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Technical Specification

KT PyeongChang 5G Special Interest Group (KT 5G-SIG);
KT 5th Generation Radio Access;
Physical Layer;
Physical channels and modulation
(Release 1)

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Document History

Version	Date	Change
1.0	2016-02-17	First Draft Version
2.4	2016-07-13	Pre-final Version
2.5	2016-08-29	Apply CR on ESS and CR for clarification
2.6	2016-09-18	CR on ePBCH configuration approved Editorial corrections

Contents

Foreword

This Technical Specification has been produced by the KT PyeongChang 5G Special Interest Group (KT 5G-SIG).

1 Scope

The present document describes the physical channels for 5G RA.

2 References

[1] TS 5G.201: "5G Radio Access (5G RA); Physical layer; General description".

[2] TS 5G.212: "5G Radio Access (5G RA); Multiplexing and channel coding".

[3] TS 5G.213: "5G Radio Access (5G RA); Physical layer procedures".

[4] TS 5G.214: "5G Radio Access (5G RA); Physical layer – Measurements".

3 Symbols and abbreviations

3.1 Symbols

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

3.2 Abbreviations

For the purposes of the present document, the following apply.

BRS	Beam measurement Reference Signal
BRRS	Beam Refinement Reference Signal
CCE	Control Channel Element
CDD	Cyclic Delay Diversity
PCRS	Phase Noise Compensation Reference Signal
CSI	Channel-State Information
DCI	Downlink Control Information
DM-RS	Demodulation Reference Signal
xPBCH	Physical Broadcast CHannel
xPDCCH	Physical Downlink Control CHannel
xPDSCH	Physical Downlink Shared CHannel
xPRACH	Physical Random Access CHannel
PRB	Physical Resource Block
xPUCCH	Physical Uplink Control CHannel
xPUSCH	Physical Uplink Shared CHannel
REG	Resource-Element Group
SCG	Secondary Cell 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 $T_\mathrm{s} = 1/(75000 \times 2048)$ seconds.

Each radio frame is $T_\mathrm{f} = 1536000 \cdot T_\mathrm{s} = 10\ \mathrm{ms}$ long and consists of 100 slots of length $T_\mathrm{slot} = 15360 \cdot \mathrm{T_s} = 0.1\ \mathrm{ms}$, numbered from 0 to 99. A subframe is defined as two consecutive slots where subframe i consists of slots $2i$ and $2i+1$.

Subframes can be dynamically used for downlink and uplink transmission with exception of control subframes used for synchronization, cell and beam search, and random access.

The first OFDM symbol in all other subframes is reserved for downlink transmission.

A UE treats all OFDM symbols in a subframe as downlink except for OFDM symbols where it has been explicitly instructed to transmit in the uplink.

A UE is not expected to receive in the downlink during the OFDM symbol prior to an uplink transmission which forms a guard period for UL-DL switch and timing advance.

A UE is not expected to receive in the downlink in any OFDM symbol where it is scheduled for uplink transmission on at least one component carrier.

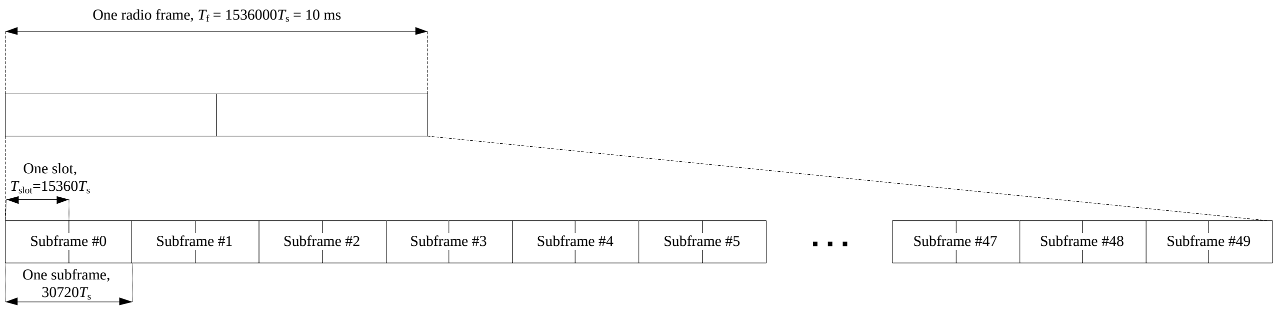

Figure 4.2-1: Frame structure

The supported subframe configurations are listed in Table 4.2-1. Subframes denoted by broadcast subframe index are used for the transmission of xPBCH, PSS, SSS, ESS, and BRS. Subframes denoted by index of K_{RACH} and K_{ePBCH} are respectively used for the transmission of RACH and ePBCH.

Subframes indicated as data subframe are comprised

a. DL control channel and DL data channel, or
b. DL control channel, DL data channel and UL control channel, or
c. DL control channel and UL data channel, or
d. DL control channel, UL data channel and UL control channel.

The supported data subframe configurations are listed in Table 4.2-2, where for each symbol in a subframe, “Dc” denotes a downlink symbol reserved for donwlink control channel transmissions, “Dd” denotes a downlink symbols reserved for downlink data channel transmissions and , “Uc” denotes a uplink symbol reserved for uplink control channel transmissions, “Ud” denotes a uplink symbols reserved for uplink data channel transmissions, and “GP” denotes a symbol reserved for guard period between downlink and uplink transmissions. CSI-RS and BRRS are respectively denoted by C.RS and B.RS.

Table 4.2-1: Subframe configurations

Control subframes	Data subframes
PSS/SSS/ESS/BRS/xPBCH, RACH, ePBCH(*)	Configurations in Table 4.2-2

(*) Systems supporting stand-alone operations have ePBCH subframes.

Table 4.2-2: Example configurations for data subframe structure

configurati	Symbol index

ons	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	Dc	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd C.RS	Dd C.RS
1	Dc	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	GP	Uc SRS
2	Dc	Dc	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd C.RS	Dd C.RS
3	Dc	Dc	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	Dd	GP	Uc SRS
4	Dc	GP	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud
5	Dc	GP	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Uc SRS
6	Dc	GP	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	C.RS
7	Dc	GP	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	SRS	C.RS
8	Dc	GP	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	Ud	SRS	Uc
9	Dc	-/Dc	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	GP	Uc SRS
10	Dc	-/Dc	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	B.RS	C.RS	C.RS

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 TS 5G. 212 [2] and the present document TS 5G.211.

The following uplink physical channels are defined:

- Physical Uplink Shared Channel, xPUSCH
- Physical Uplink Control Channel, xPUCCH
- Physical Random Access Channel, xPRACH

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 $N_{\mathrm{RB}}^{\mathrm{UL}} N_{\mathrm{sc}}^{\mathrm{RB}} = 1200$ subcarriers and $N_{\mathrm{symb}}^{\mathrm{UL}} = 7$ OFDM symbols. The resource grid is illustrated in Figure 5.2.1-1.

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.

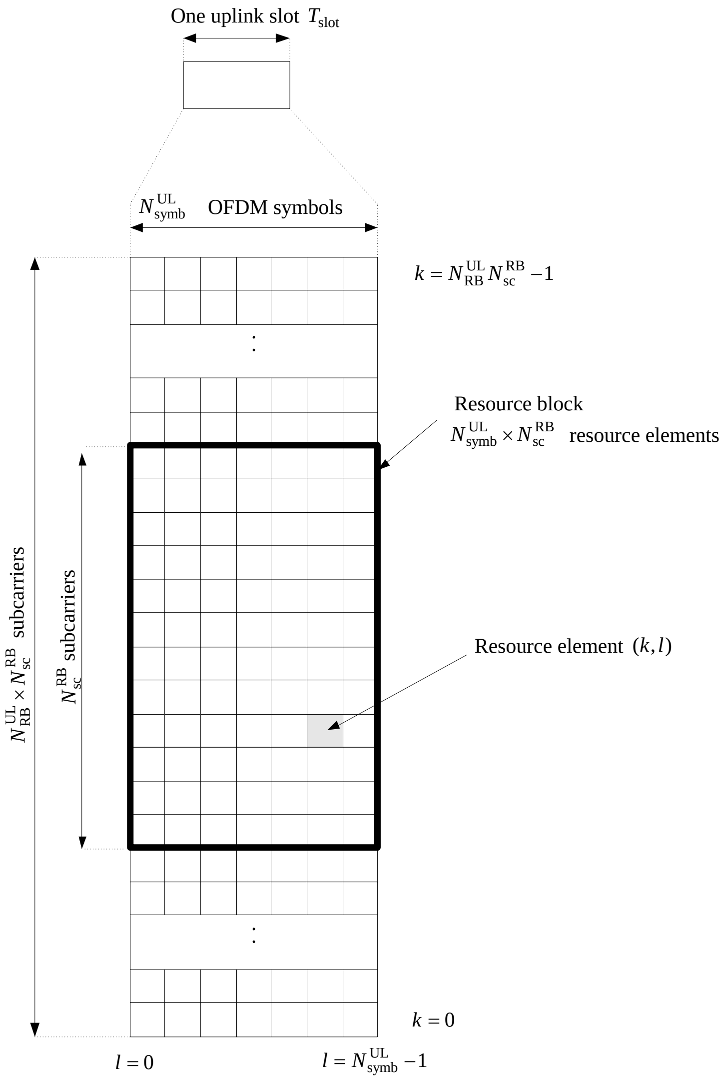

Figure 5.2.1-1: Uplink resource grid

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

Physical channel or signal	Index $\tilde{p}$	Antenna port number p as a function of the number of antenna ports configured for the respective physical channel/signal		
		1	2	4
xPUSCH	0	-	-	40
	1	-	-	41
	2	-	-	42
	3	-	-	43
SRS	0	-	-	40
	1	-	-	41
	2	-	-	42
	3	-	-	43
xPUCCH	0	100	200	-
	1	-	201	-

PCRS	0			40
	1			41
	2			42
	3			43

Up to two antenna ports per UE are supported for the PyeongChang trial system.

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 $k=0,\ldots,N_{\mathrm{RB}}^{\mathrm{UL}}N_{\mathrm{sc}}^{\mathrm{RB}}-1$ and $l=0,\ldots,N_{\mathrm{symb}}^{\mathrm{UL}}-1$ 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 $N_{\mathrm{symb}}^{\mathrm{UL}}$ consecutive OFDM symbols in the time domain and $N_{\mathrm{sc}}^{\mathrm{RB}}$ consecutive subcarriers in the frequency domain, where $N_{\mathrm{symb}}^{\mathrm{UL}}$ and $N_{\mathrm{sc}}^{\mathrm{RB}}$ are given by Table 5.2.3-1.
A physical resource block in the uplink thus consists of $N_{\mathrm{symb}}^{\mathrm{UL}}\times N_{\mathrm{sc}}^{\mathrm{RB}}$ resource elements, corresponding to one slot in the time domain and 900 kHz in the frequency domain.

Table 5.2.3-1: Resource block parameters

Configuration	$N_{\mathrm{sc}}^{\mathrm{RB}}$	$N_{\mathrm{symb}}^{\mathrm{UL}}$
Cyclic prefix	12	7

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

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

5.2.3.1 Virtual resource block groups of localized type

Virtual resource block groups of localized type are numbered from 0 to $N_{\mathrm{VRBG}}^{\mathrm{UL}}-1$, where $4N_{\mathrm{VRBG}}^{\mathrm{UL}}=N_{\mathrm{RB}}^{\mathrm{UL}}$.
Virtual resource block group of index $n_{\mathrm{VRBG}}^{\mathrm{UL}}$ is mapped to a set of physical resource block pairs given by $\{4n_{\mathrm{VRBG}}^{\mathrm{UL}},\ 4n_{\mathrm{VRBG}}^{\mathrm{UL}}+1,\ 4n_{\mathrm{VRBG}}^{\mathrm{UL}}+2,\ 4n_{\mathrm{VRBG}}^{\mathrm{UL}}+3\}$.

5.3 Physical uplink shared channel (xPUSCH)

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
- precoding of the complex-valued symbols
- mapping of precoded complex-valued symbols to resource elements
- generation of complex-valued time-domain OFDM signal for each antenna port
- analog beamforming based on the selected beam

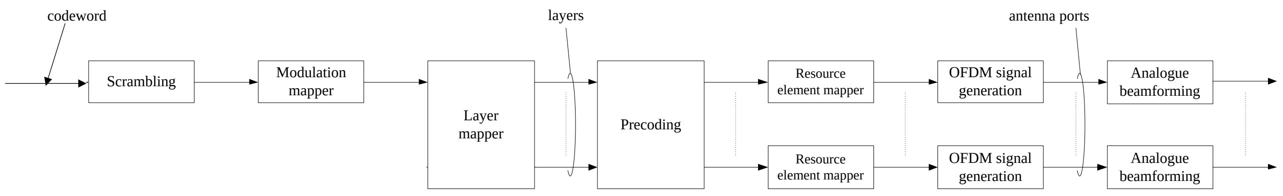

Figure 5.3-1: Overview of uplink physical channel processing

5.3.1 Scrambling

For a codeword q, the block of bits $b^{(q)}(0),\ldots,b^{(q)}(M_{\text{bit}}^{(q)}-1)$, where $M_{\text{bit}}^{(q)}$ is the number of bits transmitted in codeword q on the physical uplink shared channel in one subframe, shall be scrambled with a UE-specific scrambling sequence prior to modulation, resulting in a block of scrambled bits $\tilde{b}^{(q)}(0),\ldots,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)}-1)$ 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 TS 5G.212 [2] 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 xPUSCH transmission as described in clause 9 in TS 5G.213 [3].

Only one codewords can be transmitted in one subframe, i.e., $q = 0$.

5.3.2 Modulation

For an 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.

Table 5.3.2-1: Uplink modulation schemes

Physical channel	Modulation schemes
PUSCH	QPSK, 16QAM, 64QAM

5.3.2A Layer mapping

The complex-valued modulation symbols for the codeword to be transmitted are mapped onto one or two layers. Complex-valued modulation symbols $d^{(q)}(0),\ldots,d^{(q)}(M_{\text{symb}}^{(q)}-1)$ for codeword q shall be mapped onto the layers $x(i) = \left[x^{(0)}(i) \ \ \ldots \ \ x^{(\upsilon-1)}(i)\right]^T$, $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$ 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 one or two.

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

Number of layers	Number of codewords	Codeword-to-layer mapping $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$	
1	1	$x^{(0)}(i) = d^{(0)}(i)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}$
2	1	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2$

5.3.2A.3 Layer mapping for transmit diversity

For transmit diversity, the layer mapping shall be done according to Table 5.3.2A.3-1. There is only one codeword and the number of layers υ is two.

Table 5.3.2A.3-1: Codeword-to-layer mapping for transmit diversity

Number of layers	Number of codewords	Codeword-to-layer mapping $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$	
2	1	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/2$

5.3.3A Precoding

The precoder takes as input a block of vectors $\left[x^{(0)}(i)\quad \ldots \quad x^{(\upsilon-1)}(i)\right]^T$, $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$ from the layer mapping and generates a block of vectors $\left[z^{(0)}(i)\quad \ldots \quad z^{(P-1)}(i)\right]^T$, $i=0,1,\ldots,M_{\text{symb}}^{\text{ap}}-1$ 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, p, indicated in the uplink resource allocation, DCI format A1, precoding is defined by

$$z^{(p)}(i)=x^{(0)}(i)$$

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

5.3.3A.2 Precoding for transmit diversity

Precoding for transmit diversity is only used in combination with layer mapping for transmit diversity as described in clause 5.3.2A.3. The precoding operation for transmit diversity is defined for two antenna ports.

For transmission on two antenna ports, p_1 and p_2, indicated in the uplink resource allocation, DCI format A1 , the output $z(i)=\left[z^{(p_1)}(i)\quad z^{(p_2)}(i)\right]^T$, $i=0,1,\ldots,M_{\text{symb}}^{\text{ap}}-1$ of the precoding operation is defined by

$$\begin{bmatrix} z^{(p_1)}(2i) \\ z^{(p_2)}(2i) \\ z^{(p_1)}(2i+1) \\ z^{(p_2)}(2i+1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & j & 0 \\ 0 & -1 & 0 & j \\ 0 & 1 & 0 & j \\ 1 & 0 & -j & 0 \end{bmatrix} \begin{bmatrix} \operatorname{Re}\left(x^{(0)}(i)\right) \\ \operatorname{Re}\left(x^{(1)}(i)\right) \\ \operatorname{Im}\left(x^{(0)}(i)\right) \\ \operatorname{Im}\left(x^{(1)}(i)\right) \end{bmatrix}$$

for $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$ with $M_{\text{symb}}^{\text{ap}}=2M_{\text{symb}}^{\text{layer}}$.

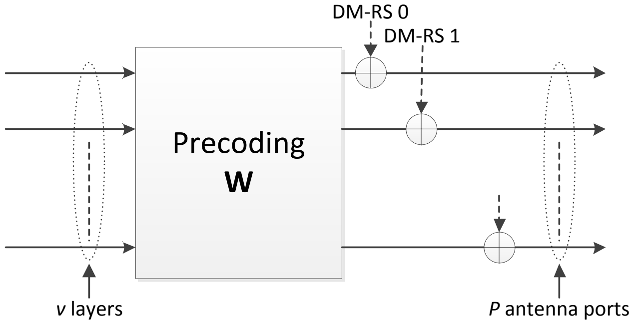

Figure 5.3.3A.2-1: DM-RS location for transmit diversity

For transmit diversity, DM-RS is located after precoding with $P=2$ antenna ports as illustrated in Figure 5.3.3A.2-1.

5.3.3A.3 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 $P=2$ antenna ports where the set of antenna ports used for spatial multiplexing are p_1 and p_2, indicated in the uplink resource allocation, DCI format A1.

Precoding for spatial multiplexing is defined by

$$\begin{bmatrix} z^{(p_1)}(i) \\ z^{(p_2)}(i) \end{bmatrix} = W \begin{bmatrix} y^{(0)}(i) \\ \vdots \\ y^{(\upsilon-1)}(i) \end{bmatrix}$$

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

For transmission on two antenna ports, p_1 and p_2 the precoding matrix $W(i)$ shall be generated according to from Table 5.3.3A.3-1.

Table 5.3.3A.3-1: Codebook for transmission on antenna ports { p_1, p_2 }

Codebook index	Number of layers υ	
	1	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	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
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	$\frac{1}{\sqrt{2}}\begin{bmatrix}0\\1\end{bmatrix}$	

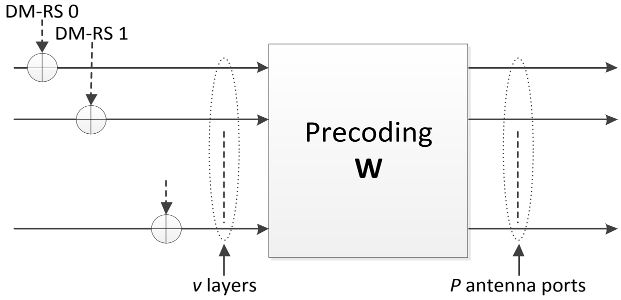

Figure 5.3.3A.3-3: DM-RS location for spatial multiplexing using antenna ports with UE-specific reference signals

For spatial multiplexing using antenna ports with UE-specific reference signals, DM-RS is located before precoding with υ layers as illustrated in Figure 5.3.3A.3-3.

5.3.4 Mapping to physical resources

For each antenna port p used for transmission of the xPUSCH in a subframe the block of complex-valued symbols $z^{(\tilde{p})}(0),...,z^{(\tilde{p})}(M_{\text{symb}}^{\text{ap}}-1)$ shall be multiplied with the amplitude scaling factor β_{xPUSCH} in order to conform to the transmit power P_{xPUSCH} specified in clause 5.1.1.1 in TS 5G.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 xPUSCH. 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 and

- not used for transmission of phase noise compensation reference signal, and- not part of OFDM symbol(s) including DM-RS in a subframe, and
- not part of the first two OFDM symbols in a subframe, and
- not part of the last OFDM symbol(s) in a subframe if indicated in the scheduling DCI (format A1/A2 in TS 5G.212 [2])

shall be in increasing order of first the index k, then the index l, starting with the first slot in the subframe.

5.4 Physical uplink control channel (xPUCCH)

The physical uplink control channel, xPUCCH, carries uplink control information. The xPUCCH can be transmitted in the last symbol of a subframe.

xPUCCH uses a cyclic shift, $n_{\text{cs}}^{\text{cell}}(n_{\text{s}})$, which varies with the slot number n_{s} according to

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

$$\bar{n}_s=n_s \bmod 20$$

where the pseudo-random sequence $c(i)$ is defined by section 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 Section 5.5.1.5.

The physical uplink control channel supports single format as shown in Table 5.4-1.

Table 5.4-1: Supported xPUCCH formats

xPUCCH format	Modulation scheme	Number of bits per subframe, M_{bit}
2	QPSK	96

5.4.1 xPUCCH formats 2

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

$$c_{\text{init}} = \left(\lfloor \bar{n}_s/2 \rfloor + 1 \right) \cdot \left(2N_{\text{ID}}^{\text{cell}} + 1 \right) \cdot 2^{16} + n_{\text{RNTI}}$$

$$\bar{n}_s = n_s \bmod 20$$

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 sub-clause 7.1, resulting in a block of complex-valued modulation symbols $d(0),...,d(M_{\text{symb}}-1)$ where $M_{\text{symb}} = M_{\text{bit}}/2$.

5.4.1.1 Layer mapping

The complex-valued modulation symbols to be transmitted are mapped onto one or two layers. Complex-valued modulation symbols $d(0),\ldots,d(M_{\text{symb}}-1)$ shall be mapped on to the layers $x(i) = \left[x^{(0)}(i) \quad \ldots \quad x^{(\upsilon-1)}(i) \right]^T$, $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$ where υ is the number of layers and $M_{\text{symb}}^{\text{layer}}$ is the number of modulation symbols per layer.

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

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

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

For transmission on two antenna ports, and the mapping rule of $\upsilon = 2$ can be defined by

$$\begin{aligned} x^{(0)}(i) &= d(2i) \\ x^{(1)}(i) &= d(2i+1) \end{aligned}$$

with $M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2$.

5.4.1.2 Precoding

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

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

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

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

For transmission on two antenna ports, $\tilde{p} \in \{0,1\}$, the output $y(i) = \left[y^{(0)}(i) \quad y^{(1)}(i) \right]^T$, $i = 0,1,\ldots,M_{\text{symb}}^{\text{ap}}-1$ of the precoding operation is defined by

$$\begin{bmatrix} y^{(0)}(2i) \\ y^{(1)}(2i) \\ y^{(0)}(2i+1) \\ y^{(1)}(2i+1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & j & 0 \\ 0 & -1 & 0 & j \\ 0 & 1 & 0 & j \\ 1 & 0 & -j & 0 \end{bmatrix} \begin{bmatrix} \operatorname{Re}\left(x^{(0)}(i)\right) \\ \operatorname{Re}\left(x^{(1)}(i)\right) \\ \operatorname{Im}\left(x^{(0)}(i)\right) \\ \operatorname{Im}\left(x^{(1)}(i)\right) \end{bmatrix}$$

for $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$ with $M_{\text{symb}}^{\text{ap}} = 2M_{\text{symb}}^{\text{layer}}$.

The mapping to resource elements is defined by operations on quadruplets of complex-valued symbols. Let $w^{(\tilde{p})}(i) = \langle y^{(\tilde{p})}(4i), y^{(\tilde{p})}(4i+1), y^{(\tilde{p})}(4i+2), y^{(\tilde{p})}(4i+3) \rangle$ denote symbol quadruplet i for antenna port $\tilde{p}$, where $i = 0,1,\ldots,M_{\text{quad}}-1$ and $M_{\text{quad}} = M_{\text{symb}}/4$

The block of quadruplets $w^{(\tilde{p})}(0),\ldots,w^{(\tilde{p})}(M_{\text{quad}}-1)$ shall be cyclically shifted, resulting in $\bar{w}^{(\tilde{p})}(0),\ldots,\bar{w}^{(\tilde{p})}(M_{\text{quad}}-1)$ where $\bar{w}^{(\tilde{p})}(i) = w^{(\tilde{p})}\left((i + n_{\text{cs}}^{\text{cell}}(n_{\text{s}})) \bmod M_{\text{quad}}\right)$. Let $\bar{w}^{(\tilde{p})}(i) = \langle \bar{y}^{(\tilde{p})}(4i), \bar{y}^{(\tilde{p})}(4i+1), \bar{y}^{(\tilde{p})}(4i+2), \bar{y}^{(\tilde{p})}(4i+3) \rangle$ denote another symbol quadruplet i for antenna port $\tilde{p}$ obtained after cell-specific cyclic shift.

The block of complex-valued symbols $\bar{w}$ shall be mapped to z according to

$$z^{(\tilde{p})}\left(n_{\text{xPUCCH}}^{(2)} \cdot N_{\text{xPUCCH}}^{\text{RB}} \cdot N_{\text{sc}}^{\text{RB}} + m' \cdot N_{\text{sc}}^{\text{RB}} + k'\right) = \bar{y}^{(\tilde{p})}\left(8m' + k\right)$$

where

$$k' = \begin{cases} k & 0 \le k \le 1 \\ k+2 & 2 \le k \le 5 \\ k+4 & 6 \le k \le 7 \end{cases}$$
$$m' = 0,1,2,\ldots,5$$
$$N_{\text{xPUCCH}}^{\text{RB}} = 6$$

and $n_{\text{xPUCCH}}^{(2)}$ is indicated in the xPDCCH.

5.5 Reference signals

Four types of uplink reference signals are supported:

- Demodulation reference signal, associated with transmission of xPUCCH
- Demodulation reference signal, associated with transmission of xPUSCH
- Phase noise compensation reference signal, associated with transmission of xPUSCH (PCRS)
- Sounding reference signal, not associated with transmission of xPUSCH or xPUCCH

5.5.1 Generation of the reference signal sequence

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

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

where $M_{\text{sc}}^{\text{RS}} = mN_{\text{sc}}^{\text{RB}}$ is the length of the reference signal sequence and $1 \le m \le N_{\text{RB}}^{\text{max, UL}}$. 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 $u \in \{0,1,\ldots,29\}$ is the group number and v is the base sequence number within the group, such that each group contains one base sequence ($v=0$) of each length $M_{\text{sc}}^{\text{RS}} = mN_{\text{sc}}^{\text{RB}}$, $2 \le m \le 5$ and two base sequences ($v = 0,1$) of each length $M_{\text{sc}}^{\text{RS}} = mN_{\text{sc}}^{\text{RB}}$, $6 \le m \le N_{\text{RB}}^{\text{max,UL}}$. 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 larger than $3N_{\mathrm{sc}}^{\mathrm{RB}}$

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

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

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

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

with q given by

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

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 $M_{\mathrm{sc}}^{\mathrm{RS}} = 2N_{\mathrm{sc}}^{\mathrm{RB}}$, base sequence is given by

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

where the value of $\varphi(n)$ is given by Table 5.5.1.2-1 for $M_{\mathrm{sc}}^{\mathrm{RS}} = 2N_{\mathrm{sc}}^{\mathrm{RB}}$, respectively.

Table 5.5.1.2-1: Definition of $\varphi(n)$ for $M_{\mathrm{sc}}^{\mathrm{RS}} = 2N_{\mathrm{sc}}^{\mathrm{RB}}$

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

5.5.1.3 Group hopping

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

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

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.

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

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

$$\bar{n}_s = n_s \bmod 20$$

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

The sequence-shift pattern f_{ss} definition differs between xPUCCH and SRS.

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

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

$$v = \begin{cases} c(n_s \bmod 20) & \text{if group hopping is disabled and sequence hopping is enabled} \\ 0 & \text{otherwise} \end{cases}$$

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.

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 xPUCCH:

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

Sounding reference signals:

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

5.5.2 Demodulation reference signals associated with xPUCCH

Demodulation reference signals associated with xPUCCH are transmitted on single antenna port $p = 100$ or two antenna ports $p = 200, p = 201$.

5.5.2.1 Sequence generation

For any of the antenna ports $p \in \{100, 200, 201\}$ the reference signal sequence $r_{l,n_s}(m)$ is defined by

$$r_{l,n_s}(m) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m+1)\right), \quad m = 0,1,\ldots,4 \cdot N_{\mathrm{RB}}^{\mathrm{UL}} - 1$$

where n_{s} is the slot number within a radio frame and l is the OFDM symbol number within the slot. The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}} = \left(\lfloor \bar{n}_s / 2 \rfloor + 1\right) \cdot \left(2 n_{\text{ID}}^{(n_{\text{SCID}})} + 1\right) \cdot 2^{16} + n_{\text{RNTI}}$$

$$\bar{n}_s = n_s \bmod 20$$

at the start of each subframe where n_{RNTI} is the C-RNTI.

The quantities $n_{\text{ID}}^{(i)}$, $i = 0,1$, are given by

- $n_{\text{ID}}^{(i)} = N_{\text{ID}}^{\text{cell}}$ if no value for $n_{\text{ID}}^{\text{xPUCCH},i}$ is provided by higher layers.
- $n_{\text{ID}}^{(i)} = n_{\text{ID}}^{\text{xPUCCH},i}$ otherwise

The value of n_{SCID} is zero unless specified otherwise. For an xPUCCH transmission, n_{SCID} is given by the DCI formats in TS 5G.212 [2] associated with the xPUCCH transmission.

5.5.2.2 Mapping to resource elements

In a physical resource block with frequency-domain index n_{PRB} assigned for the corresponding xPUCCH transmission, a part of the reference signal sequence $r(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ in a subframe according to

$$a_{k,l}^{(p)} = w_p(m \bmod 2) \cdot r_{l,n_s}(4 \cdot n_{\text{PRB}} + m)$$

where

$$w_p(i) = \begin{cases} \bar{w}_p(i) & n_{\text{PRB}} \bmod 2 = 0 \\ \bar{w}_p(1-i) & n_{\text{PRB}} \bmod 2 = 1 \end{cases}$$

$$k = N_{\text{sc}}^{\text{RB}} \cdot n_{\text{PRB}} + m'$$

$$l = 6$$

$$m' = \begin{cases} m+2 & 0 \le m \le 1 \\ m+6 & 2 \le m \le 3 \end{cases}$$

$$m = 0,1,2,3$$

$$n_s \bmod 2 = 1$$

and the sequence $\bar{w}_p(i)$ is given by Table 5.5.2.2-1.

Table 5.5.2.2-1: The sequence $\bar{w}_p(i)$

Antenna port p	$[\bar{w}_p(0) \quad \bar{w}_p(1)]$
100 or 200	$[+1 \quad +1]$
201	$[+1 \quad -1]$

Figure 5.5.2.2-1 illustrates the resource elements used for xPUCCH demodulation reference signals according to the above definition. The notation R_p is used to denote a resource elements used for reference signal transmission on antenna port *p*.

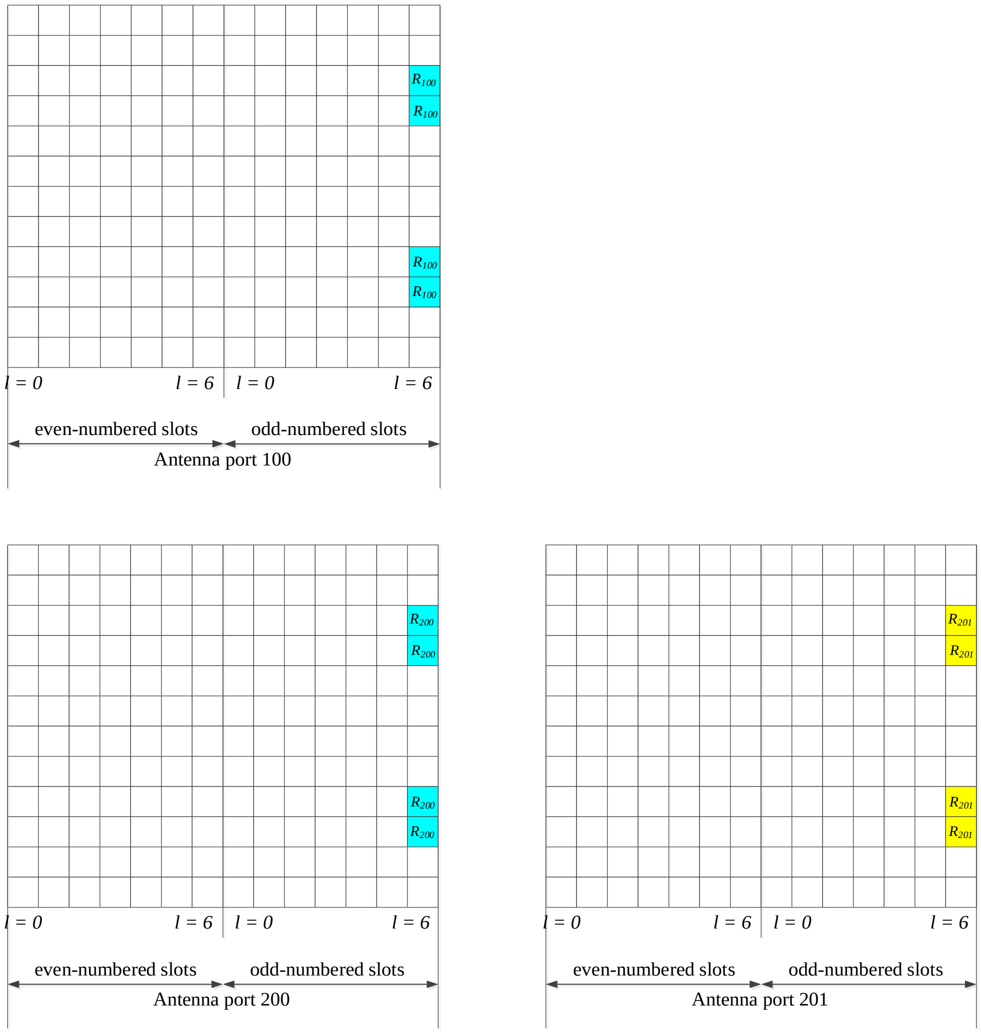

Figure 5.5.2.2-1: Mapping of xPUCCH demodulation reference signals

5.5.3 Demodulation reference signals associate with xPUSCH

UE specific reference signals associated with xPUSCH

- are transmitted on antenna port(s) $p = 40,41,42,43$;
- are present and are a valid reference for xPUSCH demodulation only if the xPUSCH transmission is associated with the corresponding antenna port according to TS 5G.213 [3];
- are transmitted only on the physical resource blocks upon which the corresponding xPUSCH is mapped.

A UE-specific reference signal associated with xPUSCH is not transmitted in resource elements (k,l) in which one of the physical channels are transmitted using resource elements with the same index pair (k,l) regardless of their antenna port p.

5.5.3.1 Sequence generation

For any of the antenna ports $p \in \{40,41,42,43\}$ the reference-signal sequence $r(m)$ is defined by

$$r(m) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m+1)\right), \qquad m = 0,1,\ldots,3N_{RB}^{\max,DL} - 1 \cdot$$

The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}} = \left(\lfloor n_s/2 \rfloor + 1\right) \cdot \left(2n_{\text{ID}}^{(n_{\text{SCID}})} + 1\right) \cdot 2^{16} + n_{\text{SCID}}$$

at the start of each subframe.

The quantities $n_{\text{ID}}^{(i)}$, $i = 0,1$, are given by

- $n_{\text{ID}}^{(i)} = N_{\text{ID}}^{\text{cell}}$ if no value for $n_{\text{ID}}^{\text{DMRS},i}$ is provided by higher layers
- $n_{\text{ID}}^{(i)} = n_{\text{ID}}^{\text{DMRS},i}$ otherwise

The value of n_{SCID} is zero unless specified otherwise. For a xPUSCH transmission, n_{SCID} is given by the DCI format in TS 5G.212 [2] associated with the xPUSCH transmission.

5.5.3.2 Mapping to resource elements

For antenna ports $p \in \{40,41,42,43\}$, in a physical resource block with frequency-domain index n_{PRB} assigned for the corresponding xPUSCH transmission, a part of the reference signal sequence $r(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ in a subframe according to

$$a_{k,l}^{(p)} = r(k'')$$

where

$$k = 4m' + N_{\text{sc}}^{\text{RB}} \cdot n_{\text{PRB}} + k'$$

$$k' = \begin{cases} 0 & p \in \{40\} \\ 1 & p \in \{41\} \\ 2 & p \in \{42\} \\ 3 & p \in \{43\} \end{cases}$$

$$k'' = \left\lfloor \frac{k}{4} \right\rfloor$$

$$l = \begin{cases} 2 \text{ (in even slot)} \\ 2 \text{ (in even slot)}, 3 \text{(in odd slot)} & \text{for high speed case} \end{cases}$$

$$m' = 0,1,2$$

Information indicating whether $l = 2$ or $l = \{2,10\}$l=2, 10 is signalled via higher layer signalling.

Resource elements (k,l) used for transmission of UE-specific reference signals to one UE on any of the antenna ports in the set S, where, $S = \{40\}$, $S = \{41\}$, $S = \{42\}$ or $S = \{43\}$ shall

- not be used for transmission of xPUSCH on any antenna port in the same subframe, and
- not be used for UE-specific reference signals to the same UE on any antenna port other than those in S in the same subframe.

Figure 5.5.3.2-1 illustrates the resource elements used for UE-specific reference signals for antenna ports 40, 41, 42 and 43.

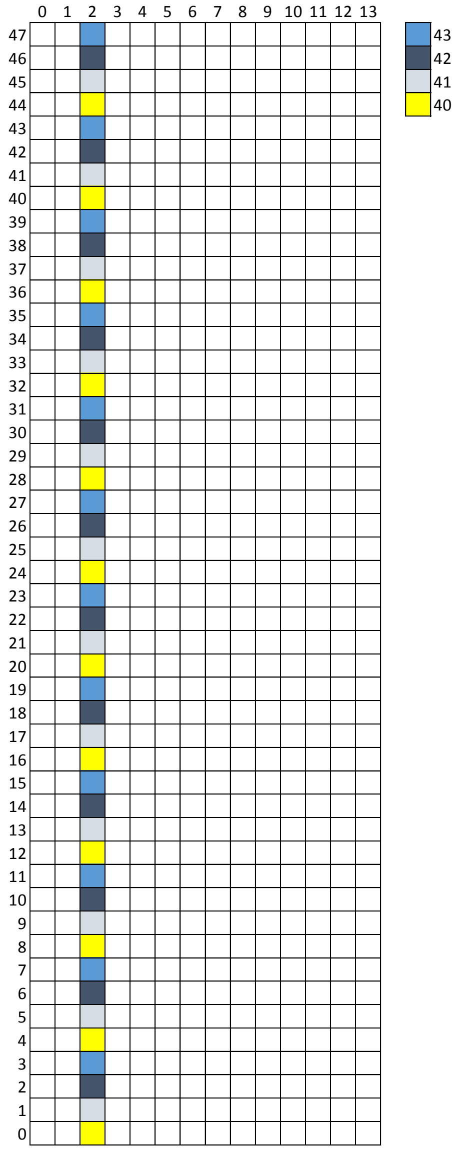

Figure 5.5.3.2-1: Mapping of UE-specific reference signals, antenna ports {40, 41,42,43}.

5.5.4 Sounding reference signal

Sounding reference signals are transmitted on antenna port(s), $p \in \{40,41\}$.

5.5.4.1 Sequence generation

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

$$
\alpha_{\tilde{p}} = 2\pi \frac{n_{\mathrm{SRS}}^{\mathrm{cs},\tilde{p}}}{8}
$$

$$
n_{\mathrm{SRS}}^{\mathrm{cs},\tilde{p}} = \left(n_{\mathrm{SRS}}^{\mathrm{cs}} + \frac{8\tilde{p}}{N_{\mathrm{ap}}} \right) \bmod 8,
$$

$$
\tilde{p} \in \{0,1,\ldots,N_{\mathrm{ap}}-1\}
$$

where $n_{\mathrm{SRS}}^{\mathrm{cs}} \in \{0,1,2,3,4,5,6,7\}$ is configured for aperiodic sounding by the higher-layer parameters *cyclicShift-ap* for each UE and N_{ap} is the number of antenna ports used for sounding reference signal transmission.

5.5.4.2 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 6.1.3.1 in 5G.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

$$a_{2k'+k_0,l}^{(p)} = \begin{cases} \frac{1}{\sqrt{N_{\mathrm{ap}}}} \beta_{\mathrm{SRS}} r_{SRS}^{(\tilde{p})}(k') & k'=0,1,\ldots,M_{\mathrm{sc},b}^{\mathrm{RS}}-1 \\ 0 & \text{otherwise} \end{cases}$$

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 quantity k_0 is the frequency-domain starting position of the sounding reference signal, $b = B_{\mathrm{SRS}}$ and $M_{\mathrm{sc},b}^{\mathrm{RS}}$ is the length of the sounding reference signal sequence defined as

$$M_{\mathrm{sc},b}^{\mathrm{RS}} = m_{\mathrm{SRS},b} N_{\mathrm{sc}}^{\mathrm{RB}} / 2$$

where $m_{\mathrm{SRS},b}$ is given by Table 5.5.3.2-1. The UE-specific parameter *srs-Bandwidth*, $B_{\mathrm{SRS}} \in \{0,1,2,3\}$ is given by higher layers.

The frequency-domain starting position k_0 is defined by

$$k_0 = \bar{k}_{TC} + n_b \cdot N_{sc}^{RB}$$

where $\bar{k}_{\mathrm{TC}} \in \{0,1\}$ is given by the UE-specific parameter *transmissionComb-ap*, provided by higher layers for the UE, and n_b is frequency position index.

The frequency position index n_b remains constant (unless re-configured) and is defined by $n_{\mathrm{b}} = 4n_{RRC}$ where the parameter n_{RRC} is given by higher-layer parameters *freqDomainPosition-ap*,

SRS can be transmitted simultaneously in multiple component carriers.

Table 5.5.4.2-1: $m_{\mathrm{SRS},b}$, $b = 0,1,2,3$, values for the uplink bandwidth of $N_{\mathrm{RB}}^{\mathrm{UL}} = 100$

SRS bandwidth configuration C_{SRS}	SRS-Bandwidth $B_{\mathrm{SRS}}=0$	SRS-Bandwidth $B_{\mathrm{SRS}}=1$	SRS-Bandwidth $B_{\mathrm{SRS}}=2$	SRS-Bandwidth $B_{\mathrm{SRS}}=3$
	$m_{\mathrm{SRS},0}$	$m_{\mathrm{SRS},1}$	$m_{\mathrm{SRS},2}$	$m_{\mathrm{SRS},3}$
0	100	48	24	4

5.5.4.3 Sounding reference signal subframe configuration

The sounding reference signal is always aperiodic and explicitly scheduled via PDCCH. The subframe number and symbol number (last symbol or the second last symbol) of SRS are conveyed in DCI.

5.5.5 Phase noise compensation reference signal, associated with transmission of PUSCH

Phase noise compensation reference signal associated with xPUSCH

- are transmitted on one antenna port assigned to UE;
- are transmitted only on the physical resource blocks upon which the corresponding xPUSCH is mapped.

5.5.5.1 Sequence generation

For any of the antenna ports $p \in \{40,41,42,43\}$, the reference-signal sequence $r(m)$ is defined by

$$r(m)=\frac{1}{\sqrt{2}}(1-2\cdot c(2m))+j\frac{1}{\sqrt{2}}(1-2\cdot c(2m+1)), \qquad m=0,1,\ldots,2N_{symb}^{UL}-1\,.$$

The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}}=(\lfloor \bar{n}_{\text{s}}/2\rfloor+1)\cdot\left(2n_{\text{ID}}^{(n_{\text{SCID}})}+1\right)\cdot 2^{16}+n_{\text{SCID}}$$

$$\bar{n}_s=n_s \bmod 20$$

at the start of each subframe.

The quantities $n_{\text{ID}}^{(i)}$, $i=0,1$, are given by

- $n_{\text{ID}}^{(i)}=N_{\text{ID}}^{\text{cell}}$ if no value for $n_{\text{ID}}^{\text{DMRS},i}$ is provided by higher layers
- $n_{\text{ID}}^{(i)}=n_{\text{ID}}^{\text{DMRS},i}$ otherwise

The value of n_{SCID} is zero unless specified otherwise. For a xPUSCH transmission, n_{SCID} is given by the DCI format in TS 5G.212 [2] associated with the xPUSCH transmission.

5.5.5.2 Mapping to resource elements

For antenna ports $p \in \{40,41,42,43\}$, in a physical resource block with frequency-domain index n_{PRB}' assigned for the corresponding xPUSCH transmission, a part of the reference signal sequence $r(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ in a subframe according to

$$a_{k,l}^{(p)}=r(l')$$

where l' is the symbol index within a subframe, the starting resource block number of xPUSCH physical resource allocation n_{PRB}^{xPUSCH} in the frequency domain, resource allocation bandwidth in terms of number of resource blocks N_{PRB}^{xPUSCH} and resource elements (k,l') in a subframe is given by

$$k = N_{\mathrm{sc}}^{\mathrm{RB}}\left(n_{PRB}^{xPUSCH} + 2\left\lfloor \frac{N_{PRB}^{xPUSCH}}{4} \right\rfloor\right) + k'$$

$$k' = \begin{cases} 20 & p \in 40 \\ 21 & p \in 41 \\ 22 & p \in 42 \\ 23 & p \in 43 \end{cases}$$

$$l = \begin{cases} 3,\ldots,13, & \text{if Subframe configuration} = 4 \\ 3,\ldots,12, & \text{if Subframe configuration} = 5\ or\ 6 \\ 3,\ldots,11, & \text{if Subframe configuration} = 7\ or\ 8 \end{cases}$$

Resource elements (k,l) used for transmission of UE-specific phase noise compensation reference signals from one UE on an antenna port $p \in S$, where $S = \{40\}$, $S = \{41\}$, $S = \{42\}$ or $S = \{43\}$ shall

- not be used for transmission of xPUSCH on any antenna port in the same subframe.

Figure 5.5.4.2-1 illustrates the resource elements used for phase noise compensation reference signals for antenna ports 40, 41, 42 and 43.

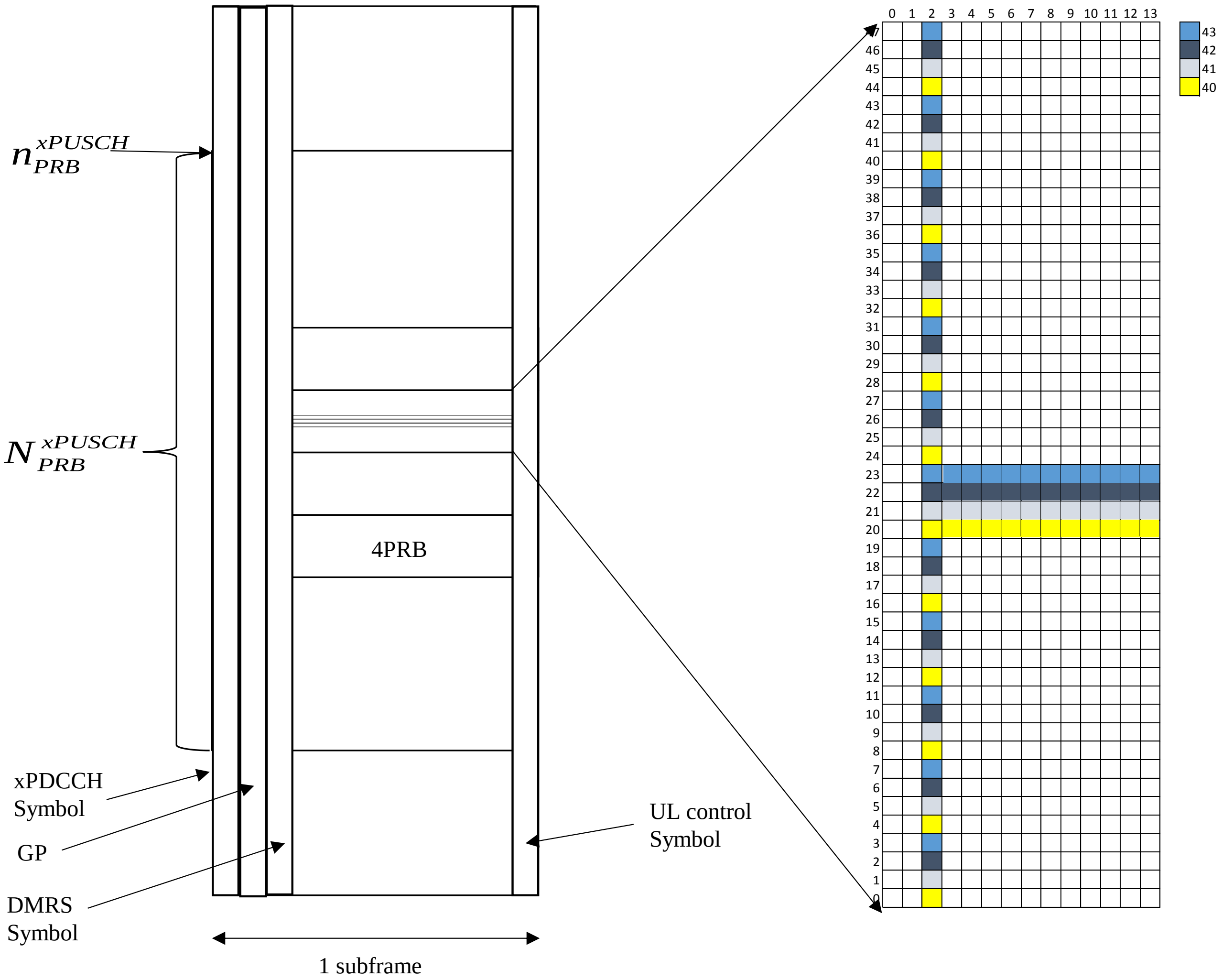

Figure 5.5.4.2-1: Mapping of phase noise compensation reference signals, antenna ports 50, 51, 52 and 53.

5.6 OFDM baseband signal generation

This clause applies to all uplink physical signals and uplink physical channels.

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

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

for $0\le t<\left(N_{\mathrm{CP},l}+N\right)\times T_{\mathrm{s}}$ where $k^{(-)}=k+\lfloor N_{\mathrm{RB}}^{\mathrm{UL}}N_{\mathrm{sc}}^{\mathrm{RB}}/2\rfloor$ and $k^{(+)}=k+\lfloor N_{\mathrm{RB}}^{\mathrm{UL}}N_{\mathrm{sc}}^{\mathrm{RB}}/2\rfloor-1$. The variable N equals 2048 and $\Delta f=75\,\mathrm{kHz}$.

The OFDM symbols in a slot shall be transmitted in increasing order of l, starting with $l=0$, where OFDM 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 value of $N_{\mathrm{CP},l}$ that shall be used.

Table 5.6-1: OFDM parameters

Configuration		Cyclic prefix length $N_{\mathrm{CP},l}$
Normal cyclic prefix	$\Delta f=75\,\mathrm{kHz}$	160 for $l=0$ 144 for $l=1,2,...,6$

5.7 Physical random access channel (xPRACH)

5.7.1 Random access preamble subframe

The physical layer random access preamble symbol, illustrated in Figure 5.7.1-1 consists of a cyclic prefix of length T_{CP} and a sequence part of length T_{SEQ}.

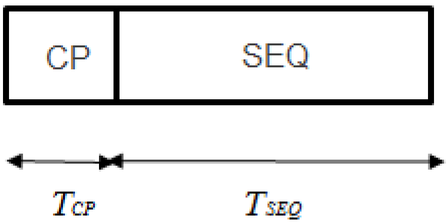

Figure 5.7.1-1: Random access preamble

Figure 5.7.1-2 denotes how the BS receives RACH from multiple UEs. These UEs occupy the same set of subcarriers. Each UE transmits for two symbols. UE1, UE3, …UE9, etc. are located close to the BS and they transmit for ten symbols in total. UE2, UE4, …, UE10, etc. are located at cell edge. These UEs also transmit in the same ten symbols. Due to the difference in distance, the signals of these UEs arrive at the BS T_{RTT} time later than those of UE1, UE3, …, UE5.

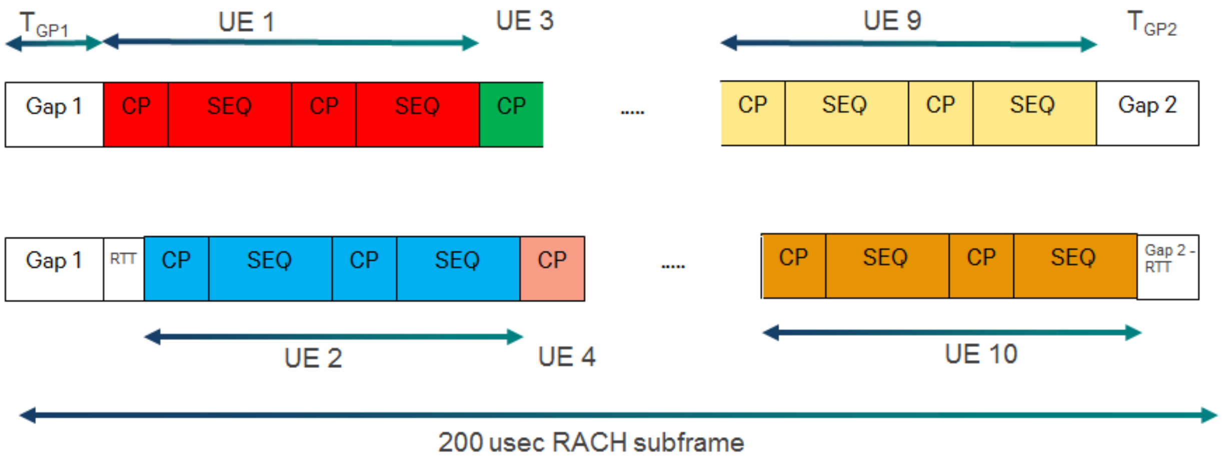

Figure 5.7.1-2: Reception of RACH signal at BS during RACH subframe

The parameter values are listed in Table 5.7.1-1.

Table 5.7.1-1: Random access preamble parameters

Preamble format	T_{GP1}	T_{CP}	T_{SEQ}	N_{SYM}	T_{GP2}
0	2224*Ts	656*Ts	2048*Ts	10	1456*Ts
1	2224*Ts	1344*Ts	2048*Ts	8	1360*Ts

Due to extended cyclic prefix, there are ten symbols in this sub-frame for preamble format 0, and eigth symbols for preamble format 1 meant for 1km distance.

Different subframe configurations for RACH are given below:

Table 5.7.1-2: Random access configuration

PRACH configuration	System Frame Number	Subframe Number
0	Any	15, 40
1	Any	15

RACH signal is transmitted by a single antenna port 1000. The antenna port for RACH signal should have the same directivity as the one during which the measurement of the best BRS beam was conducted.

5.7.2 Preamble sequence generation

The random access preambles are generated from Zadoff-Chu sequences with a length of 71. The u^{th} root Zadoff-Chu sequence is defined by

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

where the length N_{ZC} of the Zadoff-Chu sequence is 71. The value of the root u is provided by higher layers.

The random access preamble $x_u(n)$ shall be mapped to resource elements according to

$$a_{k,l} = f \cdot x_u(n) e^{-j\frac{2\pi}{3}vk},$$
$$v \in \begin{cases} \{0,1,2\} & \text{for format 0} \\ \{0\} & \text{for format 1} \end{cases}$$
$$\mathrm{k} = \mathrm{n} + 1 + 12 * (6 * \mathrm{n}_{\mathrm{RACH}} + 1), \quad \mathrm{n}_{\mathrm{RACH}} \in \{0,1...7\}$$
$$f = \begin{cases} 1 & \text{if } l \text{ is even} \\ f' & \text{if } l \text{ is odd} \end{cases}$$
$$f' \in \{-1,1\}$$
$$\mathrm{n} = 0,1...,70,$$
$$l \in \begin{Bmatrix} \{(0,1),(2,3),(4,5),(6,7),(8,9)\} & \text{for format 0} \\ \{(0,1),(2,3),(4,5),(6,7)\} & \text{for format 1} \end{Bmatrix}$$

where the cyclic shift v, RACH band index $\mathrm{n}_{\mathrm{RACH}}$ and parameter f' are provided by higher layers. As outlined by the equations above, the RACH subframe provides 8 RACH bands each occupying 6RBs. The parameter n_{RACH} determines which band is used by the UE.

During the synchroniation subframe, the UE identifies the symbol with the strongest beam. A set of parameters provided by the upper layers is used to map the symbol with the strongest beam to the RACH symbol index l, as described in 5.7.2.1.

Higher layers determine the component carrier, in which the UE transmits the RACH signal.

There are 48 preambles available in each cell. The set of 48 or 16 preambles according to preamble format in a cell is found by combination of cyclic shift, OCC, and band index. Preamble index is allocated as follows:

$$\text{Preamble index} = v + N_v \cdot \left(f' + 1\right)/2 + N_v \cdot 2 \cdot n_{RACH}$$

where

N_v : number of cyclic shift

$$\begin{pmatrix} N_v = 3, \text{ for format 0} \\ N_v = 1, \text{ for format 1} \end{pmatrix}$$

5.7.2.1 Procedure to Compute the Symbols of RACH Signal

Layer 1 receives the following parameters, from higher layers:

- System Frame Number, SFN

- the BRS transmission period as defined in clause 6.7.4.3 expressed in units of symbols

$$N_{BRS} := BRS\ transmission\ period\ in\ slots \cdot 7$$

- the number of symbols N_{RACH} during the RACH subframe for which the BS applies different rx –beams, where

$$\begin{pmatrix} N_{RACH} = 5, \text{ if preamble format} = 0 \\ N_{RACH} = 4, \text{ if preamble format} = 1 \end{pmatrix}$$

- number of RACH subframes M in each radio frame (here M can be 1 or 2 depending on RACH configuration)

- index of RACH subframe m (here m ranges between 0 to M-1)

- the symbol with the strongest sync beam, $S_{Sync}^{BestBeam}$ (here the value of $S_{Sync}^{BestBeam}$ ranges between 0 and $N_{BRS} - 1$).

The RACH subframes use the same beams as the synchronization subframes and in the same sequential order. Hence if the m-th RACH subframe occurs within a radio frame with the system frame number SFN, it will use the beams of the synchronization symbols identified by the set

$$\left(M \cdot SFN \cdot N_{RACH} + m \cdot N_{RACH} + (0{:}N_{RACH} - 1)\right)\%N_{BRS}, \quad m \in \{0,..M-1\}$$

If $S_{Sync}^{BestBeam}$ is among those symbols, the UE shall transmit the RACH preamble during the RACH subframe.

The transmission should start at symbol

$$l = \left(\left(S_{Sync}^{BestBeam} - (\mathrm{SFN} \cdot \mathrm{M} \cdot \mathrm{N_{RACH}} + \mathrm{m} \cdot \mathrm{N_{RACH}})\%\mathrm{N_{BRS}}\right)\%\mathrm{N_{BRS}}\right) \cdot \mathrm{N_{rep}},$$

where $\mathrm{N_{rep}}$ denotes the number of symbols dedicated to a single RACH transmission. Here $\mathrm{N_{rep}} = 2$.

5.7.3 Baseband Signal Generation

The baseband signal for RACH is generated in an OFDM manner according to section 5.6 with a tone spacing of $\Delta f = 75kHz$ and a cyclic prefix length N_{CP} of 656 or 1344 samples are inserted corresponding to the preamble format provided by higher layer.

5.7.4 Scheduling Request Collection during RACH Periods

5.7.4.1 Scheduling request preamble slot

Symbols for scheduling request (SR) are transmitted during the RACH subframe. They occupy a different set of subcarriers than those of RACH signal. Scheduling request is collected from any UE in a similar manner as the RACH signal. The scheduling request preamble, illustrated in Figure 5.7.4.1-1 consists of a cyclic prefix of length T_{CP} and a sequence part of length T_{SEQ}. Both have the same values as their counterparts of the RACH preamble.

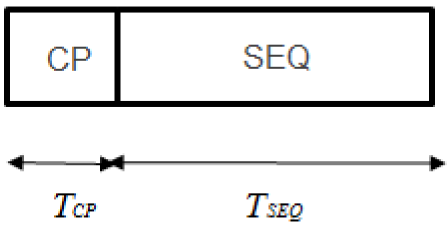

Figure 5.7.4-1: SR preamble

Table 5.7.4-1: Scheduling request preamble parameters

Preamble configuration	T_{CP}	T_{SEQ}
0	656 T_s	2048 T_s
1	1344 T_s	2048 T_s

5.7.4.2 Preamble sequence generation

The scheduling request preambles are generated from Zadoff-Chu sequences. The network configures the set of preamble sequences the UE is allowed to use.

The length of scheduling request preamble sequence is 71. The u^{th} root Zadoff-Chu sequence is defined by

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

where $N_{ZC} = 71$. Twelve different cyclic shifts of this sequence are defined to obtain scheduling request preamble sequence.

The random access preamble $x_u(n)$ shall be mapped to resource elements according to

$$
\begin{aligned}
&a_{k,l} = f \cdot x_u(n) e^{-j\frac{2\pi}{12}vk}, \qquad v \in \{0,1,2,\ldots 11\} \\
&k = n + 1 + 12 * (6 * N_{SR} + 51), \\
&n = 0,1,\ldots,70 \\
&f = \begin{cases} 1 & \text{if l is even} \\ f' & \text{if l is odd} \end{cases} \\
&f' \in \{-1,1\}. \\
&\mathrm{l} \in \begin{Bmatrix} \{(0,1),(2,3),(4,5),(6,7),(8,9)\} & \text{for format 0} \\ \{(0,1),(2,3),(4,5),(6,7)\} & \text{for format 1} \end{Bmatrix}
\end{aligned}
$$

As outlined by the equations above, the RACH subframe provides multiple subbands, each occupying 6 RBs, for transmitting SR; The parameter N_{SR} determines which band is used by the UE. The values of u, v, f' and N_{SR} are provided from higher layers. The symbol index *l* is calculated in the same way as described in 5.7.2.1

5.7.4.3 Baseband signal generation

The baseband signal for SR is generated in the same manner as RACH as outlined in 5.7.3.

5.8 Modulation and upconversion

Modulation and upconversion to the carrier frequency of the complex-valued OFDM baseband signal for each antenna port or the complex-valued xPRACH baseband signal is shown in Figure 5.8-1. The filtering required prior to transmission is defined by the requirements in TS 5G.201 [1].

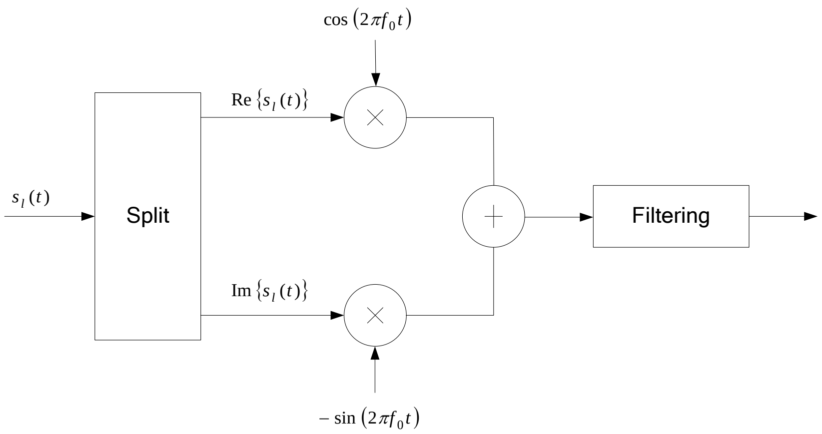

Figure 5.8-1: Uplink modulation

6 Downlink

6.1 Overview

The smallest time-frequency unit for downlink transmission is denoted a resource element and is defined in clause 6.2.2.

6.1.1 Physical channels

A downlink physical channel corresponds to a set of resource elements carrying information originating from higher layers and is the interface defined between TS 5G.212 [2] and the present document TS 5G.211.
The following downlink physical channels are defined:

- Physical Downlink Shared Channel, xPDSCH
- Physical Broadcast Channel, xPBCH
- Extended physical broadcast channel (ePBCH)
- Physical Downlink Control Channel, xPDCCH

6.1.2 Physical signals

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

- Reference signal
- Synchronization signal

6.2 Slot structure and physical resource elements

6.2.1 Resource grid

The transmitted signal in each slot is described by one or several resource grids of $N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}} = 1200$ subcarriers and $N_{\mathrm{symb}}^{\mathrm{DL}} = 7$ OFDM symbols. The resource grid structure is illustrated in Figure 6.2.2-1.

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.

For beam sweeping transmission per an OFDM symbol, i.e. SS/xPBCH/BRS, an antenna port is defined within an OFDM symbol. For beam sweeping transmission per two consecutive OFDM symbols, i.e. ePBCH, an antenna port is defined within two OFDM symbols. For the other transmission, an antenna port is defined within a subframe. There is one resource grid per antenna port.

6.2.2 Resource elements

Each element in the resource grid for antenna port p is called a resource element and is uniquely identified by the index pair (k,l) in a slot where $k = 0,\ldots,N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}} - 1$ and $l = 0,\ldots,N_{\mathrm{symb}}^{\mathrm{DL}} - 1$ 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.

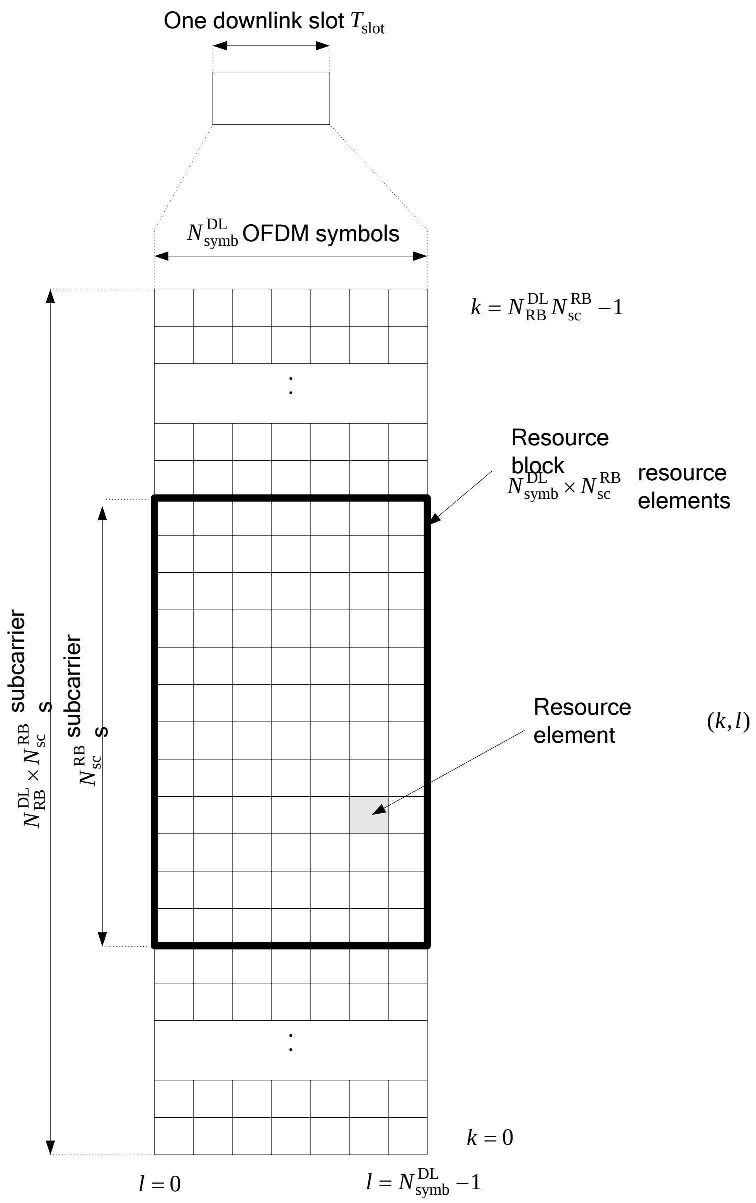

Figure 6.2.2-1: Downlink resource grid

6.2.3 Resource blocks

Resource blocks are used to describe the mapping of certain physical channels to resource elements.

A physical resource block is defined as N_{symb}^{DL} consecutive OFDM symbols in the time domain and N_{sc}^{RB} consecutive subcarriers in the frequency domain, where N_{symb}^{DL} and N_{sc}^{RB} are given by Table 6.2.3-1. A physical resource block thus consists of $N_{symb}^{DL} \times N_{sc}^{RB}$ resource elements, corresponding to one slot in the time domain and 900 kHz in the frequency domain.

Physical resource blocks are numbered from 0 to $N_{RB}^{DL} - 1$ in the frequency domain. 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

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

Table 6.2.3-1: Physical resource blocks parameters

Configuration		$N_{\text{sc}}^{\text{RB}}$	$N_{\text{symb}}^{\text{DL}}$
Normal cyclic prefix	$\Delta f = 75\,\text{kHz}$	12	7

A physical resource-block pair is defined as the two physical resource blocks in one subframe having the same physical resource-block number n_{PRB}.

The size of a virtual resource block group is four times that of a physical resource block. A pair of virtual resource block groups over two slots in a subframe is assigned together by a single virtual resource block group number, n_{VRB}.

6.2.3.1 Virtual resource block groups of localized type

Virtual resource block groups of localized type are numbered from 0 to $N_{\text{VRBG}}^{\text{DL}} - 1$, where $4N_{\text{VRBG}}^{\text{DL}} = N_{\text{RB}}^{\text{DL}}$. Virtual resource block group of index $n_{\text{VRBG}}^{\text{DL}}$ is mapped to a set of physical resource block pairs given by $\{4n_{\text{VRBG}}^{\text{DL}},\ 4n_{\text{VRBG}}^{\text{DL}}+1,\ 4n_{\text{VRBG}}^{\text{DL}}+2,\ 4n_{\text{VRBG}}^{\text{DL}}+3\}$.

6.2.4 Resource-element groups (xREGs)

xREGs are used for defining the mapping of control channels to resource elements. Each OFDM symbol has 16 xREGs.

The xREG of index $n_{\text{xREG}} \in \{0, 1, \ldots, 15\}$ consists of resource elements (k,l) with $k = k_0 + k_1 + 6m$ where

- $k_0 = 6 \cdot n_{\text{xREG}} \cdot N_{\text{sc}}^{\text{RB}}$,
- $k_1 = \{0,1,4,5\}$,
- $m = \{0,1,2,\ldots,11\}$,

The OFDM symbol index is given by either of l = 0 or l = {0, 1} according to the xPDCCH transmission configuration as described in [5G.213].

6.2.5 Guard Period for TDD Operation

The guard time necessary for switching transmission direction is obtained by puncturing the OFDM symbol prior to an uplink transmission.

6.3 General structure for downlink physical channels

The baseband signal representing a downlink physical channel is defined in terms of the following steps:

- scrambling of coded bits in a codeword to be transmitted on a physical channel
- modulation of scrambled bits to generate complex-valued modulation symbols
- mapping of the complex-valued modulation symbols onto one or several transmission layers

- precoding of the complex-valued modulation symbols on each layer for transmission on the antenna ports
- mapping of complex-valued modulation symbols for each antenna port to resource elements
- generation of complex-valued time-domain OFDM signal for each antenna port
- analog beamforming based on the selected beam

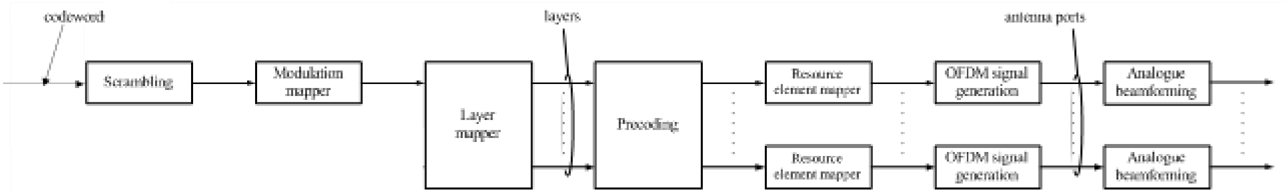

Figure 6.3-1: Overview of physical channel processing

6.3.1 Scrambling

For an codeword q, the block of bits $b^{(q)}(0),\ldots,b^{(q)}(M_{\mathrm{bit}}^{(q)}-1)$, where $M_{\mathrm{bit}}^{(q)}$ is the number of bits in codeword q transmitted on the physical channel in one subframe, shall be scrambled prior to modulation, resulting in a block of scrambled bits $\tilde{b}^{(q)}(0),\ldots,\tilde{b}^{(q)}(M_{\mathrm{bit}}^{(q)}-1)$ according to

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

where the scrambling sequence $c^{(q)}(i)$ is given by clause 7.2. The scrambling sequence generator shall be initialised at the start of each subframe, where the initialisation value of c_{init} depends on the transport channel type according to

$$c_{\mathrm{init}}=n_{\mathrm{RNTI}}\cdot 2^{14}+q\cdot 2^{13}+\lfloor \bar{n}_s/2\rfloor\cdot 2^{9}+N_{\mathrm{ID}}^{\mathrm{cell}}\quad \text{for PDSCH}$$
$$\bar{n}_s=n_s \bmod 20$$

where n_{RNTI} corresponds to the RNTI associated with the xPDSCH transmission as described in clause 8.1 TS 5G.213 [4].

Only one codewords can be transmitted in one subframe, i.e., $q=0$.

6.3.2 Modulation

For an codeword q, the block of scrambled bits $\tilde{b}^{(q)}(0),\ldots,\tilde{b}^{(q)}(M_{\mathrm{bit}}^{(q)}-1)$ shall be modulated as described in clause 7.1 using one of the modulation schemes in Table 6.3.2-1, resulting in a block of complex-valued modulation symbols $d^{(q)}(0),\ldots,d^{(q)}(M_{\mathrm{symb}}^{(q)}-1)$.

Table 6.3.2-1: Modulation schemes

Physical channel	Modulation schemes
xPDSCH	QPSK, 16QAM, 64QAM

6.3.3 Layer mapping

The complex-valued modulation symbols for the codeword to be transmitted are mapped onto one or two layers. Complex-valued modulation symbols $d^{(q)}(0),\ldots,d^{(q)}(M_{\mathrm{symb}}^{(q)}-1)$ for codeword q shall be mapped onto the layers

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

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

6.3.3.2 Layer mapping for spatial multiplexing

For spatial multiplexing, the layer mapping shall be done according to Table 6.3.3.2-1. The number of layers υ is less than or equal to the number of antenna ports P used for transmission of the physical channel.

Table 6.3.3.2-1: Codeword-to-layer mapping for spatial multiplexing

Number of layers	Number of codewords	Codeword-to-layer mapping $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$	
1	1	$x^{(0)}(i)=d^{(0)}(i)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}$
2	1	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/2$

6.3.3.3 Layer mapping for transmit diversity

For transmit diversity, the layer mapping shall be done according to Table 6.3.3.3-1. There is only one codeword and the number of layers υ is equal to the number of antenna ports P used for transmission of the physical channel.

Table 6.3.3.3-1: Codeword-to-layer mapping for transmit diversity

Number of layers	Number of codewords	Codeword-to-layer mapping $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$	
2	1	$x^{(0)}(i)=d^{(0)}(2i)$ $x^{(1)}(i)=d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}/2$

6.3.4 Precoding

The precoder takes as input a block of vectors $x(i)=\left[x^{(0)}(i) \quad \ldots \quad x^{(\upsilon-1)}(i)\right]^T$, $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$ from the layer mapping and generates a block of vectors $y(i)=\left[\ldots \quad y^{(p)}(i) \quad \ldots\right]^T$, $i=0,1,\ldots,M_{\text{symb}}^{\text{ap}}-1$ to be mapped onto resources on each of the antenna ports, where $y^{(p)}(i)$ represents the signal for antenna port p.

6.3.4.1 Precoding for transmission on a single antenna port

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

$$y^{(p)}(i)=x^{(0)}(i)$$

where p is the single antenna port number used for transmission of the physical channel and $i = 0,1,\ldots,M_{\text{symb}}^{\text{ap}} - 1$, $M_{\text{symb}}^{\text{ap}} = M_{\text{symb}}^{\text{layer}}$.

6.3.4.2 Precoding for transmit diversity

Precoding for transmit diversity is only used in combination with layer mapping for transmit diversity as described in clause 6.3.3.3. The precoding operation for transmit diversity is defined for two antenna ports.

For transmission on two antenna ports, p_1 and p_2 indicated in the DCI format B1 the output $y(i) = \left[y^{(p_1)}(i) \quad y^{(p_2)}(i) \right]^T$, $i = 0,1,\ldots,M_{\text{symb}}^{\text{ap}} - 1$ of the precoding operation is defined by

$$\begin{bmatrix} y^{(p_1)}(2i) \\ y^{(p_2)}(2i) \\ y^{(p_1)}(2i+1) \\ y^{(p_2)}(2i+1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & j & 0 \\ 0 & -1 & 0 & j \\ 0 & 1 & 0 & j \\ 1 & 0 & -j & 0 \end{bmatrix} \begin{bmatrix} \mathrm{Re}\left(x^{(0)}(i)\right) \\ \mathrm{Re}\left(x^{(1)}(i)\right) \\ \mathrm{Im}\left(x^{(0)}(i)\right) \\ \mathrm{Im}\left(x^{(1)}(i)\right) \end{bmatrix}$$

for $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1$ with $M_{\text{symb}}^{\text{ap}} = 2M_{\text{symb}}^{\text{layer}}$.

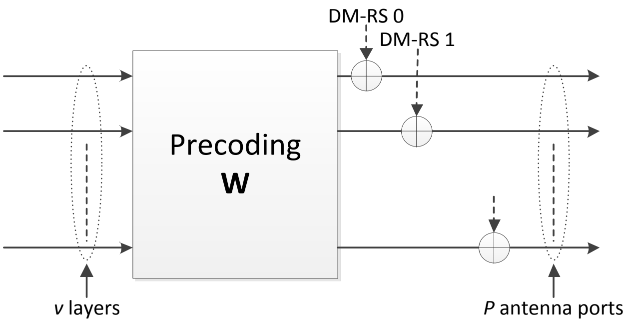

Figure 6.3.4.2-1: DM-RS location for transmit diversity

For transmit diversity, DM-RS is located after precoding with P antenna ports as illustrated in Figure 6.3.4.2-1.

6.3.4.3 Precoding for spatial multiplexing using antenna ports with UE-specific reference signals

Precoding for spatial multiplexing using antenna ports with UE-specific reference signals is only used in combination with layer mapping for spatial multiplexing as described in clause 6.3.3.2. Spatial multiplexing using antenna ports with UE-specific reference signals supports up to two antenna ports to enable MU-MIMO capability and the set of antenna ports used is $p \in \{8,\ldots,15\}$.

In the following let, p_1 and p_2, denote the two antenna ports indicated by DCI format B2 according to the definitions in TS 5G.212 [2].

For transmission of one layer on antenna port p_1, the precoding operation is defined by:

$$\left[y^{(p_1)}(i) \right] = \left[x^{(0)}(i) \right]$$

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

For transmission of two layers on antenna port p_1 and p_2, the precoding operation is defined by:

$$\begin{bmatrix} y^{(p_1)}(i) \\ y^{(p_2)}(i) \end{bmatrix} = \begin{bmatrix} x^{(0)}(i) \\ x^{(1)}(i) \end{bmatrix}$$

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

6.3.5 Mapping to resource elements

For each of the antenna ports used for transmission of the physical channel, the block of complex-valued symbols $y^{(p)}(0),\ldots,y^{(p)}(M_{\mathrm{symb}}^{\mathrm{ap}} - 1)$ shall conform to the downlink power allocation specified in clause 5.2 in TS 5G.213 [4] and be mapped in sequence starting with $y^{(p)}(0)$ to resource elements (k,l) that are in the resource blocks assigned for transmission.

The mapping to resource elements (k,l) on antenna port p not reserved for other purposes shall be in increasing order of first the index k over the assigned physical resource blocks and then the index l, starting with the first slot in a subframe.

6.4 Physical downlink shared channel (xPDSCH)

The physical downlink shared channel shall be processed and mapped to resource elements as described in clause 6.3 with the following additions and exceptions:

- The xPDSCH shall be transmitted on υ antenna port(s) in the set $p \in \{8,9,\ldots,15\}$, where the number of layers used for transmission of the xPDSCH υ is one or two.
- xPDSCH is not mapped to resource elements in the OFDM symbol carrying an xPDCCH associated with the xPDSCH.
- xPDSCH is not mapped to resource elements reserved for PCRS. If no PCRS is transmitted, xPDSCH is mapped to the PCRS REs. If PCRS is transmitted in antenna port 60 or 61 or both, xPDSCH is not mapped to the PCRS REs for both antenna port 60 and 61.
- They are not defined to be used for UE-specific reference signals associated with xPDSCH for any of the antenna ports in the set {8, 9, …, 15}.
- The index l in the first slot in a subframe fulfils $l \geq l_{\mathrm{DataStart}}$ where $l_{\mathrm{DataStart}}$ is given by clause [8.1.6.1] of TS 5G.213 [3].
- The index l in the second slot in a subframe fulfils $l \leq l_{\mathrm{DataStop}}$ where l_{DataStop} is given by clause [8.1.6.1] of TS 5G.213 [3].

6.5 Physical broadcast channel

The Physical broadcast channel is transmitted using the same multiple beams used for beam reference signals in each OFDM symbol.

6.5.1 Scrambling

The block of bits $b(0),\ldots,b(M_{\mathrm{bit}} - 1)$, where M_{bit}, the number of bits transmitted on the physical broadcast channel, equals 5248, shall be scrambled with a cell-specific sequence prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0),\ldots,\tilde{b}(M_{\mathrm{bit}} - 1)$ according to

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

where the scrambling sequence $c(i)$ is given by clause 7.2. The scrambling sequence shall be initialised with $c_{\text{init}} = N_{\text{ID}}^{\text{cell}}$ in each radio frame fulfilling $n_f \; mod \; 4 = 0$.

6.5.2 Modulation

The block of scrambled bits $\tilde{b}(0),\ldots,\tilde{b}(M_{\text{bit}}-1)$ shall be modulated as described in clause 7.1, resulting in a block of complex-valued modulation symbols $d(0),\ldots,d(M_{\text{symb}}-1)$. Table 6.5.2-1 specifies the modulation mappings applicable for the physical broadcast channel.

Table 6.5.2-1: xPBCH modulation schemes.

Physical channel	Modulation schemes
xPBCH	QPSK

6.5.3 Layer mapping and precoding

The block of modulation symbols $d(0),\ldots,d(M_{\text{symb}}-1)$ shall be mapped to layers according to one of clause 6.3.3.3 and precoded according to clause 6.3.4.2, resulting in a block of vectors $\tilde{y}(i) = \left[\tilde{y}^{(0)}(i) \quad \tilde{y}^{(1)}(i)\right]^T$, $i = 0,\ldots,M_{\text{symb}}-1$. Then block of vectors $y(i) = \left[y^{(0)}(i) \quad y^{(1)}(i)\ldots y^{(7)}(i)\right]^T$ is obtained by setting $y^{(p)}(i) = \tilde{y}^{(0)}(i)$ for $p \in \{0,2,4,6\}$ and $y^{(p)}(i) = \tilde{y}^{(1)}(i)$ for $p \in \{1,3,5,7\}$, where $y^{(p)}(i)$ represents the signal for antenna port p .The antenna ports p = 0…7 used for xPBCH are identical to the antenna ports p = 0..7 used for the mapping of BRS according to 6.7.4.2.

6.5.4 Mapping to resource elements

The block of complex-valued symbols $\mathrm{y}(0),\ldots,\mathrm{y}(M_{symb}-1)$ is transmitted during 4 consecutive radio frames starting in each radio frame fulfilling $n_f \; mod \; 4 = 0$. The block of complex-valued symbols $\mathrm{y}(0),\ldots,\mathrm{y}(M_{symb}-1)$ are divided into 16 sub-block of complex-valued symbols, which is given by

Sub-block 0 and 1: $\mathrm{y}(0)$ to $\mathrm{y}\left(\frac{M_{symb}}{16}-1\right)$, $\mathrm{y}\left(\frac{M_{symb}}{16}\right)$ to $\mathrm{y}\left(\frac{M_{symb}}{8}-1\right)$,

Sub-block 2 and 3: $\mathrm{y}\left(\frac{M_{symb}}{8}\right)$ to $\mathrm{y}\left(\frac{3M_{symb}}{16}-1\right)$, $\mathrm{y}\left(\frac{3M_{symb}}{16}\right)$ to $\mathrm{y}\left(\frac{M_{symb}}{4}-1\right)$,

Sub-block 4 and 5: $\mathrm{y}\left(\frac{M_{symb}}{4}\right)$ to $\mathrm{y}\left(\frac{5M_{symb}}{16}-1\right)$, $\mathrm{y}\left(\frac{5M_{symb}}{16}\right)$ to $\mathrm{y}\left(\frac{3M_{symb}}{8}-1\right)$,

Sub-block 6 and 7: $\mathrm{y}\left(\frac{3M_{symb}}{8}\right)$ to $\mathrm{y}\left(\frac{7M_{symb}}{16}-1\right)$, $\mathrm{y}\left(\frac{7M_{symb}}{16}\right)$ to $\mathrm{y}\left(\frac{M_{symb}}{2}-1\right)$,

Sub-block 8 and 9: $\mathrm{y}\left(\frac{M_{symb}}{2}\right)$ to $\mathrm{y}\left(\frac{9_{symb}}{16}-1\right)$, $\mathrm{y}\left(\frac{9M_{symb}}{16}\right)$ to $\mathrm{y}\left(\frac{5M_{symb}}{8}-1\right)$,

Sub-block 10 and 11: $\mathrm{y}\left(\frac{5M_{symb}}{8}\right)$ to $\mathrm{y}\left(\frac{11M_{symb}}{16}-1\right)$, $\mathrm{y}\left(\frac{11M_{symb}}{16}\right)$ to $\mathrm{y}\left(\frac{3M_{symb}}{4}-1\right)$,

Sub-block 12 and 13: $\mathrm{y}\left(\frac{3M_{symb}}{4}\right)$ to $\mathrm{y}\left(\frac{13M_{symb}}{16}-1\right)$, $\mathrm{y}\left(\frac{13M_{symb}}{16}\right)$ to $\mathrm{y}\left(\frac{7M_{symb}}{8}-1\right)$,

Sub-block 14 and 15: $\mathrm{y}\left(\frac{7M_{symb}}{8}\right)$ to $\mathrm{y}\left(\frac{15M_{symb}}{16}-1\right)$, $\mathrm{y}\left(\frac{15M_{symb}}{16}\right)$ to $\mathrm{y}(M_{symb}-1)$

The sub-frames 0 and 25 in each radio frame shall be assigned to transmit xPBCH together with synchronization signals. The sub-block of complex-valued symbols is repeated on each OFDM symbol in the subframe and it may be transmitted by different analog beams. The sub-blocks are repeated – although transmitted with different information --

after every four radio frames, i.e., after every eight synchronization sub-frames. Focusing on four adjacent radio frames whose first eight bits of SFN are same and indexing the sub-frames of these radio frames from 0 to 199, sub-block 2i and 2i+1 are transmitted in sub-frame 25i where $0 \le i \le 7$.

The even indexed sub-block of complex-valued symbols transmitted shall be mapped in increasing order of the index in each OFDM symbol. The resource-element indices are given by:

$$\mathrm{k} = k' \cdot N_{sc}^{RB} + k''$$

$$k' = \left\lfloor \frac{1}{2}(N_{RB}^{DL} + 18) \right\rfloor, \left\lfloor \frac{1}{2}(N_{RB}^{DL} + 18) \right\rfloor + 1, \dots, N_{RB}^{DL} - 1$$

$$k'' = 0, 1, 2, 3$$

$$\mathrm{l} = 0, 1, 2, \dots, 12, 13$$

The odd indexed sub-block of complex-valued symbols transmitted in each subframe shall be mapped in decreasing order of the index in each OFDM symbol. The resource-element indices are given by:

$$\mathrm{k} = k' \cdot N_{sc}^{RB} + k''$$

$$k' = \left\lfloor \frac{1}{2}(N_{RB}^{DL} - 18) \right\rfloor - 1, \left\lfloor \frac{1}{2}(N_{RB}^{DL} - 18) \right\rfloor - 2, \dots, 1, 0$$

$$k'' = 3, 2, 1, 0$$

$$\mathrm{l} = 0, 1, 2, \dots, 12, 13$$

where $N_{sc}^{RB} = 12$ and $N_{RB}^{DL} = 100$ Figures 6.7.4.2-1 illustrates the resource elements used for xPBCH according to the numerical definition.

6.5A Extended Physical broadcast channel

The system information block to support standalone mode shall be transmitted on ePBCH via two antenna ports. The ePBCH is transmitted using the same multiple beams in N_{symb}^{ePBCH} consecutive OFDM symbols, where $N_{symb}^{ePBCH} = 2$.

The ePBCH is transmitted on a predefined or configured subframe. The essential system information for initial cell attachment and radio resource configuration shall be included in the system information block.

6.5A.1 Scrambling

The block of bits $b(0),\dots,b(M_{\mathrm{bit}}-1)$, where M_{bit}, the number of bits transmitted on the extended physical broadcast channel, equals to 2000, shall be scrambled with a cell-specific sequence prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0),\dots,\tilde{b}(M_{\mathrm{bit}}-1)$ according to

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

where the scrambling sequence $c(i)$ is given by clause 7.2. The scrambling sequence shall be initialised with

$$C_{init} = 2^{10} \cdot \left(7 \cdot (\bar{n}_s + 1) + \left\lfloor l / N_{symb}^{ePBCH} \right\rfloor + 1\right) \cdot (2 \cdot N_{ID}^{cell} + 1) + 2 \cdot N_{ID}^{cell} + 1$$

where $\bar{n}_s = n_s \bmod 20$; n_s is the slot number within a radio frame and l is the OFDM symbol number within one subframe, and $l = 0, 1, 2, \cdots, 13$.

6.5A.2 Modulation

The block of scrambled bits $\tilde{b}(0),\dots,\tilde{b}(M_{\mathrm{bit}}-1)$ shall be modulated as described in clause 7.1, resulting in a block of complex-valued modulation symbols $d(0),\dots,d(M_{\mathrm{symb}}-1)$. Table 6.5.A.1-1 specifies the modulation mappings applicable for the extended physical broadcast channel.

Table 6.5A.2-1: ePBCH modulation schemes.

Physical channel	Modulation schemes
ePBCH	QPSK

6.5A.3 Layer mapping and precoding

The block of modulation symbols $d(0),\ldots,d(M_{\text{symb}}-1)$ shall be mapped to layers according to one of clause 6.3.3.3 with $M_{\text{symb}}^{(0)} = M_{\text{symb}}$ and precoded according to clause 6.3.4.2, resulting in a block of vectors

$y(i) = \left[y^{(50)}(i) \quad , \quad y^{(51)}(i)\right]^T$, $i = 0,\ldots,M_{\text{symb}}-1$, where $y^{(50)}(i)$ and $y^{(51)}(i)$ correspond to signals for antenna port 50 and 51, respectively.

6.5A.4 ePBCH Configuration

The ePBCH transmission periodicity is configured by xPBCH, which is given by Table 6.5A.4-1.

Table 6.5A.4-1: ePBCH transmission periodicity

Indication bit	ePBCH transmission periodicty	T_{ePBCH}
00	ePBCH transmission is off	N/A
01	40ms	4
10	80ms	8
11	160ms	16

The required number of subframes for ePBCH transmission is determined according to BRS transmission period, which is given by Table 6.5A.4-2.

Table 6.5A.4-2: The number of subframes for ePBCH transmission according to BRS transmission period

BRS transmission period	# of subframes, N_{ePBCH}
1 slot < 5ms	1
1 subframes = 5ms	2
2 subframes = 10ms	4
4 subframes = 20ms	8

When the ePBCH transmission is on, the multiple subframes for ePBCH transmission are configured in the radio frame fulfilling $\mathrm{n_f} \bmod \left\lceil\frac{\mathrm{T_{ePBCH}}}{\mathrm{N_{ePBCH}}}\right\rceil = 0$. The subframes in each configured radio frame shall be assigned to transmit ePBCH according to Table 6.5A.4-3.

Table 6.5A.4-3: Subframe configuration in each configured radio frame

Value of $\frac{T_{ePBCH}}{N_{ePBCH}}$	Configured subframes in each configured radio frame
$\frac{T_{ePBCH}}{N_{ePBCH}} \geq 1$	4
$\frac{T_{ePBCH}}{N_{ePBCH}} < 1$	29, 4

6.5A.5 Mapping to resource elements

In each OFDM symbol of the configured subframes, the block of complex-valued symbols $y(0),\ldots,y(M_{symb}-1)$ is transmitted via two antenna ports. The block of complex-valued symbols is transmitted using identical beams in 2 consequtive OFDM symbols. The set of logical beam sweeping indices and their order across pairs of OFDM symbols in ePBCH subframes is identical to the set of logical beam indices and their order across OFDM symbols used for BRS transmission during BRS transmission period. The beam indexing initialization for ePBCH is such that the set of logical beam indices $b_1^p(0)$ for all $p \in \{0,1,2,\dots,7\}$, as defined in Table 6.7.4.3-1, is applied on the first symbol pair of the first ePBCH subframe in $n_f = 0$.

The block of complex-valued symbols transmitted in each OFDM symbol shall be mapped in increasing order of the index k excluding DM-RS associated with ePBCH. The resource-element indices are given by

$$k = 6 \cdot k' + k''$$

$$k' = 0,1,2,\dots,2 \cdot N_{RB}^{DL} - 1$$

$$k'' = 0,1,3,4,5$$

$$l = 0,1,2,\dots,12,13$$

where $N_{RB}^{DL} = 100$.

6.6 Physical downlink control channel (xPDCCH)

6.6.1 xPDCCH formats

The physical downlink control channel (xPDCCH) carries scheduling assignments. A physical downlink control channel is transmitted using an aggregation of one or several consecutive enhanced control channel elements (CCEs) where each CCE consists of multiple resource element groups (REGs), defined in clause 6.2.4. The number of CCEs used for one PDCCH depends on the PDCCH format as given by Table 6.6.1-1 and the number of REGs per CCE is given by Table 6.6.1-1.

Table 6.6.1-1: Supported xPDCCH formats

PDCCH format	Number of CCEs	Number of resource-element groups	Number of xPDCCH bits
0	2	2	192
1	4	4	384
2	8	8	768
3	16	16	1536

6.6.2 xPDCCH multiplexing and scrambling

The block of bits $b(0),\dots,b(M_{\mathrm{bit}}-1)$ to be transmitted on an xPDCCH in a subframe shall be scrambled, resulting in a block of scrambled bits $\tilde{b}(0),\dots,\tilde{b}(M_{\mathrm{bit}}-1)$ according to

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

where the UE-specific scrambling sequence $c(i)$ is given by clause 7.2. The scrambling sequence generator shall be initialized with $c_{\mathrm{init}} = \lfloor n_s/2 \rfloor \cdot 2^9 + n_{\mathrm{ID}}^{\mathrm{xPDCCH}}$ where the quantity $n_{\mathrm{ID}}^{\mathrm{xPDCCH}}$ is given by

- $n_{\mathrm{ID}}^{\mathrm{xPDCCH}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ if no value for n_{ID} is provided by higher layers
- $n_{\mathrm{ID}}^{\mathrm{xPDCCH}} = n_{\mathrm{ID}}$ otherwise.

6.6.3 Modulation

The block of scrambled bits $\tilde{b}(0),\dots,\tilde{b}(M_{\mathrm{tot}}-1)$ shall be modulated as described in clause 7.1, resulting in a block of complex-valued modulation symbols $d(0),\dots,d(M_{\mathrm{symb}}-1)$. Table 6.6.3-1 specifies the modulation mappings applicable for the physical downlink control channel.

Table 6.6.3-1: PDCCH modulation schemes

Physical channel	Modulation schemes
xPDCCH	QPSK

6.6.4 Layer mapping and precoding

The layer mapping with space-frequency block coding shall be done according to Table 6.6.4-1. There is only one codeword and the two-layer transmission is used.

Table 6.6.4-1: Codeword-to-layer mapping for transmit diversity

Number of layers	Number of codewords	Codeword-to-layer mapping $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1$	
2	1	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} / 2$

For transmission on two antenna ports, $p \in \{107,109\}$, the output $y(i) = \begin{bmatrix} y^{(107)}(i) & y^{(109)}(i) \end{bmatrix}^T$, $i = 0,1,\ldots,M_{\text{symb}}^{\text{ap}} - 1$ of the precoding operation is defined by

$$\begin{bmatrix} y^{(107)}(2i) \\ y^{(109)}(2i) \\ y^{(107)}(2i+1) \\ y^{(109)}(2i+1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & j & 0 \\ 0 & -1 & 0 & j \\ 0 & 1 & 0 & j \\ 1 & 0 & -j & 0 \end{bmatrix} \begin{bmatrix} \mathrm{Re}(x^{(0)}(i)) \\ \mathrm{Re}(x^{(1)}(i)) \\ \mathrm{Im}(x^{(0)}(i)) \\ \mathrm{Im}(x^{(1)}(i)) \end{bmatrix}$$

for $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1$ with $M_{\text{symb}}^{\text{ap}} = 2M_{\text{symb}}^{\text{layer}}$.

6.6.5 Mapping to resource elements

The block of complex-valued symbols $y(0),\ldots,y(M_{\text{symb}} - 1)$ shall be mapped in sequence starting with $y(0)$ to resource elements (k,l) on the associated antenna port which meet all of the following criteria:

- they are part of the xREGs assigned for the xPDCCH transmission, and
- $l \in \{0, 1\}$ equals the OFDM symbol index

The mapping to resource elements (k,l) on antenna port p meeting the criteria above shall be in increasing order of the index k.

6.7 Reference signals

The following types of downlink reference signals are defined:

- UE-specific Reference Signal (DM-RS) associated with xPDSCH
- UE-specific Reference Signal (DM-RS) associated with xPDCCH
- CSI Reference Signal (CSI-RS)

- Beam measurement Reference Signal (BRS)
- Beam Refinement Reference Signal (BRRS)
- Phase noise compensation reference signal, associated with transmission of PDSCH (PCRS)
- Reference Signal (DM-RS) associated with ePBCH

There is one reference signal transmitted per downlink antenna port.

6.7.1 UE-specific reference signals associated with xPDCCH

The demodulation reference signal associated with xPDCCH is transmitted on the same antenna port $p \in \{107,109\}$ as the associated xPDCCH physical resource;

6.7.1.1 Sequence generation

For any of the antenna ports $p \in \{107,109\}$, the reference-signal sequence $r(m)$ is defined by

$$r(m) = \frac{1}{\sqrt{2}}\left(1-2\cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1-2\cdot c(2m+1)\right), \qquad m = 0,1,\ldots,23 .$$

The pseudo-random sequence $c(n)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$$c_{\mathrm{init}} = \left(\lfloor \bar{n}_s/2 \rfloor + 1\right)\cdot\left(2n_{\mathrm{ID}}^{\mathrm{xPDCCH}} + 1\right)\cdot 2^{16} + n_{\mathrm{SCID}}^{\mathrm{xPDCCH}}$$
$$\bar{n}_s = n_s \bmod 20$$

at the start of each subframe where $n_{\mathrm{SCID}}^{\mathrm{xPDCCH}} = 2$ and $n_{\mathrm{ID}}^{\mathrm{xPDCCH}}$ is configured by higher layers where the quantity $n_{\mathrm{ID}}^{\mathrm{xPDCCH}}$ is given by

- $n_{\mathrm{ID}}^{\mathrm{xPDCCH}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ if no value for n_{ID} is provided by higher layers
- $n_{\mathrm{ID}}^{\mathrm{xPDCCH}} = n_{\mathrm{ID}}$ otherwise.

6.7.1.2 Mapping to resource elements

For the antenna port $p \in \{107,109\}$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ in a subframe according to

$$a_{k,l}^{(p)} = \bar{w}_p(m'')\, r_l(m')$$

where

$$k = k_0 + 2 + (m' \bmod 2) + 6\cdot\lfloor m'/2 \rfloor$$

$$m'' = m' \bmod 2$$

$$k_0 = 6\cdot n_{\mathrm{xREG}}\cdot N_{\mathrm{sc}}^{\mathrm{RB}}$$

$$0 \le n_{\mathrm{xREG}} < 16$$

$$m' = 0,1,\ldots,23$$

The sequence $\bar{w}_p(i)$ is given by Table 6.7.1.2-1.

Table 6.7.1.2-1: The sequence $\overline{w}_p(i)$

Antenna port p	$\left[\overline{w}_p(0) \quad \overline{w}_p(1)\right]$
107	$[+1 \quad +1]$
109	$[+1 \quad -1]$

6.7.2 UE-specific reference signals associated with xPDSCH

UE specific reference signals associated with xPDSCH

- are transmitted on antenna port(s) $p \in \{8,\ldots,15\}$ indicated in DCI.
- are present and are a valid reference for xPDSCH demodulation only if the xPDSCH transmission is associated with the corresponding antenna port according to TS 5G.212 [2];
- are transmitted only on the physical resource blocks upon which the corresponding xPDSCH is mapped.

A UE-specific reference signal associated with xPDSCH is not transmitted in resource elements (k,l) in which one of the physical channels are transmitted using resource elements with the same index pair (k,l) regardless of their antenna port p.

6.7.2.1 Sequence generation

For any of the antenna ports $p \in \{8,9,\ldots,15\}$, the reference-signal sequence $r(m)$ is defined by

$$r(m)=\frac{1}{\sqrt{2}}(1-2\cdot c(2m))+j\frac{1}{\sqrt{2}}(1-2\cdot c(2m+1)), \qquad m=0,1,\ldots,3N_{RB}^{\max,DL}-1\cdot$$

The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}}=\left(\lfloor \overline{n}_{\text{s}}/2\rfloor+1\right)\cdot\left(2n_{\text{ID}}^{(n_{\text{SCID}})}+1\right)\cdot 2^{16}+n_{\text{SCID}}$$
$$\overline{n}_{\text{s}}=n_{\text{s}} \bmod 20$$

at the start of each subframe.

The quantities $n_{\text{ID}}^{(i)}$, $i=0,1$, are given by

- $n_{\text{ID}}^{(i)}=N_{\text{ID}}^{\text{cell}}$ if no value for $n_{\text{ID}}^{\text{DMRS},i}$ is provided by higher layers
- $n_{\text{ID}}^{(i)}=n_{\text{ID}}^{\text{DMRS},i}$ otherwise

The value of n_{SCID} is zero unless specified otherwise. For an xPDSCH transmission, n_{SCID} is given by the DCI format in TS 5G.212 [2] associated with the xPDSCH transmission.

6.7.2.2 Mapping to resource elements

For antenna port p_1 used for single port transmission, or ports $\{p_1, p_2\}$ used for two-port transmission in a physical resource block with frequency-domain index n_{PRB} assigned for the corresponding xPDSCH transmission, a part of the reference signal sequence $r(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ in a subframe according to

$$a_{k,l}^{(p)}=w_p(k'')\cdot r(k''')$$

where

$$k = 4m' + N_{\text{sc}}^{\text{RB}} \cdot n_{\text{PRB}} + k'$$
$$k' = \begin{cases} 0 & p \in \{8,12\} \\ 1 & p \in \{9,13\} \\ 2 & p \in \{10,14\} \\ 3 & p \in \{11,15\} \end{cases}$$
$$k'' = \begin{cases} 0 & \text{if } k \bmod 8 < 4 \\ 1 & \text{if } 4 \le k \bmod 8 \le 7 \end{cases}$$
$$k''' = \left\lfloor \frac{k}{4} \right\rfloor$$
$$l = \begin{cases} 2 & \\ 2,10 & \text{for high speed case} \end{cases}$$
$$m' = 0,1,2$$

Information indicating whether $l = 2$ or $l = \{2,10\}$ is signalled via higher layer signalling.

The sequence $\overline{w}_p(i)$ is given by Table 6.7.2.2-1.

Table 6.7.2.2-1: The sequence $\overline{w}_p(i)$

Antenna port p	$[\overline{w}_p(0)\ \ \overline{w}_p(1)]$
8	$[+1\ \ +1]$
9	$[+1\ \ +1]$
10	$[+1\ \ +1]$
11	$[+1\ \ +1]$
12	$[+1\ \ -1]$
13	$[+1\ \ -1]$
14	$[+1\ \ -1]$
15	$[+1\ \ -1]$

Resource elements (k,l) used for transmission of UE-specific reference signals to one UE on any of the antenna ports in the set S, where $S = \{8,12\}$, $S = \{9,13\}$, $S = \{10,14\}$ or $S = \{11,15\}$ shall

- not be used for transmission of xPDSCH on any antenna port in the same subframe, and
- not be used for UE-specific reference signals to the same UE on any antenna port other than those in S in the same subframe.

Figure 6.7.2.2-1 illustrates the resource elements used for UE-specific reference signals for antenna ports 8,9,10,11,12,13,14 and 15.

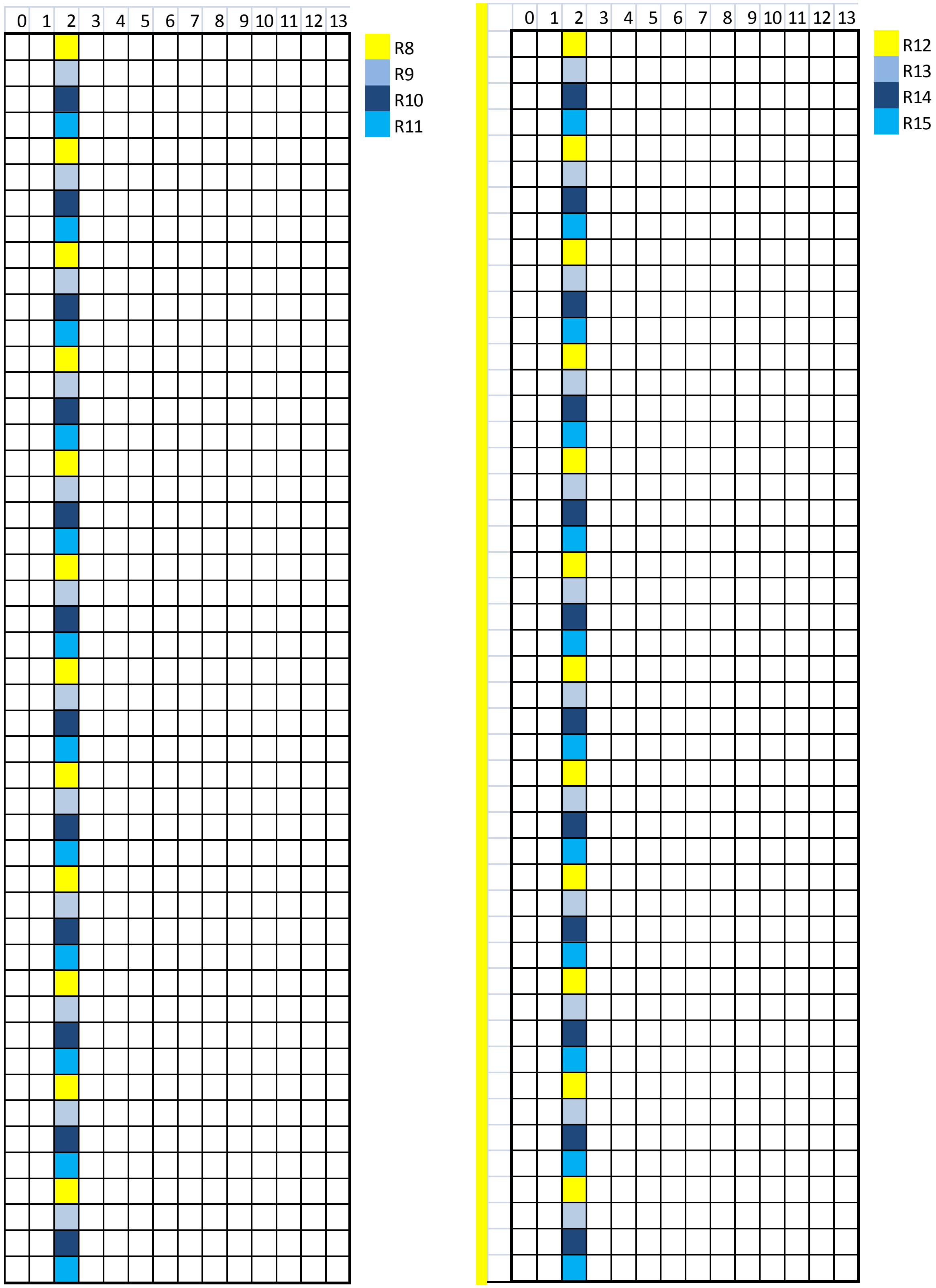

Figure 6.7.2.2-1: Mapping of UE-specific reference signals, antenna ports 8, 9, 10, 11, 12, 13, 14 and 15.

6.7.3 CSI reference signals

CSI reference signals are transmitted on 8 or 16 antenna ports using $p=16,...,23$ or $p=16,...,31$ respectively. The antenna ports associated with CSI reference signals are paired into CSI-RS groups (CRGs). A CRG comprises of two consecutive antenna ports starting from antenna port $p=16$. One or more of the CRGs is associated with zero-power and used as interference measurement resource. The transmission of CSI-RS is dynamically indicated in the xPDCCH.

6.7.3.1 Sequence generation

The reference-signal sequence $r_{l,n_s}(m)$ is defined by

$$r_{l,n_s}(m)=\frac{1}{\sqrt{2}}\big(1-2\cdot c(2m)\big)+j\frac{1}{\sqrt{2}}\big(1-2\cdot c(2m+1)\big),\quad m=0,1,\ldots,\frac{3}{2}N_{\mathrm{RB}}^{\max,\mathrm{DL}}-1$$

where n_s is the slot number within a radio frame and l is the OFDM symbol number within the slot. The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall at the start of each OFDM symbol be initialised with

$$c_{\mathrm{init}}=2^{10}\cdot\left(7\cdot\left(\bar{n}_s+1\right)+l+1\right)\cdot\left(2\cdot N_{\mathrm{ID}}^{\mathrm{CSI}}+1\right)+2\cdot N_{\mathrm{ID}}^{\mathrm{CSI}}+1$$

$$\bar{n}_s=n_s \bmod 20$$

The quantity $N_{\mathrm{ID}}^{\mathrm{CSI}}$ is configured to the UE using higher layer signalling.

6.7.3.2 Mapping to resource elements

A CSI-RS allocation comprises of one symbol (symbol 12 or symbol 13) or two consecutive symbols (symbols 12 and 13).

In a subframe used for CSI-RS transmission, the reference signal sequence $r_{l,n_s}(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ on antenna port p according to

$$a_{k,l}^{(p)}=r_{l,n_s}(m)$$

$$k=p-16+8m-\begin{cases}0 & \text{for } p\in\{16,17,18,19,20,21,22,23\}\\ 8 & \text{for } p\in\{24,25,26,27,28,29,30,31\}\end{cases}$$

$$l=\begin{cases}5 & \text{for } p\in\{16,17,18,19,20,21,22,23\}\\ 6 & \text{for } p\in\{24,25,26,27,28,29,30,31\}\end{cases},\text{and } n_s \bmod(2)=1$$

The mapping is illustrated in Figure 6.7.3.2-1.

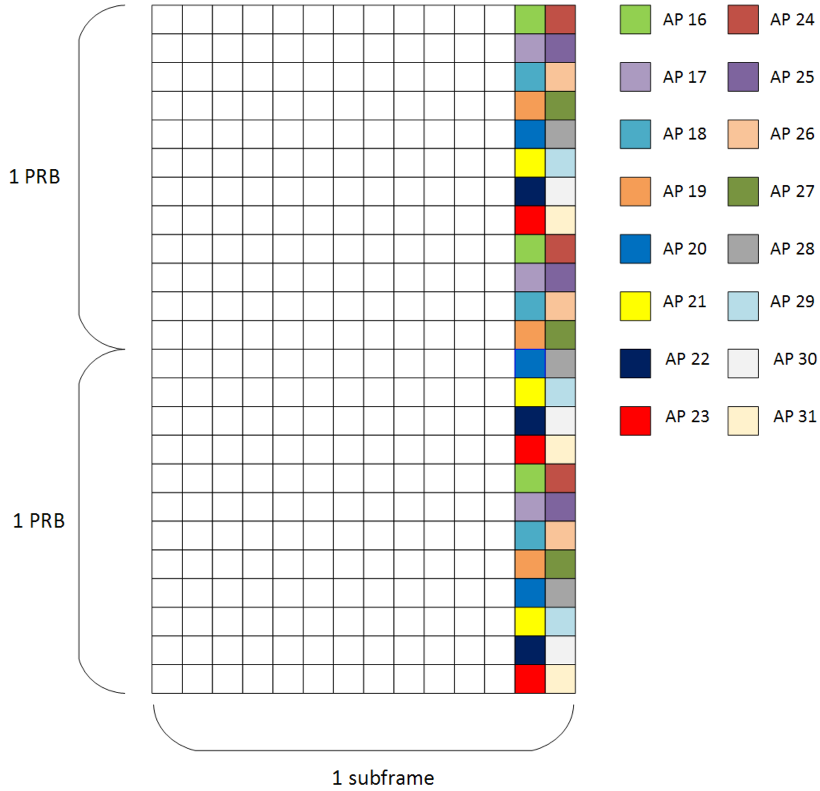

Figure 6.7.3.2-1: Mapping of CSI-RS for 2 symbol allocation

A UE can be configured with a one symbol allocation or a two symbol allocation of a CSI resource. Each of the REs comprising a CSI resource are configured as either

- CSI-RS resource (state 0) (8.2.5 in TS 5G.213 [3]);
- CSI IM resource (state 1) (8.2.6 in TS 5G.213 [3])

A CSI resource configuration is configured via high layer signalling, and it comprises of a 16 bit bitmap indicating RE mapping described in Tables 6.7.3.2-1.

The symbol allocation for a CSI resource(s) corresponding to a UE within a subframe is dynamically indicated by the 'resource configuration' field of the DCI.

Table 6.7.3.2-1: 16 bit bitmap which is indicating a CSI reosurce configuration

	k=0,8,16, *l*=12	k=1,9,17, *l*=12	k=2,10,18, *l*=12	k=3,11,19, *l*=12	k=4,12,20, *l*=12	k=5,13,21, *l*=12	k=6,14,22, *l*=12	k=7,15,23, *l*=12
State	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1
	k=0,8,16, *l*=13	k=1,9,17, *l*=13	k=2,10,18, *l*=13	k=3,11,19, *l*=13	k=4,12,20, *l*=13	k=5,13,21, *l*=13	k=6,14,22, *l*=13	k=7,15,23, *l*=13
State	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1

6.7.4 Beam reference signals

Beam reference signals are transmitted on one or several of antenna ports, p= 0…7.

6.7.4.1 Sequence generation

The reference-signal sequence $r_l(m)$ is defined by

$$r_l(m) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot \mathrm{c}(2\mathrm{m})\right) + \mathrm{j}\frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m+1)\right),\ \ m = 0,1,\dots,8 \cdot (N_{RB}^{DL} - 18) - 1$$

where l =0,1,…,13 is the OFDM symbol number within a subframe. The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$C_{init} = 2^{10} \cdot (7 \cdot (n_s + 1) + l' + 1) \cdot (2 \cdot N_{ID}^{cell} + 1) + 2 \cdot N_{ID}^{cell} + 1$ at the start of each OFDM symbol, where $n_s = \left\lfloor \frac{l}{7} \right\rfloor$ and $l' = l \bmod 7$.

6.7.4.2 Mapping to resource elements

The reference signal sequence $r_l(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ used as reference symbols for antenna port p according to

$$a_{k,l}^{(p)} = \overline{w}_p(m')r_l(m'')$$

$$\mathrm{k} = k' \cdot N_{sc}^{RB} + k''$$

$$k' = 0,1,\dots,,\left\lfloor \frac{1}{2}(N_{RB}^{DL} - 18)\right\rfloor - 1,\left\lfloor \frac{1}{2}(N_{RB}^{DL} + 18)\right\rfloor,\left\lfloor \frac{1}{2}(N_{RB}^{DL} + 18)\right\rfloor + 1,\dots,,N_{RB}^{DL} - 1$$

$$k'' = 4,5,6,7,8,9,10,11$$

$$\mathrm{l} = 0,1,2,\dots,12,13$$

$$m = 0,1,\dots,8 \cdot (N_{RB}^{DL} - 18) - 1$$

$$m'' = m + 4 \cdot (N_{RB}^{max,DL} - N_{RB}^{DL})$$

$$m' = m \bmod 8$$

where $N_{sc}^{RB} = 12$, $N_{RB}^{DL} = 100$ and the sequence $\overline{w}_p(i)$ is defined in Table 6.7.8.2-1.

Table 6.7.4.2-1: The sequence $\overline{w}_p(i)$

Antenna port p	$[\overline{w}_p(0)\ \ \overline{w}_p(1)\ \ \overline{w}_p(2)\ \ \overline{w}_p(3)\ \ \overline{w}_p(4)\ \ \overline{w}_p(5)\ \ \overline{w}_p(6)\ \ \overline{w}_p(7)]$
0	$[+1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1\ \ +1]$
1	$[+1\ \ +1\ \ +1\ \ +1\ \ -1\ \ -1\ \ -1\ \ -1]$
2	$[+1\ \ -1\ \ -1\ \ +1\ \ +1\ \ -1\ \ -1\ \ +1]$
3	$[+1\ \ -1\ \ -1\ \ +1\ \ -1\ \ +1\ \ +1\ \ -1]$
4	$[-1\ \ +1\ \ -1\ \ +1\ \ +1\ \ +1\ \ -1\ \ -1]$
5	$[-1\ \ +1\ \ -1\ \ +1\ \ -1\ \ -1\ \ +1\ \ +1]$
6	$[-1\ \ -1\ \ +1\ \ +1\ \ +1\ \ -1\ \ +1\ \ -1]$
7	$[-1\ \ -1\ \ +1\ \ +1\ \ -1\ \ +1\ \ -1\ \ +1]$

Resource elements (k,l) used for transmission of beam reference signals on any of the antenna ports in a slot shall be shared based on the orthogonal cover code in Table 6.7.4.2-1. Figures 6.7.4.2-1 illustrates the resource elements used for xPBCH and beam reference signal transmission according to the numerical definition in 6.5.3 and 6.7.4.2 at each OFDM symbol. Also shown is the cover code $\overline{w}_p$ on each resource element used for beam reference signal transmission on antenna port p.

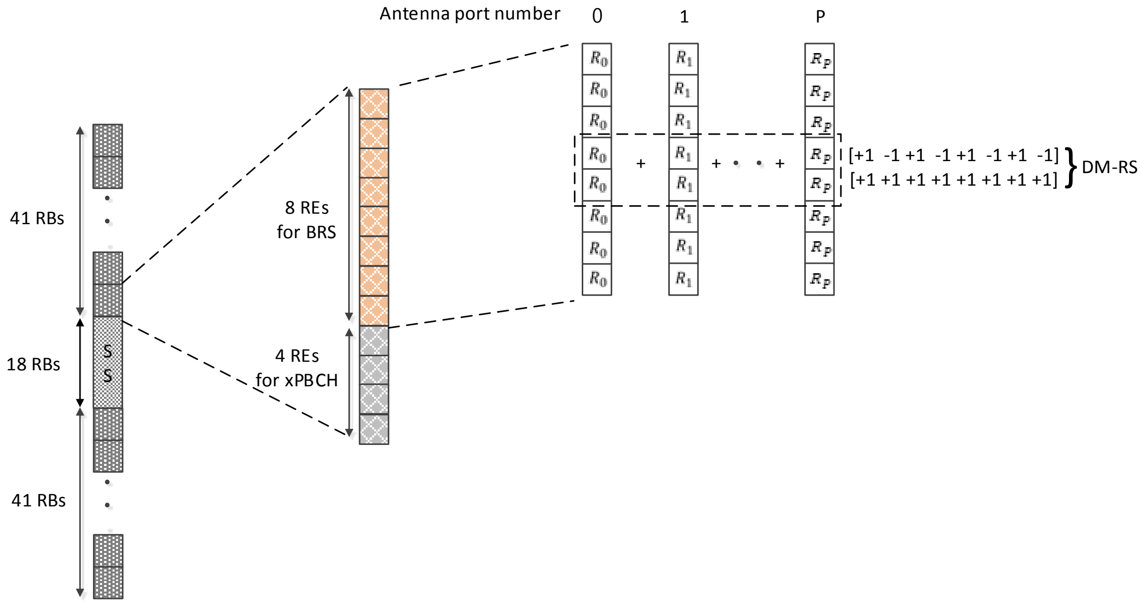

Figure 6.7.4.2-1. Mapping of beam reference signals including xPBCH and DM-RS

6.7.4.3 Beam reference signal transmission period configuration

The beam reference signal transmission period shall be configured by higher layers, which can be set to single slot, 1 subframe, 2 subframes or 4 subframes. In each configuration, the maximum # of opportunities for different TX beam training and the logical beam indexes are given by Table 6.7.4.3-1,

Table 6.7.4.3-1: Logical beam index mapping according to BRS transmission period

BRS configuarion (Indication bits)	BRS transmission period	Maximum # of beam training opportunities	Logical beam index
00	1 slot < 5ms	$\mathrm{P} \cdot N_{symb}^{DL}$	$\mathrm{i} = 0, \ldots, 1 \cdot \mathrm{P} \cdot N_{symb}^{DL} - 1$
01	1 subframe = 5ms	$2 \cdot \mathrm{P} \cdot N_{symb}^{DL}$	$\mathrm{i} = 0, \ldots, 2 \cdot \mathrm{P} \cdot N_{symb}^{DL} - 1$
10	2 subframes = 10ms	$4 \cdot \mathrm{P} \cdot N_{symb}^{DL}$	$\mathrm{i} = 0, \ldots, 4 \cdot \mathrm{P} \cdot N_{symb}^{DL} - 1$
11	4 subframes = 20ms	$8 \cdot \mathrm{P} \cdot N_{symb}^{DL}$	$\mathrm{i} = 0, \ldots, 8 \cdot \mathrm{P} \cdot N_{symb}^{DL} - 1$

where P is the total number of antenna ports. The logical beam index mapping according to the transmission period is given by Table 6.7.4.3-2,

Table 6.7.4.3-2: Beam index mapping to OFDM symbol in each beam reference signal

BRS configuarion	00	01
1st BRS Transmission Region	$b_1^p(i) = N_{symb}^{DL} \cdot \mathrm{p} + \mathrm{i}$, where $\mathrm{i} = 0, \ldots, N_{symb}^{DL} - 1$	$b_1^p(i) = 2 \cdot N_{symb}^{DL} \cdot \mathrm{p} + \mathrm{i}$, where $\mathrm{i} = 0, \ldots, 2 \cdot N_{symb}^{DL} - 1$

BRS configuarion	10	11
1st BRS Transmission Region	$b_1^p(i) = 2 \cdot N_{symb}^{DL} \cdot \mathrm{p} + \mathrm{i}$, where $\mathrm{i} = 0, \ldots, 2 \cdot N_{symb}^{DL} - 1$	$b_1^p(i) = 2 \cdot N_{symb}^{DL} \cdot \mathrm{p} + \mathrm{i}$, where $\mathrm{i} = 0, \ldots, 2 \cdot N_{symb}^{DL} - 1$
2nd BRS Transmission Region	$b_2^p(i) = 2 \cdot N_{symb}^{DL} \cdot \mathrm{P} + 2 \cdot N_{symb}^{DL} \cdot \mathrm{p} + \mathrm{i}$, where $\mathrm{i} = 0, \ldots, 2 \cdot N_{symb}^{DL} - 1$	$b_2^p(i) = 2 \cdot N_{symb}^{DL} \cdot \mathrm{P} + 2 \cdot N_{symb}^{DL} \cdot \mathrm{p} + \mathrm{i}$, where $\mathrm{i} = 0, \ldots, 2 \cdot N_{symb}^{DL} - 1$
3rd BRS Transmission Region		$b_3^p(i) = 4 \cdot N_{symb}^{DL} \cdot \mathrm{P} + 2 \cdot N_{symb}^{DL} \cdot \mathrm{p} + \mathrm{i}$, where $\mathrm{i} = 0, \ldots, 2 \cdot N_{symb}^{DL} - 1$
4th BRS Transmission Region		$b_4^p(i) = 6 \cdot N_{symb}^{DL} \cdot \mathrm{P} + 2 \cdot N_{symb}^{DL} \cdot \mathrm{p} + \mathrm{i}$, where $\mathrm{i} = 0, \ldots, 2 \cdot N_{symb}^{DL} - 1$

where BRS transmission region is defined as a slot (in case of ‘00’) or a subframe (in all configuration cases except ‘00’) to transmit BRS, $\mathrm{p} \in \{0, 1, 2, \ldots, 7\}$ is antenna port number, $b_n^p(i)$ is the logical beam index to transmit beam reference signals for antenna port number p in i-th OFDM symbol in n-th beam reference signal slot or subframe. The beam indexing initialization is such that logical beam index $b_1^p(0)$ for all $\mathrm{p} \in \{0, 1, 2, \ldots, 7\}$ is applied in $n_s = 0$ for $n_f = 0$.

6.7.5 Beam refinement reference signals

Beam refinement reference signals are transmitted on up to eight antenna ports using$p = 600, \ldots, 607$. The transmission and reception of BRRS is dynamically scheduled in the downlink resource allocation on xPDCCH.

6.7.5.1 Sequence generation

The reference signal $r_{l,n_s}(m)$ can be generated as follows.

$$r_{l,n_s}(m) = \frac{1}{\sqrt{2}}\big(1 - 2c(2m)\big) + j\frac{1}{\sqrt{2}}\big(1 - 2c(2m+1)\big), m = 0,1, \ldots, \left\lfloor \frac{3}{8} N_{RB}^{DL} \right\rfloor - 1$$

where n_s is the slot number within a radio frame; l is the OFDM symbol number within the slot; $c(n)$ denotes a pseudo-random sequence defined by clause 7.2. The pseudo-random sequence generator shall at the start of each OFDM symbol be initialised with:

$$c_{init} = 2^{10}(7(\bar{n}_s + 1) + l + 1)(2N_{ID}^{BRRS} + 1) + 2N_{ID}^{BRRS} + 1$$
$$\bar{n}_s = n_s \bmod 20$$

The quantity N_{ID}^{BRRS} is configured to the UE via RRC signalling.

6.7.5.2 Mapping to resource elements

The reference signal sequence $r_{l,n_s}(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ on antenna port p according to

$$a_{4k'+k_0,l}^{(p)} = \begin{cases} r_{l,n_s}(m) & k' = p + 8 \times m - 600 \\ 0 & otherwise \end{cases}$$

where

$$k_0 = \begin{cases} 0 & if\ 4k' < \left\lfloor \frac{N_{RB}^{DL} N_{sc}^{RB}}{2} \right\rfloor \\ 3 & otherwise \end{cases}$$

The BRRS can be transmitted in OFDM symbols l within a subframe, where l is configured by ‘Indication of OFDM symbol index for CSI-RS/BRRS allocation’ in DCI format in TS 5G.212 [2]. On each Tx antenna port, BRRS may be transmitted with different Tx beam.

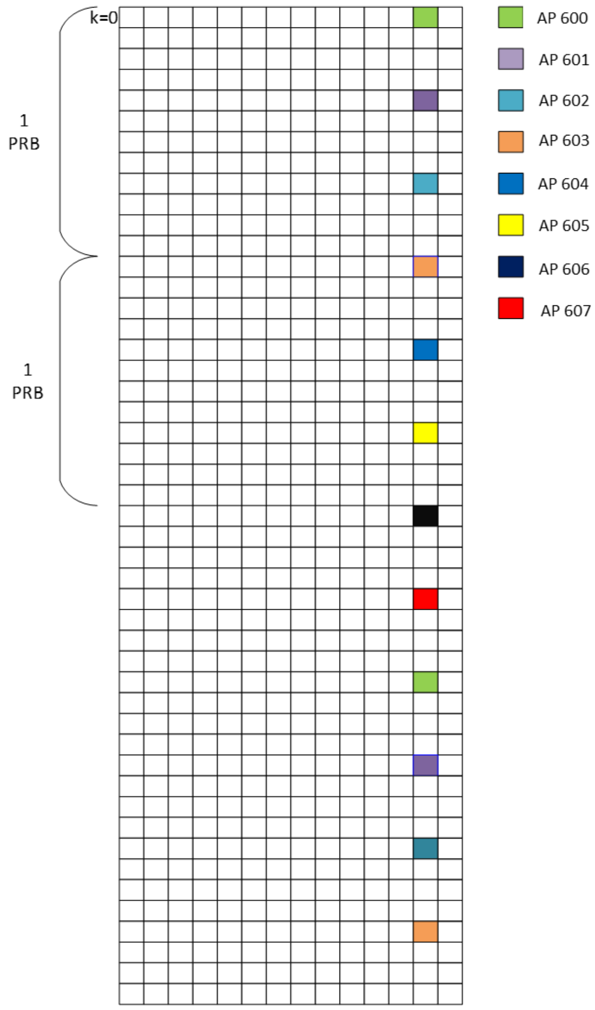

Figure 6.7.5.2-1: Mapping of BRRS showing a 1 symbol allocation, e.g. *l*=12

6.7.6 Phase noise compensation reference signal, associated with transmission of PDSCH

Phase noise compensation reference signals associated with xPDSCH

- are transmitted on antenna port(s) $p = 60$ and/or $p = 61$ signalled in DCI;
- are present and are a valid reference for phase noise compensation only if the xPDSCH transmission is associated with the corresponding antenna port according to TS 5G.213 [3];
- are transmitted only on the physical resource blocks and symbols upon which the corresponding xPDSCH is mapped;
- are identical in all symbols corresponding to xPDSCH allocation;

6.7.6.1 Sequence generation

For any of the antenna ports $p \in \{60,61\}$, the reference-signal sequence $r(m)$ is defined by

$$r(m) = \frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m)) + j\frac{1}{\sqrt{2}}(1 - 2 \cdot c(2m+1)), \qquad m = 0,1,\ldots,\lfloor N_{RB}^{\max,DL}/4 \rfloor - 1 .$$

The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$$c_{\text{init}} = \left(\lfloor n_s / 2 \rfloor + 1\right) \cdot \left(2 n_{\text{ID}}^{(n_{\text{SCID}})} + 1\right) \cdot 2^{16} + n_{\text{SCID}}$$

at the start of each subframe.

The quantities $n_{\text{ID}}^{(i)}$, $i = 0,1$, are given by

- $n_{\text{ID}}^{(i)} = N_{\text{ID}}^{\text{cell}}$ if no value for $n_{\text{ID}}^{\text{PCRS},i}$ is provided by higher layers
- $n_{\text{ID}}^{(i)} = n_{\text{ID}}^{\text{PCRS},i}$ otherwise

The value of n_{SCID} is zero unless specified otherwise. For an xPDSCH transmission, n_{SCID} is given by the DCI in [2] associated with the xPDSCH transmission.

6.7.6.2 Mapping to resource elements

For antenna ports $p \in \{60,61\}$, in a physical resource block with frequency-domain index n_{PRB}' assigned for the corresponding xPDSCH transmission, a part of the reference signal $r(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ for all xPDSCH symbols in a subframe according to:

$$a_{k,l'}^{(p)} = r(k''),$$

The starting resource block number of xPDSCH physical resource allocation n_{PRB}^{xPDSCH} in the frequency domain, resource allocation bandwidth in terms of number of resource blocks N_{PRB}^{xPDSCH} and resource elements (k,l') in a subframe is given by

$$\begin{aligned}
k &= N_{\text{sc}}^{\text{RB}} \cdot \left(n_{PRB}^{xPDSCH} + k'' \cdot 4\right) + k' \\
k' &= \begin{cases} 24 & p \in 60 \\ 23 & p \in 61 \end{cases} \\
k'' &= \lfloor m'/4 \rfloor \\
l' &= l_{first}^{'xPDSCH}, \ldots, l_{last}^{'xPDSCH} \\
m' &= 0,1,2,\ldots, N_{PRB}^{xPDSCH} - 1
\end{aligned}$$

where l' is the symbol index within a subframe. $l_{first}^{'xPDSCH}$ and $l_{last}^{'xPDSCH}$ are symbol indices of the first and last of xPDSCH, respectively for the given subframe.

Resource elements (k,l') used for transmission of UE-specific phase noise compensation reference signals on any of the antenna ports in the set S, where $S = \{60\}$ and $S = \{61\}$ shall not be used for transmission of xPDSCH on any antenna port in the same subframe.

Figure 6.7.6.1-1 illustrates the resource elements used for phase noise compensation reference signals for antenna ports 60 and 61 when xPDSCH is transmitted from $l_{first}^{'xPDSCH} = 3$ to $l_{last}^{'xPDSCH} = 13$.

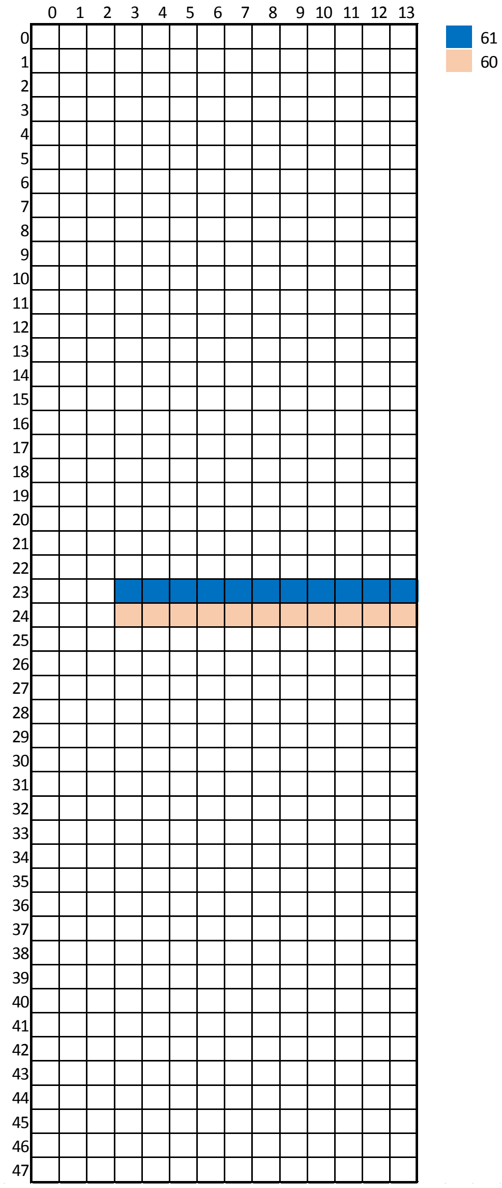

Figure 6.7.6.1-1: Mapping of phase noise compensation reference signals, antenna ports 60 and 61 in case of $l_{first}^{'xPDSCH}$ =3 and $l_{last}^{'xPDSCH}$ =13.

6.7.7 Demodulation reference signals associated with ePBCH

The demodulation reference signal associated with ePBCH is transmitted on the antenna port $p \in \{500, 501\}$. The analog beams for reference signal transmission shall be identical with the analog beams for the ePBCH transmission in each OFDM symbol.

6.7.7.1 Sequence generation

The reference-signal sequence $r_{l,n_s}(m)$ is defined by

$$r_{l,n_s}(m) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot \mathrm{c}(2m)\right) + \mathrm{j}\frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m+1)\right), \quad m = 0, 1, \ldots, 2 \cdot N_{RB}^{DL} - 1$$

where $N_{RB}^{DL} = 100$, n_s is the slot number within a radio frame and l is the OFDM symbol number within one subframe, and $l = 0, 1, 2, \ldots, 13$. The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$$C_{init} = 2^{10} \cdot \left(7 \cdot (\bar{n}_s + 1) + \bar{l} + 1\right) \cdot (2 \cdot N_{ID}^{cell} + 1) + 2 \cdot N_{ID}^{cell} + 1$$

$$\bar{n}_s = n_s \bmod 20.$$

$$\bar{l} = l \bmod 7$$

at the start of each OFDM symbol.

6.7.7.2 Mapping to resource elements

The reference signal sequence $r_{l,n_s}(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ used as reference symbols for antenna port p in each OFDM symbol according to

$$a_{k,l}^{(p)} = \bar{w}_{p,l'}(m') r_{l,n_s}(m)$$

$$\mathrm{k} = 6 \cdot m + 2$$

$$m = 0, 1, \ldots, 2 \cdot N_{RB}^{DL} - 1$$

$$\mathrm{l} = 0, 1, 2, \ldots, 12, 13$$

$$m' = m \bmod 2$$

$$l' = l \bmod 2$$

where $N_{RB}^{DL} = 100$ and the sequence $\bar{w}_p(i)$ is defined in Table 6.7.8.2-1.

Table 6.7.8.2-1: The sequence $\bar{w}_{p,0}(i)$ in odd OFDM symbol

Antenna port p	$[\bar{w}_p(0) \quad \bar{w}_p(1)]$
500	$[+1 \quad +1]$
501	$[+1 \quad -1]$

Table 6.7.8.2-2: The sequence $\bar{w}_{p,1}(i)$ in even OFDM symbol

Antenna port p	$[\bar{w}_p(0) \quad \bar{w}_p(1)]$
500	$[+1 \quad +1]$
501	$[-1 \quad +1]$

6.7.8 Demodulation reference signal for xPBCH

BRS transmitted OFDM symbol l is the demodulation reference signal associated with xPBCH in OFDM symbol l as illustrated in Figure 6.7.4.2-1.

6.8 Synchronization signals

There are 504 unique physical-layer cell identities. The physical-layer cell identities are grouped into 168 unique physical-layer cell-identity groups, each group containing three unique identities. The grouping is such that each physical-layer cell identity is part of one and only one physical-layer cell-identity group. A physical-layer cell identity

$N_{\mathrm{ID}}^{\mathrm{cell}} = 3N_{\mathrm{ID}}^{(1)} + N_{\mathrm{ID}}^{(2)}$ is thus uniquely defined by a number $N_{\mathrm{ID}}^{(1)}$ in the range of 0 to 167, representing the physical-layer cell-identity group, and a number $N_{\mathrm{ID}}^{(2)}$ in the range of 0 to 2, representing the physical-layer identity within the physical-layer cell-identity group.

6.8.1 Primary synchronization signal

The primary synchronization signal is used to acquire symbol timing and transmitted in symbol 0-13 in subframes 0 and 25 on antenna ports $p = 300,...,313$. The same sequence is used in all symbols.

6.8.1.1 Sequence generation

The sequence $d(n)$ used for the primary synchronization signal is generated from a frequency-domain Zadoff-Chu sequence according to

$$d_u(n) = \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}} & n = 0,1,\ldots,30 \\ e^{-j\frac{\pi u (n+1)(n+2)}{63}} & n = 31,32,\ldots,61 \end{cases}$$

where the Zadoff-Chu root sequence index u is given by Table 6.11.1.1-1.

Table 6.8.1.1-1: Root indices for the primary synchronization signal

$N_{\mathrm{ID}}^{(2)}$	Root index u
0	25
1	29
2	34

6.8.1.2 Mapping to resource elements

The primary synchronization signal is transmitted using the same multiple beams used for beam reference signals in each OFDM symbol. The UE shall not assume that the primary synchronization signal transmitted on any of the ports $p = 300,...,313$ is transmitted on the same antenna port as any of the downlink reference signals. The UE shall not assume that any transmission instance of the primary synchronization signal is transmitted on the same antenna port, or ports, used for any other transmission instance of the primary synchronization signal in the same subframe.

The sequence $d(n)$ shall be mapped to the resource elements according to

$$\begin{aligned} a_{k,l}^{(p)} &= d(n), \qquad n = 0,\ldots,61 \\ k &= n - 31 + \frac{N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}}{2} \\ l &= 0,1,\ldots,13 \\ p &= 300 + l \end{aligned}$$

The primary synchronization signal shall be mapped to OFDM symbols 0-13 in subframes 0 and 25 in each radio frame.

Resource elements (k,l) in the OFDM symbols used for transmission of the primary synchronization signal where

$$\begin{aligned} k &= n - 31 + \frac{N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}}{2} \\ n &= -5,-4,\ldots,-1,62,63,\ldots 66 \end{aligned}$$

are reserved and not used for transmission of the primary synchronization signal.

6.8.2 Secondary synchronization signal

The secondary synchronization signal is transmitted in symbol 0-13 in subframes 0 and 25 on antenna ports $p = 300,...,313$. The same sequence is used in all symbols.

6.8.2.1 Sequence generation

The sequence $d(0),\ldots,d(61)$ used for the second synchronization signal is an interleaved concatenation of two length-31 binary sequences. The concatenated sequence is scrambled with a scrambling sequence given by the primary synchronization signal.

The combination of two length-31 sequences defining the secondary synchronization signal differs between subframes according to

$$d(2n)=\begin{cases} s_0^{(m_0)}(n)c_0(n) & \text{in subframe 0} \\ s_1^{(m_1)}(n)c_0(n) & \text{in subframe 25} \end{cases}$$
$$d(2n+1)=\begin{cases} s_1^{(m_1)}(n)c_1(n)z_1^{(m_0)}(n) & \text{in subframe 0} \\ s_0^{(m_0)}(n)c_1(n)z_1^{(m_1)}(n) & \text{in subframe 25} \end{cases}$$

where $0\le n\le 30$. The indices m_0 and m_1 are derived from the physical-layer cell-identity group $N_{\mathrm{ID}}^{(1)}$ according to

$$\begin{aligned} m_0 &= m' \bmod 31 \\ m_1 &= \left(m_0+\lfloor m'/31\rfloor+1\right) \bmod 31 \\ m' &= N_{\mathrm{ID}}^{(1)}+q(q+1)/2, \quad q=\left\lfloor \frac{N_{\mathrm{ID}}^{(1)}+q'(q'+1)/2}{30}\right\rfloor, \quad q'=\left\lfloor N_{\mathrm{ID}}^{(1)}/30\right\rfloor \end{aligned}$$

where the output of the above expression is listed in Table 6.8.2.1-1.

The two sequences $s_0^{(m_0)}(n)$ and $s_1^{(m_1)}(n)$ are defined as two different cyclic shifts of the m-sequence $\tilde{s}(n)$ according to

$$\begin{aligned} s_0^{(m_0)}(n) &= \tilde{s}\left((n+m_0) \bmod 31\right) \\ s_1^{(m_1)}(n) &= \tilde{s}\left((n+m_1) \bmod 31\right) \end{aligned}$$

where $\tilde{s}(i)=1-2x(i)$, $0\le i\le 30$, is defined by

$$x(\bar{i}+5)=\left(x(\bar{i}+2)+x(\bar{i})\right) \bmod 2, \qquad 0\le \bar{i}\le 25$$

with initial conditions $x(0)=0,\quad x(1)=0,\quad x(2)=0,\quad x(3)=0,\quad x(4)=1$.

The two scrambling sequences $c_0(n)$ and $c_1(n)$ depend on the primary synchronization signal and are defined by two different cyclic shifts of the m-sequence $\tilde{c}(n)$ according to

$$\begin{aligned} c_0(n) &= \tilde{c}((n+N_{\mathrm{ID}}^{(2)}) \bmod 31) \\ c_1(n) &= \tilde{c}((n+N_{\mathrm{ID}}^{(2)}+3) \bmod 31) \end{aligned}$$

where $N_{\mathrm{ID}}^{(2)}\in\{0,1,2\}$ is the physical-layer identity within the physical-layer cell identity group $N_{\mathrm{ID}}^{(1)}$ and $\tilde{c}(i)=1-2x(i)$, $0\le i\le 30$, is defined by

$$x(\bar{i}+5)=\left(x(\bar{i}+3)+x(\bar{i})\right) \bmod 2, \qquad 0\le \bar{i}\le 25$$

with initial conditions $x(0)=0,\quad x(1)=0,\quad x(2)=0,\quad x(3)=0,\quad x(4)=1$.

The scrambling sequences $z_1^{(m_0)}(n)$ and $z_1^{(m_1)}(n)$ are defined by a cyclic shift of the m-sequence $\tilde{z}(n)$ according to

$$z_1^{(m_0)}(n)=\tilde{z}((n+(m_0 \bmod 8)) \bmod 31)$$

$$z_1^{(m_1)}(n) = \tilde{z}((n + (m_1 \bmod 8)) \bmod 31)$$

where m_0 and m_1 are obtained from Table 6.8.2.1-1 and $\tilde{z}(i) = 1 - 2x(i)$, $0 \le i \le 30$, is defined by

$$x(\bar{i}+5) = \left(x(\bar{i}+4) + x(\bar{i}+2) + x(\bar{i}+1) + x(\bar{i})\right) \bmod 2, \qquad 0 \le \bar{i} \le 25$$

with initial conditions $x(0)=0,\quad x(1)=0,\quad x(2)=0,\quad x(3)=0,\quad x(4)=1$.

Table 6.8.2.1-1: Mapping between physical-layer cell-identity group $N_{\mathrm{ID}}^{(1)}$ and the indices m_0 and m_1

$N_{\mathrm{ID}}^{(1)}$	m_0	m_1	$N_{\mathrm{ID}}^{(1)}$	m_0	m_1	$N_{\mathrm{ID}}^{(1)}$	m_0	m_1	$N_{\mathrm{ID}}^{(1)}$	m_0	m_1	$N_{\mathrm{ID}}^{(1)}$	m_0	m_1
0	0	1	34	4	6	68	9	12	102	15	19	136	22	27
1	1	2	35	5	7	69	10	13	103	16	20	137	23	28
2	2	3	36	6	8	70	11	14	104	17	21	138	24	29
3	3	4	37	7	9	71	12	15	105	18	22	139	25	30
4	4	5	38	8	10	72	13	16	106	19	23	140	0	6
5	5	6	39	9	11	73	14	17	107	20	24	141	1	7
6	6	7	40	10	12	74	15	18	108	21	25	142	2	8
7	7	8	41	11	13	75	16	19	109	22	26	143	3	9
8	8	9	42	12	14	76	17	20	110	23	27	144	4	10
9	9	10	43	13	15	77	18	21	111	24	28	145	5	11
10	10	11	44	14	16	78	19	22	112	25	29	146	6	12
11	11	12	45	15	17	79	20	23	113	26	30	147	7	13
12	12	13	46	16	18	80	21	24	114	0	5	148	8	14
13	13	14	47	17	19	81	22	25	115	1	6	149	9	15
14	14	15	48	18	20	82	23	26	116	2	7	150	10	16
15	15	16	49	19	21	83	24	27	117	3	8	151	11	17
16	16	17	50	20	22	84	25	28	118	4	9	152	12	18
17	17	18	51	21	23	85	26	29	119	5	10	153	13	19
18	18	19	52	22	24	86	27	30	120	6	11	154	14	20
19	19	20	53	23	25	87	0	4	121	7	12	155	15	21
20	20	21	54	24	26	88	1	5	122	8	13	156	16	22
21	21	22	55	25	27	89	2	6	123	9	14	157	17	23
22	22	23	56	26	28	90	3	7	124	10	15	158	18	24
23	23	24	57	27	29	91	4	8	125	11	16	159	19	25
24	24	25	58	28	30	92	5	9	126	12	17	160	20	26
25	25	26	59	0	3	93	6	10	127	13	18	161	21	27
26	26	27	60	1	4	94	7	11	128	14	19	162	22	28
27	27	28	61	2	5	95	8	12	129	15	20	163	23	29
28	28	29	62	3	6	96	9	13	130	16	21	164	24	30
29	29	30	63	4	7	97	10	14	131	17	22	165	0	7
30	0	2	64	5	8	98	11	15	132	18	23	166	1	8
31	1	3	65	6	9	99	12	16	133	19	24	167	2	9
32	2	4	66	7	10	100	13	17	134	20	25	-	-	-
33	3	5	67	8	11	101	14	18	135	21	26	-	-	-

6.8.2.2 Mapping to resource elements

The secondary synchronization signal shall be mapped to the same OFDM symbols as the primary synchronization signal. The same antenna port as for the primary synchronization signal shall be used for the secondary synchronization signal in a given OFDM symbol. The sequence $d(n)$ shall be mapped to resource elements according to

$$a_{k,l}^{(p)} = d(\mathrm{n}), \qquad \mathrm{n} = 0, \ldots, 61$$

$$\mathrm{k} = \mathrm{n} + 41 + \frac{N_{RB}^{DL} N_{sc}^{RB}}{2}$$

$$\mathrm{l} = 0, 1, \ldots, 12, 13$$

$$\mathrm{p} = 300 + \mathrm{l}.$$

Resource elements (k, l) in the OFDM symbols used for transmission of the secondary synchronization signal where

$$\mathrm{k} = \mathrm{n} + 41 + \frac{N_{RB}^{DL} N_{sc}^{RB}}{2}$$

$$\mathrm{n} = -5, -4, \ldots, -1, 62, 63, \ldots, 66$$

are reserved and not used for transmission of the secondary synchronization signal.

6.8.3 Extended synchronization signal

6.8.3.1 Sequence generation

The sequence $d(0), \ldots, d(62)$ used to obtain the extended synchronization signal is the length-63 Zadoff–Chu (ZC) defined by

$$d(n) = e^{-j\frac{25\pi n(n+1)}{63}}, \qquad n = 0, 1, \ldots, 62.$$

The sequence used to obtain extended synchronization signal in OFDM symbol l is defined as cyclic shifts of $d(n)$ according to

$$\tilde{d}^{l}(n) = d\big((n + \Delta_l) \bmod 63\big), \qquad n = 0, 1, \ldots, 62$$

where the cyclic shifts Δ_l for $l = 0, \ldots, 2 \cdot N_{symb}^{DL} - 1$ are given by Table 6.8.3.1-1.

Table 6.8.3.1-1: Cyclic shifts for the extended synchronization signal

l	Cyclic shift Δ_l
0	0
1	7
2	14
3	18
4	21
5	25
6	32
7	34
8	38
9	41
10	45
11	52
12	59
13	61

The sequence used for scrambling extended synchronization signal in subframe $i \in \{0,25\}$ is defined by

$$r_i(n) = \frac{1}{\sqrt{2}}\big(1 - 2 \cdot c(2n)\big) + j\frac{1}{\sqrt{2}}\big(1 - 2 \cdot c(2n+1)\big), \quad n = 0,1,\ldots,62$$

where the pseudo-random sequence $c(m)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with $c_{\text{init}} = 2^{10} \cdot (i+1) \cdot \left(2 \cdot N_{\text{ID}}^{\text{cell}} + 1\right) + 2 \cdot N_{\text{ID}}^{\text{cell}} + 1$ at the start of subframe i.

The sequence $d^{l}(n)$ used for extended synchronization signal is defined by

$$d^{l}(n) = r_i(n) \cdot \tilde{d}^{l}(n), \quad n = 0, \ldots, 62$$

6.8.3.2 Mapping to resource elements

The extended synchronization signal shall be mapped to the same OFDM symbols as the primary synchronization signal. The same antenna port as for the primary synchronization signal shall be used for the extended synchronization signal.

The sequence d^l shall be mapped to resource elements according to

$$\cancel{a_{k,l} = d^l(n), \qquad n = 0, 1, \dots, 62}$$

$$a_{k,l}^{(p)} = d^l(n), \qquad \mathrm{n} = 0,1,\dots,62$$

$$k = n - 104 + \frac{N_{RB}^{DL} N_{sc}^{RB}}{2}$$

$$l = 0, 1, \dots, 12, 13.$$

$$p = 300 + l$$

Resource elements (k,l) in the OFDM symbols used for transmission of the extended synchronization signal where

$$k = n - 104 + \frac{N_{RB}^{DL} N_{sc}^{RB}}{2}$$

$$n = -4, \dots, -1, 63, 64, \dots, 67$$

are reserved and not used for transmission of the extended synchronization signal.

6.9 OFDM baseband signal generation

The time-continuous signal $s_l^{(p)}(t)$ on antenna port p in OFDM symbol l in a downlink slot is defined by

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

for $0 \le t < \left(N_{\mathrm{CP},l} + N\right) \times T_{\mathrm{s}}$ where $k^{(-)} = k + \lfloor N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}/2 \rfloor$ and $k^{(+)} = k + \lfloor N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}/2 \rfloor - 1$. The variable N equals 2048 and $\Delta f = 75\,\mathrm{kHz}$.

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

Table 6.9-1 lists the value of $N_{\mathrm{CP},l}$ that shall be used. Note that different OFDM symbols within a slot in some cases have different cyclic prefix lengths.

Table 6.9-1: OFDM parameters

Configuration		Cyclic prefix length $N_{\mathrm{CP},l}$
Normal cyclic prefix	$\Delta f = 75\,\mathrm{kHz}$	160 for $l = 0$ 144 for $l = 1,2,\dots,6$

6.10 Modulation and upconversion

Modulation and upconversion to the carrier frequency of the complex-valued OFDM baseband signal for each antenna port is shown in Figure 6.10-1.

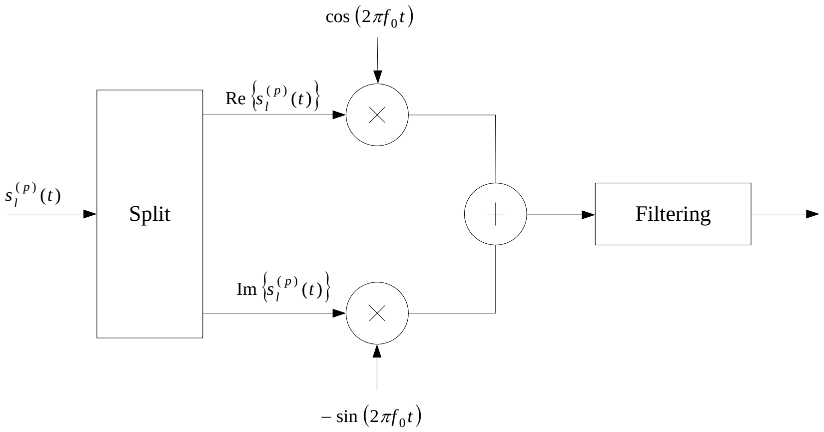

Figure 6.10-1: Downlink modulation

7 Generic functions

7.1 Modulation mapper

The modulation mapper takes binary digits, 0 or 1, as input and produces complex-valued modulation symbols, $x=I+jQ$, as output.

7.1.1 BPSK

In case of BPSK modulation, a single bit, $b(i)$, is mapped to a complex-valued modulation symbol $x=I+\mathrm{j}Q$ according to Table 7.1.1-1.

Table 7.1.1-1: BPSK modulation mapping

$b(i)$	***I***	***Q***
0	$1/\sqrt{2}$	$1/\sqrt{2}$
1	$-1/\sqrt{2}$	$-1/\sqrt{2}$

7.1.2 QPSK

In case of QPSK modulation, pairs of bits, $b(i), b(i+1)$, are mapped to complex-valued modulation symbols $x=I+\mathrm{j}Q$ according to Table 7.1.2-1.

Table 7.1.2-1: QPSK modulation mapping

$b(i), b(i+1)$	***I***	***Q***
00	$1/\sqrt{2}$	$1/\sqrt{2}$
01	$1/\sqrt{2}$	$-1/\sqrt{2}$
10	$-1/\sqrt{2}$	$1/\sqrt{2}$
11	$-1/\sqrt{2}$	$-1/\sqrt{2}$

7.1.3 16QAM

In case of 16QAM modulation, quadruplets of bits, $b(i), b(i+1), b(i+2), b(i+3)$, are mapped to complex-valued modulation symbols x=I+jQ according to Table 7.1.3-1.

Table 7.1.3-1: 16QAM modulation mapping

$b(i), b(i+1), b(i+2), b(i+3)$	*I*	*Q*
0000	$1/\sqrt{10}$	$1/\sqrt{10}$
0001	$1/\sqrt{10}$	$3/\sqrt{10}$
0010	$3/\sqrt{10}$	$1/\sqrt{10}$
0011	$3/\sqrt{10}$	$3/\sqrt{10}$
0100	$1/\sqrt{10}$	$-1/\sqrt{10}$
0101	$1/\sqrt{10}$	$-3/\sqrt{10}$
0110	$3/\sqrt{10}$	$-1/\sqrt{10}$
0111	$3/\sqrt{10}$	$-3/\sqrt{10}$
1000	$-1/\sqrt{10}$	$1/\sqrt{10}$
1001	$-1/\sqrt{10}$	$3/\sqrt{10}$
1010	$-3/\sqrt{10}$	$1/\sqrt{10}$
1011	$-3/\sqrt{10}$	$3/\sqrt{10}$
1100	$-1/\sqrt{10}$	$-1/\sqrt{10}$
1101	$-1/\sqrt{10}$	$-3/\sqrt{10}$
1110	$-3/\sqrt{10}$	$-1/\sqrt{10}$
1111	$-3/\sqrt{10}$	$-3/\sqrt{10}$

7.1.4 64QAM

In case of 64QAM modulation, hextuplets of bits, $b(i), b(i+1), b(i+2), b(i+3), b(i+4), b(i+5)$, are mapped to complex-valued modulation symbols $x = I + jQ$ according to Table 7.1.4-1.

Table 7.1.4-1: 64QAM modulation mapping

$b(i), b(i+1), b(i+2), b(i+3), b(i+4), b(i+5)$	*I*	*Q*	$b(i), b(i+1), b(i+2), b(i+3), b(i+4), b(i+5)$	*I*	*Q*
000000	$3/\sqrt{42}$	$3/\sqrt{42}$	100000	$-3/\sqrt{42}$	$3/\sqrt{42}$
000001	$3/\sqrt{42}$	$1/\sqrt{42}$	100001	$-3/\sqrt{42}$	$1/\sqrt{42}$
000010	$1/\sqrt{42}$	$3/\sqrt{42}$	100010	$-1/\sqrt{42}$	$3/\sqrt{42}$
000011	$1/\sqrt{42}$	$1/\sqrt{42}$	100011	$-1/\sqrt{42}$	$1/\sqrt{42}$
000100	$3/\sqrt{42}$	$5/\sqrt{42}$	100100	$-3/\sqrt{42}$	$5/\sqrt{42}$
000101	$3/\sqrt{42}$	$7/\sqrt{42}$	100101	$-3/\sqrt{42}$	$7/\sqrt{42}$
000110	$1/\sqrt{42}$	$5/\sqrt{42}$	100110	$-1/\sqrt{42}$	$5/\sqrt{42}$
000111	$1/\sqrt{42}$	$7/\sqrt{42}$	100111	$-1/\sqrt{42}$	$7/\sqrt{42}$
001000	$5/\sqrt{42}$	$3/\sqrt{42}$	101000	$-5/\sqrt{42}$	$3/\sqrt{42}$
001001	$5/\sqrt{42}$	$1/\sqrt{42}$	101001	$-5/\sqrt{42}$	$1/\sqrt{42}$
001010	$7/\sqrt{42}$	$3/\sqrt{42}$	101010	$-7/\sqrt{42}$	$3/\sqrt{42}$
001011	$7/\sqrt{42}$	$1/\sqrt{42}$	101011	$-7/\sqrt{42}$	$1/\sqrt{42}$
001100	$5/\sqrt{42}$	$5/\sqrt{42}$	101100	$-5/\sqrt{42}$	$5/\sqrt{42}$
001101	$5/\sqrt{42}$	$7/\sqrt{42}$	101101	$-5/\sqrt{42}$	$7/\sqrt{42}$
001110	$7/\sqrt{42}$	$5/\sqrt{42}$	101110	$-7/\sqrt{42}$	$5/\sqrt{42}$
001111	$7/\sqrt{42}$	$7/\sqrt{42}$	101111	$-7/\sqrt{42}$	$7/\sqrt{42}$
010000	$3/\sqrt{42}$	$-3/\sqrt{42}$	110000	$-3/\sqrt{42}$	$-3/\sqrt{42}$
010001	$3/\sqrt{42}$	$-1/\sqrt{42}$	110001	$-3/\sqrt{42}$	$-1/\sqrt{42}$
010010	$1/\sqrt{42}$	$-3/\sqrt{42}$	110010	$-1/\sqrt{42}$	$-3/\sqrt{42}$
010011	$1/\sqrt{42}$	$-1/\sqrt{42}$	110011	$-1/\sqrt{42}$	$-1/\sqrt{42}$
010100	$3/\sqrt{42}$	$-5/\sqrt{42}$	110100	$-3/\sqrt{42}$	$-5/\sqrt{42}$
010101	$3/\sqrt{42}$	$-7/\sqrt{42}$	110101	$-3/\sqrt{42}$	$-7/\sqrt{42}$
010110	$1/\sqrt{42}$	$-5/\sqrt{42}$	110110	$-1/\sqrt{42}$	$-5/\sqrt{42}$
010111	$1/\sqrt{42}$	$-7/\sqrt{42}$	110111	$-1/\sqrt{42}$	$-7/\sqrt{42}$
011000	$5/\sqrt{42}$	$-3/\sqrt{42}$	111000	$-5/\sqrt{42}$	$-3/\sqrt{42}$
011001	$5/\sqrt{42}$	$-1/\sqrt{42}$	111001	$-5/\sqrt{42}$	$-1/\sqrt{42}$
011010	$7/\sqrt{42}$	$-3/\sqrt{42}$	111010	$-7/\sqrt{42}$	$-3/\sqrt{42}$
011011	$7/\sqrt{42}$	$-1/\sqrt{42}$	111011	$-7/\sqrt{42}$	$-1/\sqrt{42}$
011100	$5/\sqrt{42}$	$-5/\sqrt{42}$	111100	$-5/\sqrt{42}$	$-5/\sqrt{42}$
011101	$5/\sqrt{42}$	$-7/\sqrt{42}$	111101	$-5/\sqrt{42}$	$-7/\sqrt{42}$
011110	$7/\sqrt{42}$	$-5/\sqrt{42}$	111110	$-7/\sqrt{42}$	$-5/\sqrt{42}$
011111	$7/\sqrt{42}$	$-7/\sqrt{42}$	111111	$-7/\sqrt{42}$	$-7/\sqrt{42}$

7.2 Pseudo-random sequence generation

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

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

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

8 Timing

8.1 Uplink-downlink frame timing

Transmission of the uplink radio frame number i from the UE shall start $(N_{\text{TA}} + N_{\text{TA offset}}) \times T_{\text{s}}$ seconds before the start of the corresponding downlink radio frame at the UE, where $0 \le N_{\text{TA}} \le 1200$. $N_{\text{TA offset}} = 768$ unless stated otherwise in [4].

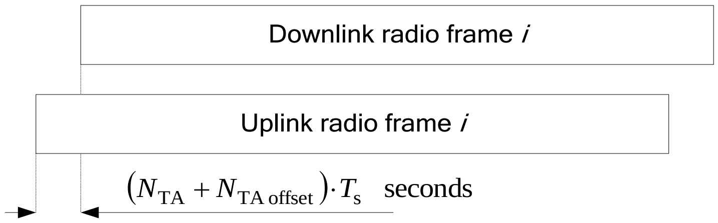

Figure 8.1-1: Uplink-downlink timing relation