2,0,1,0)	(0,0,0,0) (0,0,0,1) (0,0,0,2) (1,0,0,0) (1,0,0,2)	(0,0,0,0) (0,0,0,1) (1,0,0,0) (1,0,0,1) (2,0,0,0)	N/A	N/A
17	(0,0,0,0) (0,0,0,1) (0,0,0,2) (0,0,1,0) (0,0,1,2)	(0,0,0,0) (0,0,0,1) (0,0,1,0) (0,0,1,1) (1,0,0,0)	N/A	(0,0,0,0) (0,0,0,1) (0,0,0,2) (1,0,0,0) (1,0,0,1)	N/A	N/A	N/A
18	(0,0,0,0) (0,0,0,1) (0,0,0,2) (0,0,1,0) (0,0,1,1) (0,0,1,2)	(0,0,0,0) (0,0,0,1) (0,0,1,0) (0,0,1,1) (1,0,0,1) (1,0,1,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0) (1,0,1,0) (2,0,0,0) (2,0,1,0)	(0,0,0,0) (0,0,0,1) (0,0,0,2) (1,0,0,0) (1,0,0,1) (1,0,0,2)	(0,0,0,0) (0,0,0,1) (1,0,0,0) (1,0,0,1) (2,0,0,0) (2,0,0,1)	(0,0,0,0) (1,0,0,0) (2,0,0,0) (3,0,0,0) (4,0,0,0) (5,0,0,0)	(0,0,0,0) (0,0,0,1) (0,0,0,2) (0,0,1,0) (0,0,1,1) (1,0,0,2)
19	N/A	(0,0,0,0) (0,0,0,1) (0,0,1,0) (0,0,1,1) (1,0,0,0) (1,0,1,0)	N/A	N/A	N/A	N/A	(0,0,0,0) (0,0,0,1) (0,0,0,2) (0,0,1,0) (0,0,1,1) (1,0,1,1)
20 / 30	(0,1,0,1)	(0,1,0,0)	N/A	(0,1,0,1)	(0,1,0,0)	N/A	(0,1,0,1)
21 / 31	(0,2,0,1)	(0,2,0,0)	N/A	(0,2,0,1)	(0,2,0,0)	N/A	(0,2,0,1)
22 / 32	(0,1,1,1)	(0,1,1,0)	N/A	N/A	N/A	N/A	(0,1,1,0)
23 / 33	(0,0,0,1)	(0,0,0,0)	N/A	(0,0,0,1)	(0,0,0,0)	N/A	(0,0,0,1)
24 / 34	(0,0,1,1)	(0,0,1,0)	N/A	N/A	N/A	N/A	(0,0,1,0)

25 / 35	(0,0,0,1) (0,0,1,1)	(0,0,0,0) (0,0,1,0)	N/A	(0,0,0,1) (1,0,0,1)	(0,0,0,0) (1,0,0,0)	N/A	(0,0,0,1) (0,0,1,0)
26 / 36	(0,0,0,1) (0,0,1,1) (1,0,0,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0)	N/A	(0,0,0,1) (1,0,0,1) (2,0,0,1)	(0,0,0,0) (1,0,0,0) (2,0,0,0)	N/A	(0,0,0,1) (0,0,1,0) (1,0,0,1)
27 / 37	(0,0,0,1) (0,0,1,1) (1,0,0,1) (1,0,1,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0) (1,0,1,0)	N/A	(0,0,0,1) (1,0,0,1) (2,0,0,1) (3,0,0,1)	(0,0,0,0) (1,0,0,0) (2,0,0,0) (3,0,0,0)	N/A	(0,0,0,1) (0,0,1,0) (1,0,0,1) (1,0,1,0)
28 / 38	(0,0,0,1) (0,0,1,1) (1,0,0,1) (1,0,1,1) (2,0,0,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0) (1,0,1,0) (2,0,0,0)	N/A	(0,0,0,1) (1,0,0,1) (2,0,0,1) (3,0,0,1) (4,0,0,1)	(0,0,0,0) (1,0,0,0) (2,0,0,0) (3,0,0,0) (4,0,0,0)	N/A	(0,0,0,1) (0,0,1,0) (1,0,0,1) (1,0,1,0) (2,0,0,1)
29 /39	(0,0,0,1) (0,0,1,1) (1,0,0,1) (1,0,1,1) (2,0,0,1) (2,0,1,1)	(0,0,0,0) (0,0,1,0) (1,0,0,0) (1,0,1,0) (2,0,0,0) (2,0,1,0)	N/A	(0,0,0,1) (1,0,0,1) (2,0,0,1) (3,0,0,1) (4,0,0,1) (5,0,0,1)	(0,0,0,0) (1,0,0,0) (2,0,0,0) (3,0,0,0) (4,0,0,0) (5,0,0,0)	N/A	(0,0,0,1) (0,0,1,0) (1,0,0,1) (1,0,1,0) (2,0,0,1) (2,0,1,0)
40	(0,1,0,0)	N/A	N/A	(0,1,0,0)	N/A	N/A	(0,1,0,0)
41	(0,2,0,0)	N/A	N/A	(0,2,0,0)	N/A	N/A	(0,2,0,0)
42	(0,1,1,0)	N/A	N/A	N/A	N/A	N/A	N/A
43	(0,0,0,0)	N/A	N/A	(0,0,0,0)	N/A	N/A	(0,0,0,0)
44	(0,0,1,0)	N/A	N/A	N/A	N/A	N/A	N/A
45	(0,0,0,0) (0,0,1,0)	N/A	N/A	(0,0,0,0) (1,0,0,0)	N/A	N/A	(0,0,0,0) (1,0,0,0)
46	(0,0,0,0) (0,0,1,0) (1,0,0,0)	N/A	N/A	(0,0,0,0) (1,0,0,0) (2,0,0,0)	N/A	N/A	(0,0,0,0) (1,0,0,0) (2,0,0,0)
47	(0,0,0,0) (0,0,1,0) (1,0,0,0) (1,0,1,0)	N/A	N/A	(0,0,0,0) (1,0,0,0) (2,0,0,0) (3,0,0,0)	N/A	N/A	(0,0,0,0) (1,0,0,0) (2,0,0,0) (3,0,0,0)
48	(0,1,0,*)	(0,1,0,*)	(0,1,0,*)	(0,1,0,*)	(0,1,0,*)	(0,1,0,*)	(0,1,0,*)
49	(0,2,0,*)	(0,2,0,*)	(0,2,0,*)	(0,2,0,*)	(0,2,0,*)	(0,2,0,*)	(0,2,0,*)
50	(0,1,1,*)	(0,1,1,*)	(0,1,1,*)	N/A	N/A	N/A	(0,1,1,*)
51	(0,0,0,*)	(0,0,0,*)	(0,0,0,*)	(0,0,0,*)	(0,0,0,*)	(0,0,0,*)	(0,0,0,*)
52	(0,0,1,*)	(0,0,1,*)	(0,0,1,*)	N/A	N/A	N/A	(0,0,1,*)
53	(0,0,0,*) (0,0,1,*)	(0,0,0,*) (0,0,1,*)	(0,0,0,*) (0,0,1,*)	(0,0,0,*) (1,0,0,*)	(0,0,0,*) (1,0,0,*)	(0,0,0,*) (1,0,0,*)	(0,0,0,*) (0,0,1,*)
54	(0,0,0,*) (0,0,1,*) (1,0,0,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*)
55	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*)
56	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*) (2,0,0,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*) (2,0,0,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*) (2,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*) (4,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*) (4,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*) (4,0,0,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*) (2,0,0,*)
57	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*) (2,0,0,*) (2,0,1,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*) (2,0,0,*) (2,0,1,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*) (2,0,0,*) (2,0,1,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*) (4,0,0,*) (5,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*) (4,0,0,*) (5,0,0,*)	(0,0,0,*) (1,0,0,*) (2,0,0,*) (3,0,0,*) (4,0,0,*) (5,0,0,*)	(0,0,0,*) (0,0,1,*) (1,0,0,*) (1,0,1,*) (2,0,0,*) (2,0,1,*)
58	N/A	N/A	N/A	N/A	N/A	N/A	N/A
59	N/A	N/A	N/A	N/A	N/A	N/A	N/A
60	N/A	N/A	N/A	N/A	N/A	N/A	N/A
61	N/A	N/A	N/A	N/A	N/A	N/A	N/A
62	N/A	N/A	N/A	N/A	N/A	N/A	N/A
63	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NOTE: * UpPTS							

5.7.2 Preamble sequence generation

The random access preambles are generated from Zadoff-Chu sequences with zero correlation zone, generated from one or several root Zadoff-Chu sequences. The network configures the set of preamble sequences the UE is allowed to use.

There are up to two sets of 64 preambles available in a cell where Set 1 corresponds to higher layer PRACH configuration using *prach-ConfigurationIndex and prach-FrequencyOffset* and Set 2, if configured, corresponds to higher layer PRACH configuration using *prach-ConfigurationIndexHighSpeed and prach-FrequencyOffsetHighSpeed*. The set of 64 preamble sequences in a cell is found by including first, in the order of increasing cyclic shift, all the available cyclic shifts of a root Zadoff-Chu sequence with the logical index *rootSequenceIndexHighSpeed* (for Set 2, if configured) or with the logical index RACH_ROOT_SEQUENCE (for Set 1), where both *rootSequenceIndexHighSpeed* (if configured) and RACH_ROOT_SEQUENCE are broadcasted as part of the System Information. Additional preamble sequences, in case 64 preambles cannot be generated from a single root Zadoff-Chu sequence, are obtained from the root sequences with the consecutive logical indexes until all the 64 sequences are found. The logical root sequence order is cyclic: the logical index 0 is consecutive to 837. The relation between a logical root sequence index and physical root sequence index u is given by Tables 5.7.2-4 and 5.7.2-5 for preamble formats 0 – 3 and 4, respectively.

The u^{th} root Zadoff-Chu sequence is defined by

$$x_u(n) = e^{-j\frac{\pi un(n+1)}{N_{\text{ZC}}}}, \quad 0 \le n \le N_{\text{ZC}} - 1$$

where the length N_{ZC} of the Zadoff-Chu sequence is given by Table 5.7.2-1. From the u^{th} root Zadoff-Chu sequence, random access preambles with zero correlation zones of length $N_{\text{CS}} - 1$ are defined by cyclic shifts according to

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

where the cyclic shift is given by

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

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

and N_{CS} is given by Tables 5.7.2-2 and 5.7.2-3 for preamble formats 0-3 and 4, respectively, where the higher-layer parameters *zeroCorrelationZoneConfig* and *zeroCorrelationZoneConfigHighSpeed* shall be used for PRACH preamble Set 1 and Set 2 (if configured), respectively. Restricted set type B shall be used for PRACH preamble Set 2 (if configured), and the parameter *High-speed-flag* provided by higher layers determines if unrestricted set or restricted set type A shall be used for PRACH preamble Set 1.

The variable d_u is the cyclic shift corresponding to a Doppler shift of magnitude $1/T_{\text{SEQ}}$ and is given by

$$d_u = \begin{cases} p & 0 \le p < N_{\text{ZC}}/2 \\ N_{\text{ZC}} - p & \text{otherwise} \end{cases}$$

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

For restricted set type A and $N_{\text{CS}} \le d_u < N_{\text{ZC}}/3$, the parameters are given by

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

For restricted set type A and $N_{\text{ZC}}/3 \le d_u \le (N_{\text{ZC}} - N_{\text{CS}})/2$, the parameters are given by

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

For restricted set type B and $N_{\text{CS}} \le d_u < N_{\text{ZC}}/5$, the parameters are given by

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

For restricted set type B and $N_{\text{ZC}}/5 \le d_u \le (N_{\text{ZC}} - N_{\text{CS}})/4$, the parameters are given by

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

For restricted set type B and $(N_{\text{ZC}} + N_{\text{CS}})/4 \le d_u < 2N_{\text{ZC}}/7$, the parameters are given by

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

For restricted set type B and $2N_{\text{ZC}}/7 \le d_u \le (N_{\text{ZC}} - N_{\text{CS}})/3$, the parameters are given by

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

For restricted set type B and $(N_{\text{ZC}} + N_{\text{CS}})/3 \le d_u < 2N_{\text{ZC}}/5$, the parameters are given by

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

For restricted set type B and $2N_{\text{ZC}}/5 \le d_u \le (N_{\text{ZC}} - N_{\text{CS}})/2$, the parameters are given by

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

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

Table 5.7.2-1: Random access preamble sequence length

Preamble format	N_{ZC}
0 – 3	839
4	139

Table 5.7.2-2: N_{CS} for preamble generation (preamble formats 0-3)

zeroCorrelationZoneConfig, zeroCorrelationZoneConfigHighSpeed	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 5.7.2-3: N_{CS} for preamble generation (preamble format 4)

zeroCorrelationZoneConfig	N_{CS} value
0	2
1	4
2	6
3	8
4	10
5	12
6	15
7	N/A
8	N/A
9	N/A
10	N/A
11	N/A
12	N/A
13	N/A
14	N/A
15	N/A

Table 5.7.2-4: Root Zadoff-Chu sequence order for preamble formats 0 – 3

Logical root sequence number	Physical root sequence number u (in increasing order of the corresponding logical sequence number)
0–23	129, 710, 140, 699, 120, 719, 210, 629, 168, 671, 84, 755, 105, 734, 93, 746, 70, 769, 60, 779 2, 837, 1, 838
24–29	56, 783, 112, 727, 148, 691
30–35	80, 759, 42, 797, 40, 799
36–41	35, 804, 73, 766, 146, 693
42–51	31, 808, 28, 811, 30, 809, 27, 812, 29, 810
52–63	24, 815, 48, 791, 68, 771, 74, 765, 178, 661, 136, 703
64–75	86, 753, 78, 761, 43, 796, 39, 800, 20, 819, 21, 818
76–89	95, 744, 202, 637, 190, 649, 181, 658, 137, 702, 125, 714, 151, 688
90–115	217, 622, 128, 711, 142, 697, 122, 717, 203, 636, 118, 721, 110, 729, 89, 750, 103, 736, 61, 778, 55, 784, 15, 824, 14, 825
116–135	12, 827, 23, 816, 34, 805, 37, 802, 46, 793, 207, 632, 179, 660, 145, 694, 130, 709, 223, 616
136–167	228, 611, 227, 612, 132, 707, 133, 706, 143, 696, 135, 704, 161, 678, 201, 638, 173, 666, 106, 733, 83, 756, 91, 748, 66, 773, 53, 786, 10, 829, 9, 830
168–203	7, 832, 8, 831, 16, 823, 47, 792, 64, 775, 57, 782, 104, 735, 101, 738, 108, 731, 208, 631, 184, 655, 197, 642, 191, 648, 121, 718, 141, 698, 149, 690, 216, 623, 218, 621
204–263	152, 687, 144, 695, 134, 705, 138, 701, 199, 640, 162, 677, 176, 663, 119, 720, 158, 681, 164, 675, 174, 665, 171, 668, 170, 669, 87, 752, 169, 670, 88, 751, 107, 732, 81, 758, 82, 757, 100, 739, 98, 741, 71, 768, 59, 780, 65, 774, 50, 789, 49, 790, 26, 813, 17, 822, 13, 826, 6, 833
264–327	5, 834, 33, 806, 51, 788, 75, 764, 99, 740, 96, 743, 97, 742, 166, 673, 172, 667, 175, 664, 187, 652, 163, 676, 185, 654, 200, 639, 114, 725, 189, 650, 115, 724, 194, 645, 195, 644, 192, 647, 182, 657, 157, 682, 156, 683, 211, 628, 154, 685, 123, 716, 139, 700, 212, 627, 153, 686, 213, 626, 215, 624, 150, 689
328–383	225, 614, 224, 615, 221, 618, 220, 619, 127, 712, 147, 692, 124, 715, 193, 646, 205, 634, 206, 633, 116, 723, 160, 679, 186, 653, 167, 672, 79, 760, 85, 754, 77, 762, 92, 747, 58, 781, 62, 777, 69, 770, 54, 785, 36, 803, 32, 807, 25, 814, 18, 821, 11, 828, 4, 835
384–455	3, 836, 19, 820, 22, 817, 41, 798, 38, 801, 44, 795, 52, 787, 45, 794, 63, 776, 67, 772, 72 767, 76, 763, 94, 745, 102, 737, 90, 749, 109, 730, 165, 674, 111, 728, 209, 630, 204, 635, 117, 722, 188, 651, 159, 680, 198, 641, 113, 726, 183, 656, 180, 659, 177, 662, 196, 643, 155, 684, 214, 625, 126, 713, 131, 708, 219, 620, 222, 617, 226, 613
456–513	230, 609, 232, 607, 262, 577, 252, 587, 418, 421, 416, 423, 413, 426, 411, 428, 376, 463, 395, 444, 283, 556, 285, 554, 379, 460, 390, 449, 363, 476, 384, 455, 388, 451, 386, 453, 361, 478, 387, 452, 360, 479, 310, 529, 354, 485, 328, 511, 315, 524, 337, 502, 349, 490, 335, 504, 324, 515
514–561	323, 516, 320, 519, 334, 505, 359, 480, 295, 544, 385, 454, 292, 547, 291, 548, 381, 458, 399, 440, 380, 459, 397, 442, 369, 470, 377, 462, 410, 429, 407, 432, 281, 558, 414, 425, 247, 592, 277, 562, 271, 568, 272, 567, 264, 575, 259, 580
562–629	237, 602, 239, 600, 244, 595, 243, 596, 275, 564, 278, 561, 250, 589, 246, 593, 417, 422, 248, 591, 394, 445, 393, 446, 370, 469, 365, 474, 300, 539, 299, 540, 364, 475, 362, 477, 298, 541, 312, 527, 313, 526, 314, 525, 353, 486, 352, 487, 343, 496, 327, 512, 350, 489, 326, 513, 319, 520, 332, 507, 333, 506, 348, 491, 347, 492, 322, 517
630–659	330, 509, 338, 501, 341, 498, 340, 499, 342, 497, 301, 538, 366, 473, 401, 438, 371, 468, 408, 431, 375, 464, 249, 590, 269, 570, 238, 601, 234, 605
660–707	257, 582, 273, 566, 255, 584, 254, 585, 245, 594, 251, 588, 412, 427, 372, 467, 282, 557, 403, 436, 396, 443, 392, 447, 391, 448, 382, 457, 389, 450, 294, 545, 297, 542, 311, 528, 344, 495, 345, 494, 318, 521, 331, 508, 325, 514, 321, 518
708–729	346, 493, 339, 500, 351, 488, 306, 533, 289, 550, 400, 439, 378, 461, 374, 465, 415, 424, 270, 569, 241, 598
730–751	231, 608, 260, 579, 268, 571, 276, 563, 409, 430, 398, 441, 290, 549, 304, 535, 308, 531, 358, 481, 316, 523
752–765	293, 546, 288, 551, 284, 555, 368, 471, 253, 586, 256, 583, 263, 576
766–777	242, 597, 274, 565, 402, 437, 383, 456, 357, 482, 329, 510
778–789	317, 522, 307, 532, 286, 553, 287, 552, 266, 573, 261, 578
790–795	236, 603, 303, 536, 356, 483
796–803	355, 484, 405, 434, 404, 435, 406, 433
804–809	235, 604, 267, 572, 302, 537
810–815	309, 530, 265, 574, 233, 606
816–819	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 5.7.2-5: Root Zadoff-Chu sequence order for preamble format 4

Logical root sequence number	Physical root sequence number u (in increasing order of the corresponding logical sequence number)																			
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																			

5.7.3 Baseband signal generation

The time-continuous random access signal $s(t)$ is defined by

$$s(t) = \beta_{\mathrm{PRACH}} \sum_{k=0}^{N_{\mathrm{ZC}}-1} \sum_{n=0}^{N_{\mathrm{ZC}}-1} x_{u,v}(n) \cdot e^{-j\frac{2\pi nk}{N_{\mathrm{ZC}}}} \cdot e^{j2\pi\left(k+\varphi+K\left(k_0+\frac{1}{2}\right)\right)\Delta f_{\mathrm{RA}}\left(t-T_{\mathrm{CP}}\right)}$$

where $0 \le t < T_{\mathrm{SEQ}} + T_{\mathrm{CP}}$, β_{PRACH} is an amplitude scaling factor in order to conform to the transmit power P_{PRACH} specified in clause 6.1 in 3GPP TS 36.213 [4], and $k_0 = n_{\mathrm{PRB}}^{\mathrm{RA}} N_{\mathrm{sc}}^{\mathrm{RB}} - N_{\mathrm{RB}}^{\mathrm{UL}} N_{\mathrm{sc}}^{\mathrm{RB}} / 2$. The location in the frequency domain is controlled by the parameter $n_{\mathrm{PRB}}^{\mathrm{RA}}$ is derived from clause 5.7.1. The factor $K = \Delta f / \Delta f_{\mathrm{RA}}$ accounts for the difference in subcarrier spacing between the random access preamble and uplink data transmission. The variable Δf_{RA} , the subcarrier spacing for the random access preamble, and the variable φ , a fixed offset determining the frequency-domain location of the random access preamble within the physical resource blocks, are both given by Table 5.7.3-1.

Table 5.7.3-1: Random access baseband parameters

Preamble format	Δf_{RA}	φ
0 – 3	1250 Hz	7
4	7500 Hz	2

5.8 Modulation and upconversion

Modulation and upconversion to the carrier frequency of the complex-valued SC-FDMA baseband signal for each antenna port or the complex-valued PRACH baseband signal is shown in Figure 5.8-1. The filtering required prior to transmission is defined by the requirements in 3GPP TS 36.101 [7].

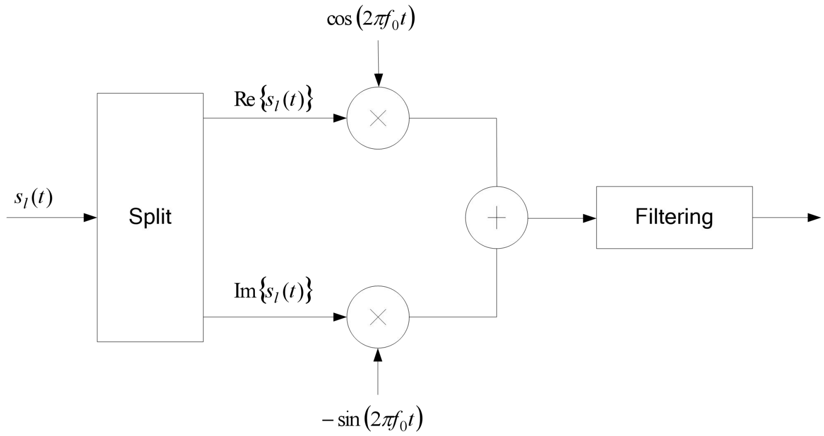

Figure 5.8-1: Uplink modulation