Verizon 5G TF; Air Interface Working Group; Verizon 5th Generation Radio Access; Physical channels and modulation (Release 1)

10, 2016

Cisco, Ericsson, Intel Corp., LG Electronics, Nokia, Qualcomm Technologies Inc., Samsung Electronics & Verizon

V 1.7

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## Document History

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1 Scope

The present document describes the physical channels for Verizon 5G Radio.

2 References

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

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a V5G document, a non-specific reference implicitly refers to the latest version of that document in the same Release as the present document.

[1]: TS V5G.201: "Verizon 5G Radio Access (V5G RA); Physical layer; General description".
[2]: TS V5G.212: "Verizon 5G Radio Access (V5G RA); Multiplexing and channel coding".
[3]: TS V5G.213: "Verizon 5G Radio Access (V5G RA); Physical layer procedures".

3 Symbols and abbreviations

3.1 Symbols

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

- \((k,l)\) Resource element with frequency-domain index \(k\) and time-domain index \(l\)
- \(a_{k,l}^{(p)}\) Value of resource element \((k,l)\) for antenna port \(p\)
- \(D\) Matrix for supporting cyclic delay diversity
- \(D_{RA}\) Density of random access opportunities per radio frame
- \(f_0\) Carrier frequency
- \(f_{RA}\) xPRACH resource frequency index within the considered time-domain location
- \(M_{PUSCH}^{SC}\) Scheduled bandwidth for uplink transmission, expressed as a number of subcarriers
- \(M_{PUSCH}^{RB}\) Scheduled bandwidth for uplink transmission, expressed as a number of resource blocks
$M_{\text{bit}}$  Number of coded bits to transmit on a physical channel

$M_{\text{symb}}$  Number of modulation symbols to transmit on a physical channel

$M_{\text{layer \ symb}}$  Number of modulation symbols to transmit per layer for a physical channel

$M_{\text{ap \ symb}}$  Number of modulation symbols to transmit per antenna port for a physical channel

$N$  A constant equal to 2048 for $\Delta f = 75 \text{kHz}$

$N_{\text{CP,l}}$  Downlink cyclic prefix length for OFDM symbol $l$ in a slot

$N_{\text{CS}}$  Cyclic shift value used for random access preamble generation

$N_{\text{RB}}^{(2)}$  Bandwidth available for use by xPUCCH formats 2, expressed in multiples of $N_{\text{sc}}^{\text{RB}}$

$N_{\text{RB}}^{\text{HO}}$  The offset used for xPUSCH frequency hopping, expressed in number of resource blocks (set by higher layers)

$N_{\text{cell}}^{\text{ID}}$  Physical layer cell identity

$N_{\text{RB}}^{\text{DL}}$  Downlink bandwidth configuration, expressed in multiples of $N_{\text{sc}}^{\text{RB}}$

$N_{\text{RB}}^{\text{min, DL}}$  Smallest downlink bandwidth configuration, expressed in multiples of $N_{\text{sc}}^{\text{RB}}$

$N_{\text{RB}}^{\text{max, DL}}$  Largest downlink bandwidth configuration, expressed in multiples of $N_{\text{sc}}^{\text{RB}}$

$N_{\text{RB}}^{\text{UL}}$  Uplink bandwidth configuration, expressed in multiples of $N_{\text{sc}}^{\text{RB}}$

$N_{\text{RB}}^{\text{min, UL}}$  Smallest uplink bandwidth configuration, expressed in multiples of $N_{\text{sc}}^{\text{RB}}$

$N_{\text{RB}}^{\text{max, UL}}$  Largest uplink bandwidth configuration, expressed in multiples of $N_{\text{sc}}^{\text{RB}}$

$N_{\text{DL \ symb}}$  Number of OFDM symbols in a downlink slot

$N_{\text{UL \ symb}}$  Number of OFDMA symbols in an uplink slot

$N_{\text{sc}}^{\text{RB}}$  Resource block size in the frequency domain, expressed as a number of subcarriers

$N_{\text{sb}}$  Number of sub-bands for xPUSCH frequency-hopping with predefined hopping pattern

$N_{\text{sb \ RB}}$  Size of each sub-band for xPUSCH frequency-hopping with predefined hopping pattern, expressed as a number of resource blocks

$N_{\text{SP}}$  Number of downlink to uplink switch points within the radio frame
\( N_{RS}^{\text{PUCCH}} \) \( N_{RS}^{\text{PUCCH}} \) Number of reference symbols per slot for xPUCCH

\( N_{TA} \) \( N_{TA} \) Timing offset between uplink and downlink radio frames at the UE, expressed in units of \( T_s \)

\( N_{TA\text{offset}} \) \( N_{TA\text{offset}} \) Fixed timing advance offset, expressed in units of \( T_s \)

\( n_x^{(2)} \) \( n_x^{(2)} \) Resource index for xPUCCH formats 2

\( n_{PDCCH} \) \( n_{PDCCH} \) Number of xPDCCHs present in a subframe

\( n_{PRB} \) \( n_{PRB} \) Physical resource block number

\( n_{PRB}^{RA} \) \( n_{PRB}^{RA} \) First physical resource block occupied by xPRACH resource considered

\( n_{PRB\text{offset}}^{RA} \) \( n_{PRB\text{offset}}^{RA} \) First physical resource block available for xPRACH

\( n_{VRB} \) \( n_{VRB} \) Virtual resource block number

\( n_{RNTI} \) \( n_{RNTI} \) Radio network temporary identifier

\( n_f \) \( n_f \) System frame number

\( n_s \) \( n_s \) Slot number within a radio frame

\( P \) \( P \) Number of antenna ports used for transmission of a channel

\( p \) \( p \) Antenna port number

\( n_{RA} \) \( n_{RA} \) Index for xPRACH versions with same preamble format and xPRACH density

\( Q_m \) \( Q_m \) Modulation order: 2 for QPSK, 4 for 16QAM and 6 for 64QAM

\( s_{i}^{(p)}(t) \) \( s_{i}^{(p)}(t) \) Time-continuous baseband signal for antenna port \( p \) and OFDM symbol \( i \) in a slot

\( t_{RA}^{(0)} \) \( t_{RA}^{(0)} \) Radio frame indicator index of xPRACH opportunity

\( t_{RA}^{(1)} \) \( t_{RA}^{(1)} \) Half frame index of xPRACH opportunity within the radio frame

\( t_{RA}^{(2)} \) \( t_{RA}^{(2)} \) Uplink subframe number for start of xPRACH opportunity within the half frame

\( T_f \) \( T_f \) Radio frame duration

\( T_s \) \( T_s \) Basic time unit
\( T_{\text{slot}} \) Slot duration

\( W \) Precoding matrix for downlink spatial multiplexing

\( \beta_{\text{PRACH}} \) Amplitude scaling for xPRACH

\( \beta_{\text{PUCCH}} \) Amplitude scaling for xPUCCH

\( \beta_{\text{PUSCH}} \) Amplitude scaling for xPUSCH

\( \beta_{\text{SRS}} \) Amplitude scaling for sounding reference symbols

\( \Delta f \) Subcarrier spacing

\( \Delta f_{\text{RA}} \) Subcarrier spacing for the random access preamble

\( \nu \) Number of transmission layers

### 3.2 Abbreviations

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

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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 \( T_s = \frac{1}{(75000 \times 2048)} \) seconds.

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

Four subframe types are supported:

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

Subframe type can change on subframe basis.

Transmissions in multiple cells can be aggregated where up to 7 secondary cells can be used in addition to the primary cell. Unless otherwise noted, the description in this specification applies to each of the up to 8 serving cells. In case of multi-cell aggregation, different subframe type can be used in the different serving cells. UE may assume that there is no conflicting DL or UL transmit direction in a given OFDM symbol on all scheduled component carriers.

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 [2] and the present document TS V5G.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 $N_{\text{UL}}^{\text{RB}} N_{\text{sc}}^{\text{RB}} = 1200$ subcarriers and $N_{\text{UL}}^{\text{symb}} = 7$ 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 5.5.4 when a sequential numbering of the antenna ports is necessary.

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

<table>
<thead>
<tr>
<th>Physical channel or signal</th>
<th>Index $\tilde{p}$</th>
<th>Antenna port number $p$ as a function of the number of antenna ports configured for the respective physical channel/signal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>xPUSCH</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>SRS</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>PCRS</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>xPUCCH</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>
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 $k = 0, \ldots, N_{RB}^{UL} N_{sc}^{RB} - 1$ and $l = 0, \ldots, N_{sym}^{UL} - 1$ are the indices in the frequency and time domains, respectively. Resource element $(k, l)$ on antenna port $p$ corresponds to the complex value $a_{k,l}^{(p)}$. When there is no risk for confusion, or no particular antenna port is specified, the index $p$ may be dropped. Quantities $a_{k,l}^{(p)}$ corresponding to resource elements not used for transmission of a physical channel or a physical signal in a slot shall be set to zero.
5.2.3 Resource blocks

A physical resource block is defined as \( N_{\text{symb}}^{\text{UL}} \) consecutive OFDM symbols in the time domain and \( N_{\text{sc}}^{\text{RB}} \) consecutive subcarriers in the frequency domain, where \( N_{\text{symb}}^{\text{UL}} \) and \( N_{\text{sc}}^{\text{RB}} \) are given by Table 5.2.3-1. A physical resource block in the uplink thus consists of \( N_{\text{symb}}^{\text{UL}} \times N_{\text{sc}}^{\text{RB}} \) resource elements, corresponding to one slot in the time domain and 900 kHz in the frequency domain.

**Table 5.2.3-1: Resource block parameters**

<table>
<thead>
<tr>
<th>Configuration</th>
<th>( N_{\text{sc}}^{\text{RB}} )</th>
<th>( N_{\text{symb}}^{\text{UL}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal cyclic prefix</td>
<td>12</td>
<td>7</td>
</tr>
</tbody>
</table>

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

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

5.2.3.1 Virtual resource block groups of localized type

Virtual resource block groups of localized type are numbered from 0 to \( N_{\text{UL}}^{\text{VRBG}} - 1 \), where \( 4N_{\text{VRBG}}^{\text{UL}} = N_{\text{RB}}^{\text{UL}} \).

Virtual resource block group of index \( n_{\text{VRBG}}^{\text{UL}} \) is mapped to a set of physical resource blocks given by \( \{ 4n_{\text{VRBG}}^{\text{UL}}, 4n_{\text{VRBG}}^{\text{UL}} + 1, 4n_{\text{VRBG}}^{\text{UL}} + 2, 4n_{\text{VRBG}}^{\text{UL}} + 3 \} \).

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

![Figure 5.3-1: Overview of uplink physical channel processing](image-url)
5.3.1 Scrambling
The block of codeword bits $b(0),...,b(M_{bit} - 1)$, where $M_{bit}$ is the number of codeword bits transmitted 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 $\tilde{b}(0),...,\tilde{b}(M_{bit} - 1)$ according to the following pseudo code:

Set $i = 0$

while $i < M_{bit}$

if $b(i) = x$ // ACK/NACK or Rank Indication placeholder bits

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

else

if $b(i) = y$ // ACK/NACK or Rank Indication repetition placeholder bits

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

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

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

end if

end if

$i = i + 1$

end while

where $x$ and $y$ are tags defined in [2] clause 5.2.2.6 and where the scrambling sequence $c(i)$ is given by clause 7.2. The scrambling sequence generator shall be initialised with

$c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{14} + q \cdot 2^{13} + \left\lfloor \tilde{n}_s/2 \right\rfloor \cdot 2^9 + N_{\text{cell}}$ at the start of each subframe where $\tilde{n}_s = n_s \mod 20$ and $n_{\text{RNTI}}$ corresponds to the RNTI associated with the xPUSCH transmission as described in clause 9 in [3].

5.3.2 Modulation
The block of scrambled bits $\tilde{b}(0),...,\tilde{b}(M_{bit} - 1)$ shall be modulated as described in clause 7.1, resulting in a block of complex-valued symbols $d(0),...,d(M_{\text{symb}} - 1)$. Table 5.3.2-1 specifies the modulation mappings applicable for the physical uplink shared channel.

Table 5.3.2-1: Uplink modulation schemes
5.3.2A  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 onto the layers \( x(i) = x^{(0)}(i) \) or \( x(i) = [x^{(0)}(i) \; x^{(1)}(i)]^T \), for one and two layer transmission respectively, \( i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1 \) where \( M_{\text{symb}}^{\text{layer}} \) 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, \( v = 1 \), and the mapping is defined by

\[
x^{(0)}(i) = d(i)
\]

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

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.

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

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Codeword-to-layer mapping</th>
<th>( i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( x^{(0)}(i) = d(i) )</td>
<td>( M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} )</td>
</tr>
<tr>
<td>2</td>
<td>( x^{(0)}(i) = d(2i) )</td>
<td>( x^{(1)}(i) = d(2i + 1) ) ( M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2 )</td>
</tr>
</tbody>
</table>

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.

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

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Codeword-to-layer mapping</th>
<th>( i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>( x^{(0)}(i) = d(2i) )</td>
<td>( x^{(1)}(i) = d(2i + 1) ) ( M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2 )</td>
</tr>
</tbody>
</table>
5.3.3 Precoding

The precoder takes as input a block of vectors \( x^{(0)}(i) \) \( \ldots \) \( x^{(P-1)}(i) \), \( i = 0,1,\ldots, M^{\text{layer}}_{\text{symb}} - 1 \) from the layer mapping and generates a block of vectors \( z^{(0)}(i) \) \( \ldots \) \( z^{(P-1)}(i) \), \( i = 0,1,\ldots, M^{\text{ap}}_{\text{symb}} - 1 \) to be mapped onto resources elements.

5.3.3.1 Precoding for transmission on a single antenna port

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

\[
z^{(o)}(i) = x^{(0)}(i)
\]

where \( i = 0,1,\ldots, M^{\text{ap}}_{\text{symb}} - 1 \), \( M^{\text{ap}}_{\text{symb}} = M^{\text{layer}}_{\text{symb}} \).

5.3.3.2 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. Transmit diversity supports \( P = 2 \) antenna ports where the set of antenna ports used for transmit diversity is \( p \in \{40,41\} \).

The output \( z(i) \), \( i = 0,1,\ldots, M^{\text{ap}}_{\text{symb}} - 1 \) of the precoding operation is defined by

\[
\begin{bmatrix}
  z^{(0)}(2i) \\
  z^{(1)}(2i) \\
  z^{(0)}(2i + 1) \\
  z^{(1)}(2i + 1)
\end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix}
  1 & 0 & j & 0 \\
  0 & -1 & 0 & j \\
  0 & 1 & 0 & j \\
  1 & 0 & -j & 0
\end{bmatrix} \begin{bmatrix}
  \text{Re}(x^{(0)}(i)) \\
  \text{Re}(x^{(1)}(i)) \\
  \text{Im}(x^{(0)}(i)) \\
  \text{Im}(x^{(1)}(i))
\end{bmatrix}
\]

for \( i = 0,1,\ldots, M^{\text{layer}}_{\text{symb}} - 1 \) with \( M^{\text{ap}}_{\text{symb}} = 2M^{\text{layer}}_{\text{symb}} \).

5.3.3.3 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 is \( p \in \{40,41\} \).

Precoding for spatial multiplexing is defined by

\[
\begin{bmatrix}
  z^{(0)}(i) \\
  z^{(1)}(i)
\end{bmatrix} = W \begin{bmatrix}
  y^{(0)}(i) \\
  \vdots \\
  y^{(\nu-1)}(i)
\end{bmatrix}
\]

where \( i = 0,1,\ldots, M^{\text{ap}}_{\text{symb}} - 1 \), \( M^{\text{ap}}_{\text{symb}} = M^{\text{layer}}_{\text{symb}} \) and \( \nu = 1,2 \). The precoding matrix \( W(i) \) shall be generated according to Table 5.3.3.3-1.
Table 5.3.3-1: Codebook for transmission on antenna ports \{40, 41\}

<table>
<thead>
<tr>
<th>Codebook index</th>
<th>Number of layers (U)</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(\begin{bmatrix} 1 \ \sqrt{2} \ 1 \end{bmatrix})</td>
<td>(\begin{bmatrix} 1 \ \sqrt{2} \ 0 \end{bmatrix})</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>(\begin{bmatrix} 1 \ \sqrt{2} \ -1 \end{bmatrix})</td>
<td>(\begin{bmatrix} 1 \ 1 \end{bmatrix})</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>(\begin{bmatrix} 1 \ \sqrt{2} \ j \end{bmatrix})</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>(\begin{bmatrix} 1 \ \sqrt{2} \ -j \end{bmatrix})</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>(\begin{bmatrix} 1 \ \sqrt{2} \ 0 \end{bmatrix})</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>(\begin{bmatrix} 1 \ \sqrt{2} \ 1 \end{bmatrix})</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

5.3.4 Mapping to physical resources

For each antenna port \(p\), used for transmission of the physical channel, the block of complex-valued symbols \(z^{(p)}(0), \ldots, z^{(p)}(M^{ap}_{\text{symbl}} - 1)\) shall be multiplied with the amplitude scaling factor \(\beta_{\text{xPUSCH}}\) in order to conform to the transmit power for xPUSCH as specified in [3], and mapped in sequence starting with \(z^{(p)}(0)\). The relation between the index \(\tilde{p}\) and the antenna port \(p\) is given by Table 5.2.1-1. The mapping to resource elements \((k, i)\) meets the following criteria in the current subframe:

- they are in the physical resource blocks corresponding assigned for transmission.
- they are within the allocated symbols \(l \in \{2, L_{\text{xPUSCH}}^{\text{last}}\}\) as described in the UL assignment using DCI format A1/A2 in [2].
- they are not used for transmission of phase noise compensation reference signal.
- they are not defined on REs in symbol \(l = 2\) which are reserved to be used for UE-specific reference signals associated with xPUSCH.

The mapping to resource elements \((k, i)\) 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 \(i\).

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, \(n_{\text{cell}}^{\text{cell}}(n_s)\), which varies with the slot number \(n_s\) according to

\[
n_{\text{cell}}^{\text{cell}}(n_s) = \sum_{(8N_{\text{symbl}}^\text{UL}, \bar{m}_s + i)} c(8N_{\text{symbl}}^\text{UL}, \bar{m}_s + i) \cdot 2^i
\]
\[ n_s = n_s \mod 20 \]

where the pseudo-random sequence \( c(i) \) is defined by clause 7.2. The pseudo-random sequence generator shall be initialized with \( c_{\text{init}} = n_{\text{ID}}^{n_{\text{RNTI}}} \) where \( n_{\text{ID}}^{n_{\text{RNTI}}} \) is given by clause 5.5.2.1.

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

Table 5.4-1: Supported xPUCCH format

<table>
<thead>
<tr>
<th>xPUCCH format</th>
<th>Modulation scheme</th>
<th>Number of bits per subframe, ( M_{\text{bit}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>QPSK</td>
<td>96</td>
</tr>
</tbody>
</table>

**5.4.1 xPUCCH format 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

\[ \tilde{b}(i) = (b(i) + c(i)) \mod 2 \]

where the scrambling sequence \( c(i) \) is given by clause 7.2. The scrambling sequence generator shall be initialized with

\[ c_{\text{init}} = \left( \left\lfloor \frac{n_s}{2} \right\rfloor + 1 \right) \cdot \left( 2N_{\text{cell}} + 1 \right) \cdot 2^{16} + n_{\text{RNTI}} \]

\[ n_s = n_s \mod 20 \]

at the start of each subframe where \( n_{\text{RNTI}} \) 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 \( d(0),...,d(M_{\text{symb}}-1) \) shall be mapped on to the layers

\[ x(i) = \begin{bmatrix} x^{(0)}(i) & \cdots & x^{(\nu-1)}(i) \end{bmatrix}^T, \quad i = 0,1,...,M_{\text{symb}}^{\text{layer}_{\text{symb}}} - 1 \]

where \( \nu \) is the number of layers and \( M_{\text{symb}}^{\text{layer}_{\text{symb}}} \) is the number of modulation symbols per layer.

For transmission on a single antenna port, a single layer is used, \( \nu = 1 \), and the mapping is defined by

\[ x^{(0)}(i) = d(i) \]

with \( M_{\text{symb}}^{\text{layer}_{\text{symb}}} = M_{\text{symb}}^{(0)} \).
For transmission on two antenna ports, and the mapping rule of $\nu = 2$ can be defined by

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

with $M_{\text{layer}} = M_{\text{symb}} / 2$.

### 5.4.1.2 Precoding

The precoder takes as input a block of vectors $\begin{bmatrix} x^{(0)}(i) & \cdots & x^{(\nu - 1)}(i) \end{bmatrix}^T$, $i = 0, 1, \ldots, M_{\text{layer}} - 1$ from the layer mapping and generates a block of vectors $\begin{bmatrix} y^{(0)}(i) & \cdots & y^{(\nu - 1)}(i) \end{bmatrix}^T$, $i = 0, 1, \ldots, M_{\text{symb}} - 1$ to be mapped onto resource elements.

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

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

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

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

$$
\begin{bmatrix}
    y^{(0)}(2i) \\
    y^{(1)}(2i) \\
    y^{(0)}(2i + 1) \\
    y^{(1)}(2i + 1)
\end{bmatrix} = \begin{bmatrix}
    1 & 0 & j & 0 \\
    0 & -1 & 0 & j \\
    0 & 1 & 0 & j \\
    1 & 0 & -j & 0
\end{bmatrix} \begin{bmatrix}
    \text{Re}(x^{(0)}(i)) \\
    \text{Re}(x^{(1)}(i)) \\
    \text{Im}(x^{(0)}(i)) \\
    \text{Im}(x^{(1)}(i))
\end{bmatrix}
$$

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

The mapping to resource elements is defined by operations on quadruplets of complex-valued symbols. Let $w^{(\tilde{p})}(i) = \{y^{(0)}(4i), y^{(0)}(4i + 1), y^{(1)}(4i + 2), y^{(1)}(4i + 3)\}$ 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

$$
\begin{align*}
    \overline{w}^{(\tilde{p})}(0), \ldots, \overline{w}^{(\tilde{p})}(M_{\text{quad}} - 1)
\end{align*}
$$

where $\overline{w}^{(\tilde{p})}(i) = w^{(\tilde{p})}(i + n_{\text{cs}} \mod M_{\text{quad}})$.

Let $\overline{w}^{(\tilde{p})}(i) = \{\overline{y}^{(0)}(4i), \overline{y}^{(0)}(4i + 1), \overline{y}^{(1)}(4i + 2), \overline{y}^{(1)}(4i + 3)\}$ denote another symbol quadruplet $i$ for antenna port $\tilde{p}$ obtained after cell-specific cyclic shift.

The block of complex-valued symbols $\overline{w}$ shall be mapped to $\mathbf{z}$ according to
\[ z^{(\beta)} \left( n_{\text{PUCCH}}^{(2)} \cdot N_{\text{PUCCH}}^{\text{RB}} \cdot N_{\text{sc}}^{\text{RB}} + m' \cdot N_{\text{sc}}^{\text{RB}} + k' \right) = y^{(\beta)} \left( 8m' + k \right) \]

where

\[
\begin{align*}
  k & \quad 0 \leq k \leq 1 \\
  k' & = \begin{cases} 
    k + 2 & 2 \leq k \leq 5 \\
    k + 4 & 6 \leq k \leq 7 
  \end{cases} \\
m' & = 0, 1, 2, \ldots, 5 \\
N_{\text{PUCCH}}^{\text{RB}} & = 6
\end{align*}
\]

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

5.5 Reference signals

The following uplink reference signals are supported:

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

5.5.1 Generation of the reference signal sequence

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

\[ r_{u,v}^{(\alpha)}(n) = e^{j\alpha n} \tilde{r}_{u,v}(n), \quad 0 \leq n < M_{\text{sc}}^{\text{RS}} \]

where \( M_{\text{sc}}^{\text{RS}} = mN_{\text{sc}}^{\text{RB}} \) is the length of the reference signal sequence and \( 1 \leq m \leq N_{\text{sc}}^{\text{RB}, UL}^{\text{max}} \). Multiple reference signal sequences are defined from a single base sequence through different values of \( \alpha \).

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

5.5.1.1 Base sequences of length larger than \( 3N_{\text{sc}}^{\text{RB}} \)

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

\[ \tilde{r}_{u,v}(n) = x_{q}(n \mod N_{\text{ZC}}^{\text{RS}}), \quad 0 \leq n < M_{\text{sc}}^{\text{RS}} \]
where the $q^{th}$ root Zadoff-Chu sequence is defined by

$$x_q(m) = e^{-j\frac{2\pi m(m+1)}{N_{\text{ZC}}}}, \quad 0 \leq m \leq N_{\text{ZC}} - 1$$

with $q$ given by

$$q = \left\lfloor \frac{\overline{q} + 1/2}{v} \cdot (-1)^{\left\lfloor \frac{u}{31} \right\rfloor} \right\rfloor$$

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

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

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

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

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

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

**Table 5.5.1.2-1: Definition of $\varphi(n)$ for $M_{\text{sc}}^{RS} = 2N_{\text{sc}}^{RB}$**
The group provided by higher layers. Hopping can be enabled or disabled by means of the cell-specific parameter Group-hopping-enabled provided by higher layers.

The group-hopping pattern $f_{gh}(n_s)$ for SRS and is given by

$$f_{gh}(n_s) = \begin{cases} 0 & \text{if group hopping is disabled} \\ \left( \sum_{i=0}^{7} c(8n_s + i) \cdot 2^i \right) \mod 30 & \text{if group hopping is enabled} \end{cases}$$
where the pseudo-random sequence $c(i)$ is defined by clause 7.2. The pseudo-random sequence generator shall be initialized with $c_{\text{init}} = \left\lfloor \frac{n_{\text{ID}}^{\text{RS}}}{30} \right\rfloor$ at the beginning of each radio frame where $n_{\text{ID}}^{\text{RS}}$ is given by clause 5.5.1.5.

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

5.5.1.4 Sequence hopping

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

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

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

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

where the pseudo-random sequence $c(i)$ is given by section 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

$$c_{\text{init}} = \left\lfloor \frac{n_{\text{ID}}^{\text{RS}}}{30} \right\rfloor \cdot 2^5 + \left(n_{\text{ID}}^{\text{RS}} + \Delta_{ss}\right) \mod 30$$

at the beginning of each radio frame where $n_{\text{ID}}^{\text{RS}}$ is given by clause 5.5.1.5 and $\Delta_{ss}$ is given by clause 5.5.1.3.

5.5.1.5 Determining virtual cell identity for sequence generation

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

Sounding reference signals:

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

5.5.2 Demodulation reference signal 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 \( r_{i,n_s}(m) \) is defined by

\[
r_{i,n_s}(m) = \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m)) + j \cdot \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m+1)), \quad m = 0,1,\ldots, 4 \cdot N_{RB}^{\max UL} - 1
\]

where \( n_s \) is the slot number within a radio frame and \( i \) 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

\[
c_{int} = \left( \lfloor \frac{n_s}{2} \rfloor + 1 \right) \cdot \left( 2n_{\text{ID}}^{(\text{cell})} + 1 \right) \cdot 2^{16} + n_{\text{RNTI}}
\]

\[
\bar{n}_s = n_s \mod 20
\]

at the start of each subframe where \( n_{\text{RNTI}} \) 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 \( n_{\text{ID}}^{x\text{PUCCH}} \) is provided by higher layers
- \( n_{\text{ID}}^{(i)} = n_{\text{ID}}^{x\text{PUCCH}} \) otherwise.

The value of \( n_{\text{SCID}} \) is zero unless specified otherwise. For a xPUCCH transmission, \( n_{\text{SCID}} \) is given by the DCI formats in [2] associated with the xPUCCH transmission.

5.5.2.2 Mapping to resource elements

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

\[
a_{k,j}^{(i)} = w_p(m \mod 2) \cdot r_{i,n_s}(4 \cdot n_{RB} + m)
\]

where
\[ w_p(i) = \begin{cases} w_p(i) & n_{PRB} \text{ mod } 2 = 0 \\ w_p(1-i) & n_{PRB} \text{ mod } 2 = 1 \end{cases} \]

\[ k = N_{sc}^{RB} \cdot n_{PRB} + m' \]

\[ l = 6 \]

\[ m' = \begin{cases} m + 2 & 0 \leq m \leq 1 \\ m + 6 & 2 \leq m \leq 3 \end{cases} \]

\[ m = 0,1,2,3 \]

\[ n_i \text{ mod } 2 = 1 \]

and the sequence \( w_p(i) \) is given by Table 5.5.2-1.

**Table 5.5.2-1: The sequence \( w_p(i) \)**

<table>
<thead>
<tr>
<th>Antenna port ( p )</th>
<th>( \bar{w}_p(0) )</th>
<th>( \bar{w}_p(1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 or 200</td>
<td>\ [+1 ]</td>
<td>\ [+1 ]</td>
</tr>
<tr>
<td>201</td>
<td>\ [+1 ]</td>
<td>\ [+1 ]</td>
</tr>
</tbody>
</table>

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 \( p \).
5.5.3 Demodulation reference signal associated with xPUSCH

The xPUSCH demodulation reference signals

- are associated and transmitted with antenna port(s) \( p \in \{40, 41\} \) for single antenna port transmission and Tx diversity;
- are associated with layer(s) \( \lambda \in \{0, 1, \ldots, \nu - 1\} \) and transmitted with antenna port(s) \( p \in \{40, 41\} \) for spatial multiplexing;
- are transmitted only on the physical resource blocks upon which the corresponding xPUSCH is mapped.

(a) DMRS for single antenna port transmission and Tx diversity
Figure 5.5.3-1: DM-RS location

5.5.3.1 Sequence generation

The reference-signal sequence \( r(m) \) is defined by

\[
r(m) = \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m + 1)), \quad m = 0, 1, \ldots, 3N_{\text{RB}}^{\text{max},U/L} - 1.
\]

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

\[
c_{\text{init}} = \left( \left\lfloor \frac{n_s}{2} \right\rfloor + 1 \right) \cdot \left( 2n_{\text{ID},\text{DMRS},i}^{(\text{DMRS})} + 1 \right) \cdot 2^{16} + n_{\text{SCID}}
\]

\[
\bar{n}_s = n_s \mod 20
\]

at the start of each subframe.

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

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

\[
- n_{\text{ID},i}^{(i)} = n_{\text{ID},\text{DMRS},i}^{\text{DMRS}} \quad \text{otherwise}
\]

The value of \( n_{\text{SCID}} \) is zero unless specified otherwise. For a xPUSCH transmission, \( n_{\text{SCID}} \) is given by the DCI format A1/A2 in [2] associated with the xPUSCH transmission.

5.5.3.2 Mapping to resource elements

In a physical resource block with frequency-domain index \( n_{\text{PRB}} \) assigned for the corresponding xPUSCH transmission, a part of the reference signal sequence \( r(m) \) shall be mapped to complex-valued
modulation symbols $a_{k+i,k,j}^{(p)}$ in a subframe. Based on the RE mapping index $k_i$ indicated by DCI, the symbols $a_{k+i,k,j}^{(p)}$ is mapped to resource elements $(k+k_i,l)$ on antenna port $p$ according to

- For single antenna port transmission,
  $$a_{k+i,k,j}^{(40)} = r(k^*)$$

- For Tx diversity,
  $$\begin{bmatrix}
  a_{k+k_i,l}^{(40)} \\
  a_{k+k_i,l}^{(41)}
  \end{bmatrix} = \begin{bmatrix}
  r(k^*) \\
  r(k^*)
  \end{bmatrix}$$

- For spatial multiplexing with 1 layer transmission,
  $$\begin{bmatrix}
  a_{k+k_i,40,j}^{(40)} \\
  a_{k+k_i,41,j}^{(41)}
  \end{bmatrix} = W[r(k^*)]$$

- For spatial multiplexing with 2 layer transmission,
  $$\begin{bmatrix}
  a_{k+k_0,40,j}^{(40)} & a_{k+k_1,40,j}^{(40)} \\
  a_{k+k_0,41,j}^{(41)} & a_{k+k_1,41,j}^{(41)}
  \end{bmatrix} = W\begin{bmatrix}
  r(k^*) & 0 \\
  0 & r(k^*)
  \end{bmatrix}$$

where

- $k = 4m' + N_{sc}^{RB} n_{PRB}$
- $k^* = \left\lfloor \frac{k}{4} \right\rfloor$
- $l = 2$ (in even slot only)
- $m' = 0,1,2$

The precoding matrix $W$ shall be identical to the precoding matrix used in clause 5.3.4 for precoding of the xPUSCH in the same subframe.

Figure 5.5.3.2-1 illustrates the resource elements used for reference signals.
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 $r_{\text{srs}}^{|p|}(n) = r_{u,v}^{|p|}(n)$ 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 $\alpha^{|p|}$ of the sounding reference signal is given as
\[ \alpha_p = 2\pi \frac{n_{SRS}^{\text{cs}} p}{8} \]
\[ n_{SRS}^{\text{cs}} = \left( n_{SRS}^{\text{cs}} + \frac{8 \bar{p}}{N_{ap}} \right) \mod 8, \]
\[ \bar{p} \in \{0, 1, \ldots, N_{ap} - 1\} \]

where \( n_{SRS}^{\text{cs}} \in \{0, 1, 2, 3, 4, 5, 6, 7\} \) 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 \( \beta_{SRS} \) in order to conform to the transmit power \( P_{SRS} \) specified in clause 6.1.3 in [3], and mapped in sequence starting with \( n_{SRS}^{(p)}(0) \) to resource elements \((k,l)\) on antenna port \( p \) according to

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

where \( N_{ap} \) is the number of antenna ports used for sounding reference signal transmission and the relation between the index \( p \) 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, \( b = B_{SRS} \) and \( M_{sc,b}^{\text{RS}} \) is the length of the sounding reference signal sequence defined as

\[ M_{sc,b}^{\text{RS}} = m_{SRS,b} N_{sc}^{\text{RB}} / 2 \]

where \( m_{SRS,b} \) is given by Table 5.3.2-1. The UE-specific parameter srs-Bandwidth, \( B_{SRS} \in \{0, 1, 2, 3\} \) is given by higher layers.

The frequency-domain starting position \( k_0 \) is defined by

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

where \( \bar{k}_{TC} \in \{0, 1\} \) 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 \( n_b = 4n_{RBC} \) where the parameter \( n_{RBC} \) is given by higher-layer parameters freqDomainPosition-ap.

SRS can be transmitted simultaneously in multiple component carriers.
Table 5.5.3.2-1: \( m_{\text{SRS},b} \), \( b = 0,1,2,3 \), values for the uplink bandwidth of \( N_{\text{RB}}^{\text{UL}} = 100 \)

<table>
<thead>
<tr>
<th>SRS Bandwidth configuration ( c_{\text{SRS}} )</th>
<th>SRS-Bandwidth ( B_{\text{SRS}} = 0 )</th>
<th>SRS-Bandwidth ( B_{\text{SRS}} = 1 )</th>
<th>SRS-Bandwidth ( B_{\text{SRS}} = 2 )</th>
<th>SRS-Bandwidth ( B_{\text{SRS}} = 3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>48</td>
<td>24</td>
<td>4</td>
</tr>
</tbody>
</table>

5.5.4.3 **Sounding reference signal subframe configuration**

The sounding reference signal shall be transmitted in the last symbol or the second last symbol according to parameter conveyed in DCI. UE can distinguish which symbol (last or second last symbol) is for SRS transmission via 'SRS request (2 bits)' in DCI.

5.5.5 **Phase noise compensation reference signal**

Phase noise compensation reference signals associated with xPUSCH

- are transmitted on antenna port(s) \( p \in \{40, 41\} \);
- are present and are a valid reference for phase noise compensation only if the xPUSCH transmission is associated with the corresponding antenna port according to [2];
- are transmitted only on the physical resource blocks and symbols upon which the corresponding xPUSCH is mapped.

5.5.5.1 **Sequence generation**

The reference-signal sequence \( r(m) \) is defined by

\[
r(m) = \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m + 1)), \quad m = 0,1,\ldots, \left\lfloor \frac{N_{\text{RB}}^{\text{UL}}}{4} \right\rfloor - 1.
\]

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

\[
c_{\text{init}} = \left\lfloor \frac{n_s}{2} \right\rfloor + 1 \cdot (2n_{\text{id}}^{(\text{PCRS},i)} + 1) \cdot 2^{16} + n_{\text{SCID}}
\]

\[\bar{n}_s = n_s \mod 20\]

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 \( n_{\text{id}}^{\text{PCRS},i} \) is provided by higher layers
- \( n_{\text{id}}^{(i)} = n_{\text{id}}^{\text{PCRS},i} \) otherwise
The value of $n_{\text{SCID}}$ is zero unless specified otherwise. For a xPUSCH transmission, $n_{\text{SCID}}$ is given by the DCI format in [2] associated with the xPUSCH transmission.

5.5.5.2 Mapping to resource elements

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

- For single antenna port transmission,
  \[ a_{k,l_0}^{(40)} = r(k'') \]

- For Tx diversity,
  \[
  \begin{bmatrix}
  a_{k,l_0}^{(40)} \\
  a_{k,l_1}^{(41)}
  \end{bmatrix}
  =
  \begin{bmatrix}
  r(k^*) \\
  r(k^*)
  \end{bmatrix}
  \]

- For spatial multiplexing with 1 layer transmission,
  \[
  \begin{bmatrix}
  a_{k,l_0}^{(40)} \\
  a_{k,l_0}^{(41)}
  \end{bmatrix}
  = W[r(k'')]
  \]

- For spatial multiplexing with 2 layer transmission,
  \[
  \begin{bmatrix}
  a_{k,l_0}^{(40)} & a_{k,l_1}^{(40)} \\
  a_{k,l_0}^{(41)} & a_{k,l_1}^{(41)}
  \end{bmatrix}
  = W
  \begin{bmatrix}
  r(k'') & 0 \\
  0 & r(k'')
  \end{bmatrix}
  \]

where the precoding matrix $W$ shall be identical to the precoding matrix used in clause 5.3.3 for precoding of the xPUSCH in the same subframe.

For the starting physical resource block index of xPUSCH physical resource allocation $n_{\text{PRB}}^{\text{xPUSCH}}$, total number of allocated xPUSCH physical resource blocks $N_{\text{PRB}}^{\text{xPUSCH}}$, and RE mapping index $k_i$ indicated by DCI, the symbols $a_{k,l_i}^{(p)}$ is mapped to resource elements $(k,l_i)$ on antenna port $p$ according to:
\[ k = N_{sc}^{RB} \cdot (n_{PRB}^{PUSCH} + k'' \cdot 4) + k' \]

\[
k' = \begin{cases} 
16 & k_i \in \{0,1\} \\
31 & k_i \in \{2,3\}
\end{cases}
\]

\[ k'' = \left\lfloor \frac{m'}{4} \right\rfloor \]

\[ l'_i = \begin{cases} 
\{l'_i | l'_i \in \{3, \ldots, l_{last}^{PUSCH}\} \text{ and } l'_i \text{ is an odd number}\}, & \text{if } k_i \in \{0 + m'', 2 + m''\} \\
\{l'_i | l'_i \in \{3, \ldots, l_{last}^{PUSCH}\} \text{ and } l'_i \text{ is an even number}\}, & \text{if } k_i \in \{1 - m'', 3 - m''\}
\end{cases} \]

\[
m' = 0, 1, 2, \ldots, N_{PRB}^{PUSCH} - 1 \]

\[ m'' = \left\lfloor \frac{m'}{4} \right\rfloor \mod 2 \]

where \( l'_i \) is the symbol index within a subframe and \( l_{last}^{PUSCH} \) is the symbol index of the end of xPUSCH for the given subframe.

Resource elements \((k, l'_i)\) used for transmission of UE-specific phase noise compensation reference signals regarding any value of RE mapping index \( k_i \in \{0,1,2,3\}\) shall not be used for transmission of xPUSCH on any antenna port in the same subframe.

Figure 5.5.5.2-1 illustrates the resource elements used for phase noise compensation reference signals.
Figure 5.5.5.2-1: Mapping of phase noise compensation reference signals according to RE mapping index $k_i$ in case of $l_{lastPUSCH}=12$.

5.6 OFDM baseband signal generation

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

The time-continuous signal $s_i^{(p)}(t)$ for antenna port $p$ in OFDM symbol $i$ in an uplink slot is defined by
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 \( \sum_{l' \leq 0} (N_{CP,l'} + N)T_s \) within the slot.

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

### Table 5.6-1: OFDM parameters

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Cyclic prefix length ( N_{CP,l} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal cyclic prefix</td>
<td>160 for ( l = 0 )</td>
</tr>
<tr>
<td></td>
<td>144 for ( l = 1,2,\ldots,6 )</td>
</tr>
</tbody>
</table>

### 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 \( T_{SEQ} \).

![Random access preamble](image)

Figure 5.7.1-1: Random access preamble

Figure 5.7.1-2 denotes how the 5GNB receives RACH from multiple UEs with preamble format 0 in Table 5.7.1-1. These UEs occupy the same set of subcarriers. Each UE transmits for two symbols. UE1, UE3, …, UE9, etc. are located close to the 5GNB 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 5GNB \( T_{RTT} \) time later than those of UE1, UE3, …, UE5.
Figure 5.7.1-2: Reception of RACH signal at 5GNB during RACH subframe

The parameter values are listed in Table 5.7.1-1.

Table 5.7.1-1: Random access preamble parameters

<table>
<thead>
<tr>
<th>Preamble format</th>
<th>( T_{GP1} )</th>
<th>( T_{GP2} )</th>
<th>( T_{CP} )</th>
<th>( T_{SEQ} )</th>
<th>( N_{SYM} )</th>
<th>( T_{GP2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>( 2224*T_s )</td>
<td>10</td>
<td>( 656*T_s )</td>
<td>( 2048*T_s )</td>
<td>10</td>
<td>( 1456*T_s )</td>
</tr>
<tr>
<td>1</td>
<td>( 2224*T_s )</td>
<td>( 3016*T_s )</td>
<td>( 1344*T_s )</td>
<td>( 2048*T_s )</td>
<td>8</td>
<td>( 1360*T_s )</td>
</tr>
</tbody>
</table>

Due to extended cyclic prefix, there are ten symbols in this sub-frame for preamble format 0, and eight 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

<table>
<thead>
<tr>
<th>PRACH configuration</th>
<th>System Frame Number</th>
<th>Subframe Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Any</td>
<td>15, 40</td>
</tr>
<tr>
<td>1</td>
<td>Any</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>SFN%4=0</td>
<td>15, 40</td>
</tr>
<tr>
<td>3</td>
<td>SFN%4=0</td>
<td>15</td>
</tr>
</tbody>
</table>

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 selected 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 \( r^{th} \) root Zadoff-Chu sequence is defined by
\[ x_u(n) = e^{-j \frac{\pi m(n+1)}{N_{zc}}} , \quad 0 \leq n \leq N_{zc} - 1 \]

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

\[
a_{ij} = f \cdot x_u(n)e^{-j \frac{2\pi in_{RACH}}{6}},
\]

\[
\nu \in \begin{cases} [0,1,2] & \text{for format 0} \\ [0] & \text{for format 1} \end{cases}
\]

\[
k = n + 1 + 12 \times (6 \times n_{RACH} + 1), \quad n_{RACH} \in \{0,1...7\}
\]

\[
f = \begin{cases} 1 & \text{if } l \text{ is even} \\ 2f' - 1 & \text{if } l \text{ is odd} \end{cases}
\]

\[
f' \in \{0,1\}
\]

\[
n = 0,1...70,
\]

\[
l \in \begin{cases} \{(0.1),(2.3),(4.5),(6.7),(8.9)\} & \text{for format 0} \\ \{(0.1),(2.3),(4.5),(6.7)\} & \text{for format 1} \end{cases}
\]

where the cyclic shift \( \nu \), RACH subband index \( n_{RACH} \) and parameter \( f' \) are provided by higher layers.

For preamble format 0, the cyclic shift \( \nu \) has 3 values. On the other hand, one cyclic shift value is used in a cell if preamble format 1 is configured. As outlined by the equations above, the RACH subframe provides 8 RACH subbands each occupying 6RBs; the parameter \( n_{RACH} \) determines which subband is used by the UE.

During the synchronization subframe, the UE identifies the symbol with a strong beam. A set of parameters provided by the upper layers is used to map the symbol with the selected 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 or 16 preambles available according to preamble format in each cell. The set of preambles in a cell is found by combination of cyclic shift, OCC, and band index. Preamble index is allocated as follows:

\[
Preamble \ index = \nu + N_{\nu} \cdot f' + N_{\nu} \cdot 2 \cdot n_{RACH}
\]

where,

\[
N_{\nu} = \text{number of cyclic shifts} = \begin{cases} 3, \text{for format 0} \\ 1, \text{for format 1} \end{cases}
\]
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
- \( N_{\text{BRS}} := \text{BRS transmission period in slots \cdot 7} \)
  - the number of symbols \( N_{\text{RACH}} \) during the RACH subframe for which the 5G-NG applies different \( \text{rx-beams} \)
    \( N_{\text{RACH}} = 5, \) if preamble format = 0
    \( N_{\text{RACH}} = 4, \) if preamble format = 1
- number of RACH subframes \( M \) during 4 radio frames (\( M \in \{1, 2, 4, 8\} \) depending on RACH configuration)
- index of RACH subframe \( m \) (\( m \in \{0, \ldots, M - 1\} \))
- the synchronization symbol index of the selected beam, \( S_{\text{sync}}^{\text{beam}} \) (\( S_{\text{sync}}^{\text{beam}} \in \{0, \ldots, N_{\text{BRS}} - 1\} \)).

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 4 radio frames with the system frame number \([SFN/4]\), it will use the beams of the synchronization symbols identified by the set

\[
(M \cdot \lfloor SFN / 4 \rfloor \cdot N_{\text{RACH}} + m \cdot N_{\text{RACH}} + (0 : N_{\text{RACH}} - 1)) \% N_{\text{BRS}}, \quad m \in \{0, \ldots, M - 1\}
\]

If \( S_{\text{sync}}^{\text{beam}} \) is among those symbols, the UE shall transmit the RACH preamble during the RACH subframe.

The transmission should start at symbol

\[
l = \left( S_{\text{sync}}^{\text{beam}} - \left( \lfloor SFN / 4 \rfloor \cdot M \cdot N_{\text{RACH}} + m \cdot N_{\text{RACH}} \right) \% N_{\text{BRS}} \right) \% N_{\text{BRS}} \cdot N_{\text{rep}},
\]

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

5.7.3 Baseband signal generation

The baseband signal for PRACH is generated according to subclause 5.6 with a tone spacing of \( \Delta f = 75kHz \). The cyclic prefix with length \( N_{\text{CP}} \) 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 \( T_{\text{CP}} \) and a sequence part of length \( T_{\text{SEQ}} \). Both have the same values as their counterparts of the RACH preamble.
5.7.4.2. Preamble sequence generation

The scheduling request preambles are generated from Zadoff-Chu sequences. Higher layers control the set of preamble sequences used by the UE.

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

$$x_u(n) = e^{-j \frac{2\pi n(n+1)}{N_{ZC}}}, \quad 0 \leq n \leq N_{ZC} - 1,$$

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

$$a_{k,l} = f \cdot x_u(n)e^{-j \frac{2\pi v k}{12}}, \quad v \in \{0,1,2,...,11\}$$

$$k = n + 1 + 12 \cdot (6 \cdot N_{SR} + 51),$$

$$n = 0,1,...,70$$

$$f = \begin{cases} 1 & \text{if } l \text{ is even} \\ f' & \text{if } l \text{ is odd} \end{cases}$$

$$f' \in \{-1,1\}.$$

$$l \in \begin{cases} \{(0,1),(2,3),(4,5),(6,7),(8,9)\} & \text{for format 0} \\ \{(0,1),(2,3),(4,5),(6,7)\} & \text{for format 1} \end{cases}$$

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

![Figure 5.8-1: Uplink modulation](image)

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 [2] and the present document TS V5G.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 $N_{RB}^{DL}N_{sc}^{RB} = 1200$ subcarriers and $N_{symb}^{DL} = 7$ 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. synchronization signals/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 $k = 0,\ldots,N_{RB}^{DL}N_{sc}^{RB} - 1$ and $l = 0,\ldots,N_{symb}^{DL} - 1$ 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.
6.2.3 Resource blocks

Resource blocks are used to describe the mapping of certain physical channels to resource elements. Physical resource blocks are defined. A physical resource block is defined as \( N_{\text{symb}}^{\text{DL}} \) consecutive OFDM symbols in the time domain and \( N_{\text{sc}}^{\text{RB}} \) consecutive subcarriers in the frequency domain, where \( N_{\text{symb}}^{\text{DL}} \) and \( N_{\text{sc}}^{\text{RB}} \) are given by Table 6.2.3-1. A physical resource block thus consists of \( N_{\text{symb}}^{\text{DL}} \times N_{\text{sc}}^{\text{RB}} \) 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

\[
n_{PRB} = \left\lfloor \frac{k}{N_{RB}} \right\rfloor
\]

<table>
<thead>
<tr>
<th>Configuration</th>
<th>( N_{sc}^{RB} )</th>
<th>( N_{symb}^{DL} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal cyclic prefix</td>
<td>( \Delta f = 75 \text{ kHz} )</td>
<td>12</td>
</tr>
</tbody>
</table>

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 4 times that of a physical resource block.

### 6.2.3.1 Virtual resource block groups of localized type

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

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

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

The OFDM symbol index is given by either of \( l = 0 \) or \( l = \{0, 1\} \) according to the xPDCCH transmission configuration as described in [3].

### 6.2.5 Guard Period for TDD Operation

One OFDM symbol serves as a guard period which shall be allocated at the switching period from a downlink transmission to an uplink transmission.
6.3 General structure for downlink physical channels

This clause describes a general structure, applicable to more than one physical channel.

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

- scrambling of coded bits in each of the codewords 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

Figure 6.3-1: Overview of physical channel processing

6.3.1 Scrambling

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

\[
\tilde{b}(i) = (b(i) + c(i)) \mod 2
\]

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

\[
c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{14} + q \cdot 2^{13} + \left\lfloor \bar{n}_s / 2 \right\rfloor \cdot 2^9 + N_{\text{cell}} \text{ for xPDSCH}
\]

\[
\bar{n}_s = n_s \mod 20
\]

where \( n_{\text{RNTI}} \) corresponds to the RNTI associated with the xPDSCH transmission as described in clause 7.1 in [3].
6.3.2 Modulation
The block of scrambled bits \( \tilde{b}(0), \ldots, \tilde{b}(M_{\text{bits}} - 1) \) 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 \( d(0), \ldots, d(M_{\text{syms}} - 1) \).

Table 6.3.2-1: Modulation schemes

<table>
<thead>
<tr>
<th>Physical channel</th>
<th>Modulation schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>xPDSCH</td>
<td>QPSK, 16QAM, 64QAM</td>
</tr>
</tbody>
</table>

6.3.3 Layer mapping
The complex-valued modulation symbols for the single codeword to be transmitted are mapped onto one or several layers. Complex-valued modulation symbols \( d(0), \ldots, d(M_{\text{syms}} - 1) \) shall be mapped onto the layers \( x(i) = [x^{(0)}(i), \ldots, x^{(u-1)}(i)]^T \), \( i = 0, 1, \ldots, M_{\text{layer}}^{M_{\text{syms}} - 1} \) where \( u \) is the number of layers and \( M_{\text{layer}}^{M_{\text{syms}} - 1} \) 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, \( u = 1 \), and the mapping is defined by
\[
x^{(0)}(i) = d(i)
\]
with \( M_{\text{layer}}^{M_{\text{syms}} - 1} = M_{\text{syms}} \).

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 \( u \) 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.

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Codeword-to-layer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>( i = 0, 1, \ldots, M_{\text{layer}}^{M_{\text{syms}} - 1} )</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>( x^{(0)}(i) = d(i) )</td>
</tr>
<tr>
<td>2</td>
<td>( x^{(0)}(i) = d(2i) )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Codeword-to-layer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>( i = 0, 1, \ldots, M_{\text{layer}}^{M_{\text{syms}} - 1} )</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>( x^{(0)}(i) = d(2i) )</td>
</tr>
</tbody>
</table>

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 \( u \) 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.
<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Codeword-to-layer mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>( x^{(0)}(i) = d(2i) )</td>
</tr>
<tr>
<td></td>
<td>( x^{(1)}(i) = d(2i+1) )</td>
</tr>
<tr>
<td></td>
<td>( M_{\text{symb}}^\text{ap} = M_{\text{symb}}/2 )</td>
</tr>
</tbody>
</table>

**6.3.4 Precoding**

The precoder takes as input one or two of vectors from the layer mapping and generates a block of vectors \( y(i) = [\ldots, y^{(p)}(i), \ldots]^T \), \( i = 0,1,\ldots,M_{\text{symb}}^\text{ap} - 1 \) 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 number of the single antenna port 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.

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

\[
\begin{bmatrix}
  y^{(p_1)}(2i) \\
  y^{(p_2)}(2i) \\
  y^{(p_1)}(2i+1) \\
  y^{(p_2)}(2i+1)
\end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix}
  1 & 0 & j & 0 \\
  0 & -1 & 0 & j \\
  0 & 1 & 0 & j \\
  1 & 0 & -j & 0
\end{bmatrix} \begin{bmatrix}
  \text{Re}(x^{(0)}(i)) \\
  \text{Re}(x^{(1)}(i)) \\
  \text{Im}(x^{(0)}(i)) \\
  \text{Im}(x^{(1)}(i))
\end{bmatrix}
\]

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

**6.3.4.3 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 in the set of antenna ports \( p \in \{8,\ldots,15\} \).

In the following let, \( p_1 \) and \( p_2 \), denote the two antenna ports identified in the downlink resource allocation (see DCI Format definitions in [2]).
For transmission on one antenna port, the precoding operation is defined by:
\[ y^{(p)}(i) = x^{(0)}(i) \]
for \( i = 0, 1, \ldots, M_{\text{layer}}^\text{sy} - 1 \).

For transmission on two antenna ports, the precoding operation is defined by:
\[
\begin{bmatrix}
  y^{(p_1)}(i) \\
  y^{(p_2)}(i)
\end{bmatrix}
= \begin{bmatrix}
  x^{(0)}(i) \\
  x^{(0)}(i)
\end{bmatrix}
\]
for \( i = 0, 1, \ldots, M_{\text{layer}}^\text{sy} - 1 \).

### 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 \( y^{(p)}(0), \ldots, y^{(p)}(M_{\text{sy}}^\text{sy} - 1) \) shall conform to the downlink power allocation specified in clause 6 in [3] 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 \( l \).

### 6.4 Physical downlink shared channel (xPDSCH)
The xPDSCH 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 \( \nu \) antenna port(s) in the set \( p \in \{8, 9, \ldots, 15\} \), where the number of layers used for transmission of the xPDSCH \( \nu \) is one or two.
- The index \( l \) in a subframe fulfills \( l \geq l_{\text{first}}^\text{PDSCH} \) and \( l \leq l_{\text{last}}^\text{PDSCH} \) where \( l_{\text{first}}^\text{PDSCH} \) and \( l_{\text{last}}^\text{PDSCH} \) are given in DCI formats B1 and B2 in [2].
- 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, \ldots, 15\}.

### 6.5 Physical broadcast channel (xBCH)
The Physical broadcast channel is transmitted using the same beams used for beam reference signals in each OFDM symbol.
6.5.1 Scrambling
The block of bits $b(0),...,b(M_{\text{bit}}-1)$, where $M_{\text{bit}}$, the number of bits transmitted on the physical broadcast channel, equals to 5248, shall be scrambled with a cell-specific sequence prior to modulation, resulting in a block of scrambled bits $\tilde{b}(0),...,\tilde{b}(M_{\text{bit}}-1)$ according to

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

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 $n_r \pmod{4} = 0$.

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

Table 6.5.2-1: xPBCH modulation schemes.

<table>
<thead>
<tr>
<th>Physical channel</th>
<th>Modulation schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>xPBCH</td>
<td>QPSK</td>
</tr>
</tbody>
</table>

6.5.3 Layer mapping and precoding
The block of modulation symbols $d(0),...,d(M_{\text{symb}}-1)$ shall be mapped to layers according to clause 6.3.3.3 and precoded according to clause 6.3.4.2, resulting in a block of vectors $\tilde{y}(i) = \begin{bmatrix} y^{(0)}(i) & y^{(1)}(i) & \cdots & y^{(7)}(i) \end{bmatrix}^T$, $i=0,...,M_{\text{symb}}-1$. Then block of vectors $y(i) = \begin{bmatrix} y^{(0)}(i) & y^{(1)}(i) & \cdots & y^{(7)}(i) \end{bmatrix}^T$ is obtained by setting $y^{(p)}(i) = \tilde{y}^{(0)}(i)$ for $p \in \{0,2,4,6\}$ and $y^{(p)}(i) = \tilde{y}^{(i)}(i)$ 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 $y(0),...,y(M_{\text{symb}}-1)$ is transmitted during 4 consecutive radio frames starting in each radio frame fulfilling $n_r \mod 4 = 0$. The block of complex-valued symbols $y(0),...,y(M_{\text{symb}}-1)$ are divided into 16 sub-block of complex-valued symbols, which is given by

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

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

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

Sub-block 6 and 7: $y\left(\frac{3M_{\text{symb}}}{8}\right)$ to $y\left(\frac{7M_{\text{symb}}}{16} - 1\right)$, $y\left(\frac{7M_{\text{symb}}}{16}\right)$ to $y\left(\frac{M_{\text{symb}}}{2} - 1\right)$,
Sub-block 8 and 9: \( y \left( \frac{M_{\text{symb}}}{2} \right) \) to \( y \left( \frac{9M_{\text{symb}}}{16} - 1 \right) \), \( y \left( \frac{9M_{\text{symb}}}{16} \right) \) to \( y \left( \frac{5M_{\text{symb}}}{8} - 1 \right) \),

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

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

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

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 \( 0 \leq i \leq 7 \).

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:

\[
k = k' \cdot N_{sc}^{RB} + k''
\]

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

\[
k'' = 0, 1, 2, 3
\]

\[
l = 0, 1, 2, \ldots, 12, 13
\]

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:

\[
k = k' \cdot N_{sc}^{RB} + k''
\]

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

\[
k'' = 3, 2, 1, 0
\]

\[
l = 0, 1, 2, \ldots, 12, 13
\]

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 \( b(0), \ldots, b(M_{\text{bit}} - 1) \), where \( M_{\text{bit}} \), 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 \( \tilde{b}(0), \ldots, \tilde{b}(M_{\text{bit}} - 1) \) according to

\[
\tilde{b}(i) = (b(i) + c(i)) \mod 2
\]

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

\[
C_{\text{init}} = 2^{10} \cdot (7 \cdot [\bar{n}_s/2] + 1) + [l/N_{\text{sym}}^{\text{ePBCH}}] + 1) \cdot (2 \cdot N_{ID}^{\text{cell}} + 1) + 2 \cdot N_{ID}^{\text{cell}} + 1
\]

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

### 6.5A.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 \( d(0), \ldots, d(M_{\text{sym}} - 1) \). Table 6.5.A.2-1 specifies the modulation mappings applicable for the extended physical broadcast channel.

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

<table>
<thead>
<tr>
<th>Physical channel</th>
<th>Modulation schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ePBCH</td>
<td>QPSK</td>
</tr>
</tbody>
</table>

### 6.5A.3 Layer mapping and precoding
The block of modulation symbols \( d(0), \ldots, d(M_{\text{sym}} - 1) \) shall be mapped to layers according to clause 6.3.3 with \( M_{\text{sym}}^{(0)} = M_{\text{sym}} \) and precoded according to clause 6.3.4.2, resulting in a block of vectors

\[
y(i) = \left[ y^{(500)}(i) \quad y^{(501)}(i) \right]^T, \quad i = 0, \ldots, M_{\text{sym}} - 1,
\]

where \( y^{(500)}(i) \) and \( y^{(501)}(i) \) correspond to signals for antenna port 500 and 501, respectively.

### 6.5A.4 ePBCH Configuration
The ePBCH transmission periodicity is configured by xPBCH, which is given by Table 6.5.A.4-1.
The required number of subframes for ePBCH transmission is determined according to BRS transmission period, which is given by Table 6.5.A.4-2.

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

<table>
<thead>
<tr>
<th>BRS transmission period</th>
<th># of subframes, $N_{ePBCH}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 slot &lt; 5ms</td>
<td>1</td>
</tr>
<tr>
<td>1 subframes = 5ms</td>
<td>2</td>
</tr>
<tr>
<td>2 subframes = 10ms</td>
<td>4</td>
</tr>
<tr>
<td>4 subframes = 20ms</td>
<td>8</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Value of $\frac{T_{ePBCH}}{N_{ePBCH}}$</th>
<th>Configured subframes in each configured radio frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{T_{ePBCH}}{N_{ePBCH}} \geq 1$</td>
<td>4</td>
</tr>
<tr>
<td>$\frac{T_{ePBCH}}{N_{ePBCH}} &lt; 1$</td>
<td>29, 4</td>
</tr>
</tbody>
</table>

### 6.5A.5 Mapping to resource elements

In each OFDM symbol of the configured subframes, the block of complex-valued symbols $y(0), \ldots, y(M_{sym} - 1)$ is transmitted via two antenna ports. The block of complex-valued symbols is transmitted using identical beams in 2 consecutive 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 $b_p^0(0)$ for all $p \in \{0, 1, 2, \ldots, 7\}$, 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

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

where

$$k' = 0, 1, 2, \ldots, 2 \cdot N_{ePBCH}^l - 1$$

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

and

$$l = 0, 1, 2, \ldots, 12, 13$$
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 xPDCCH depends on the xPDCCH 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>
<thead>
<tr>
<th>PDCCH format</th>
<th>Number of CCEs</th>
<th>Number of resource-element groups</th>
<th>Number of xPDCCH bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>2</td>
<td>192</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
<td>384</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>8</td>
<td>768</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>16</td>
<td>1536</td>
</tr>
</tbody>
</table>

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

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

where the UE-specific scrambling sequence $c(i)$ is given by clause 7.2. The scrambling sequence generator shall be initialized with $c_{init} = \left\lfloor \frac{\pi_s}{2} \right\rfloor \cdot 2^n + n_{ID}^{xPDCCH}$ where $\pi_s = n_s \mod 20$ and the quantity $n_{ID}^{xPDCCH}$ is given by

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

6.6.3 Modulation
The block of scrambled bits $\tilde{b}(0),...\tilde{b}(M_{tot} - 1)$ shall be modulated as described in clause 7.1, resulting in a block of complex-valued modulation symbols $d(0),...,d(M_{symb} - 1)$. Table 6.8.3-1 specifies the modulation mappings applicable for the physical downlink control channel.

<table>
<thead>
<tr>
<th>Physical channel</th>
<th>Modulation schemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>xPDCCH</td>
<td>QPSK</td>
</tr>
</tbody>
</table>
6.6.4  Layer mapping and precoding
The layer mapping shall be done according to Table 6.6.4-1. There is only one codeword and the number of layers is equal to two.

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

<table>
<thead>
<tr>
<th>Number of layers</th>
<th>Number of codewords</th>
<th>Codeword-to-layer mapping $i = 0,1,...,M^\text{layer}_{\text{symb}} - 1$</th>
</tr>
</thead>
</table>
| 2                | 1                   | $x^{(0)}(i) = d^{(0)}(2i)$  
                    |                     | $x^{(1)}(i) = d^{(0)}(2i + 1)$  
                    |                     | $M^\text{layer}_{\text{symb}} = M_{\text{symb}} / 2$ |

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

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

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

6.6.5  Mapping to resource elements
The block of complex-valued symbols $y(0),...,y(M_{\text{symb}} - 1)$ 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 reference signal, associated with transmission of xPDSCH
- Demodulation reference signal for xPBCH
- Reference Signal (DM-RS) associated with ePBCCH
There is one reference signal transmitted per downlink antenna port.

6.7.1 UE-specific reference signals associated with xPDSCH

UE specific reference signals associated with xPDSCH

- are transmitted on antenna port(s), \( p \in \{8,9,\ldots,15\} \), indicated via 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 [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 \( p \).

6.7.1.1 Sequence generation

For any of the antenna ports \( p \in \{8,9,\ldots,v+7\} \), the reference-signal sequence \( r(m) \) is defined by

\[
r(m) = \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m + 1)), \quad m = 0, 1, \ldots, 3N_{\text{DMRS}} - 1.
\]

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

\[
c_{\text{init}} = \left( \left\lfloor \frac{n_{\text{ID}}}{2} \right\rfloor + 1 \right) \cdot \left( 2^{n_{\text{SCID}}^{(i)}} + 1 \right) \cdot 2^{16} + n_{\text{SCID}}
\]

at the start of each subframe.

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

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

The value of \( n_{\text{SCID}} \) is zero unless specified otherwise. For a xPDSCH transmission, \( n_{\text{SCID}} \) is given by the DCI format in [2] associated with the xPDSCH transmission.

6.7.1.2 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 \( n_{\text{PRB}} \) 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
\[ a_{ij}^{(p)} = w_p(k'') r(k''') \]

where

\[ k = 4m' + N_{sc}^w - 1 + k' \]

\[ k' = \begin{cases} 
0 & p \in \{8,12\} \\
1 & p \in \{9,13\} \\
2 & p \in \{10,14\} \\
3 & p \in \{11,15\} 
\end{cases} \]

\[ k'' = \begin{cases} 
0 & \text{if } k \mod 8 < 4 \\
1 & \text{if } 4 \leq k \mod 8 \leq 7 
\end{cases} \]

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

\[ l = 2 \text{ (in even slot only)} \]

\[ m' = 0,1,2 \]

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

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

<table>
<thead>
<tr>
<th>Antenna port ( p )</th>
<th>( \bar{w}_p(0) )</th>
<th>( \bar{w}_p(1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>[+1 ]</td>
<td>[+1 ]</td>
</tr>
<tr>
<td>9</td>
<td>[+1 ]</td>
<td>[+1 ]</td>
</tr>
<tr>
<td>10</td>
<td>[+1 ]</td>
<td>[+1 ]</td>
</tr>
<tr>
<td>11</td>
<td>[+1 ]</td>
<td>[+1 ]</td>
</tr>
<tr>
<td>12</td>
<td>[+1 ]</td>
<td>[-1 ]</td>
</tr>
<tr>
<td>13</td>
<td>[+1 ]</td>
<td>[-1 ]</td>
</tr>
<tr>
<td>14</td>
<td>[+1 ]</td>
<td>[-1 ]</td>
</tr>
<tr>
<td>15</td>
<td>[+1 ]</td>
<td>[-1 ]</td>
</tr>
</tbody>
</table>

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 \( S = \{1,1,1,5\} \) 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 6.7.1.2-1 illustrates the resource elements used for UE-specific reference signals for antenna ports 8, 9, 10, 11, 12, 13, 14 and 15.
Figure 6.7.1.2-1: Mapping of UE-specific reference signals, antenna ports 8, 9, 10, 11, 12, 13, 14 and 15.

6.7.2 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.

6.7.2.1 Sequence generation

For any of the antenna ports \( p \in \{107, 109\} \), the reference-signal sequence \( r(m) \) is defined by
\[
\begin{align*}
  r(m) &= \frac{1}{\sqrt{2}} (1-2\cdot c(2m)) + j \frac{1}{\sqrt{2}} (1-2\cdot c(2m+1)), \quad m = 0,1,...,23.
\end{align*}
\]

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

\[
  c_{\text{init}} = ([\bar{n}_s / 2] + 1) \cdot (2n_{\text{ID}}^{\text{PDCCH}} + 1) \cdot 2^{16} + n_{\text{scID}}^{\text{PDCCH}}
\]

\[
  \bar{n}_s = n_s \mod 20
\]

at the start of each subframe where \( n_{\text{scID}}^{\text{PDCCH}} = 2 \) and \( n_{\text{ID}}^{\text{PDCCH}} \) is configured by higher layers where the quantity \( n_{\text{ID}}^{\text{PDCCH}} \) is given by

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

### 6.7.2.2 Mapping to resource elements

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

\[
a_{l,j}^{(p)} = \overline{w}_p (m^*) r_l (m')
\]

where

\[
k = k_0 + 2 + (m' \mod 2) + 6 \cdot [m'/2]
\]

\[
m'' = m' \mod 2
\]

\[
k_0 = 6 \cdot n_{\text{REG}} \cdot N_{\text{sc}}^{\text{RB}}
\]

\[
0 \leq n_{\text{REG}} < 16
\]

\[
m' = 0,1,...,23
\]

\( l \in \{0, 1\} \)

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

Table 6.7.2.2-1: The sequence \( \overline{w}_p (i) \)
6.7.3 CSI reference signals

CSI reference signals are transmitted on 8 or 16 antenna ports using \( p = 16, \ldots, 23 \) or \( p = 16, \ldots, 31 \) 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 \( r_{i,n} (m) \) is defined by

\[
r_{i,n} (m) = \frac{1}{\sqrt{2}} \left( 1 - 2 \cdot c(2m) \right) + j \cdot \frac{1}{\sqrt{2}} \left( 1 - 2 \cdot c(2m + 1) \right), \quad m = 0, 1, \ldots, 3 \cdot N_{RB}^{\text{max,DL}} - 1
\]

where \( n_s \) is the slot number within a radio frame and \( i \) 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

\[
c_{\text{init}} = 2^{10} \cdot \left( 7 \cdot (n_s + 1) + l + 1 \right) \cdot \left( 2 \cdot N_{\text{ID}}^{\text{CSI}} + 1 \right) + 2 \cdot N_{\text{ID}}^{\text{CSI}} + 1
\]

\( \bar{n}_s = n_s \mod 20 \)

The quantity \( N_{\text{ID}}^{\text{CSI}} \) is configured to the UE using higher layer signalling.

6.7.3.2 Mapping to resource elements

A CSI-RS resource allocation in a subframe comprises of one symbol which is either the last or the second last symbol, or the last two consecutive symbols.

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

\[
a_{k,l}^{(p)} = r_{i,n} (m),
\]

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

where

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

### Table

<table>
<thead>
<tr>
<th>Antenna port ( p )</th>
<th>( \bar{c}_p(0) )</th>
<th>( \bar{c}_p(1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>107</td>
<td>[+1]</td>
<td>[+1]</td>
</tr>
<tr>
<td>109</td>
<td>[+1]</td>
<td>[-1]</td>
</tr>
</tbody>
</table>
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-RS resource. Each of the REs comprising a CSI resource are configured as either

- CSI-RS resource (state 0) (clause 8.2.5 in [3])
- CSI IM resource (state 1) (clause 8.2.6 in [3])

A CSI resource configuration is configured via RRC 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 indicating a CSI resource configuration

<table>
<thead>
<tr>
<th>k</th>
<th>l</th>
<th>State</th>
<th>k</th>
<th>l</th>
<th>State</th>
<th>k</th>
<th>l</th>
<th>State</th>
<th>k</th>
<th>l</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,8,16</td>
<td>12</td>
<td>0/1</td>
<td>1,9,17</td>
<td>12</td>
<td>0/1</td>
<td>2,10,18</td>
<td>12</td>
<td>0/1</td>
<td>3,11,19</td>
<td>12</td>
<td>0/1</td>
</tr>
<tr>
<td>5,13,21</td>
<td>12</td>
<td>0/1</td>
<td>6,14,22</td>
<td>12</td>
<td>0/1</td>
<td>7,15,23</td>
<td>12</td>
<td>0/1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.7.4 Beam reference signal (BRS)

Beam reference signals are transmitted on one or several of antenna ports \( p = \{0,1,\ldots,7\} \).

6.7.4.1 Sequence generation

The reference-signal sequence \( r_i(m) \) is defined by

\[
r_i(m) = \frac{1}{\sqrt{2}} \left( 1 - 2 \cdot c(2m) + j \cdot \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m + 1)) \right), \quad m = 0, 1, \ldots, 8 \cdot (N_{RBB}^{\text{max,DL}} - 18) - 1
\]

Where \( l = 0,1,\ldots,13 \) is the OFDM symbol number. The pseudo-random sequence \( c(i) \) is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

\[
C_{\text{init}} = 2^{l_0} \cdot (7 \cdot (n_s + 1) + l' + 1) \cdot (2 \cdot \frac{N_{\text{cell}}^L}{N_{RBB}^L} + 1) + 2 \cdot \frac{N_{\text{cell}}^L}{N_{RBB}^L} + 1
\]

at the start of each OFDM symbol, where \( n_s = \left\lfloor \frac{l}{7} \right\rfloor \) and \( l' = l \mod 7 \).

6.7.4.2 Mapping to resource elements

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

\[
a_{k,l}^{(p)} = \bar{w}_p(m')r_i(m'')
\]

with

\[
k = k' \cdot N_{RBB}^{RB} + k''
\]

\[
k' = 0, 1, \ldots, \left\lfloor \frac{1}{2} (N_{RBB}^{DL} - 18) \right\rfloor - 1,
\left\lfloor \frac{1}{2} (N_{RBB}^{DL} + 18) \right\rfloor,
\left\lfloor \frac{1}{2} (N_{RBB}^{DL} + 18) \right\rfloor + 1, \ldots, N_{RBB}^{DL} - 1
\]

\[
k'' = 0, 1, \ldots, \frac{1}{2} (N_{RBB}^{DL} - 18) - 1
\]
\[ k'' = 4, 5, 6, 7, 8, 9, 10, 11 \]
\[ l = 0, 1, 2, ..., 12, 13 \]
\[ m = 0, 1, ..., 8 \cdot (N_{RB}^{UL} - 18) - 1 \]
\[ m'' = m + 4 \cdot (N_{RB}^{max,UL} - N_{RB}^{UL}) \]
\[ m' = m \mod 8 \]

where \( N_{sc}^{RB} = 12 \) and the sequence \( \bar{w}_p(i) \) is defined in Table 6.7.8.2-1. BRS is transmitted from antenna ports \( p=0\ldots7 \).

**Table 6.7.4.2-1: The sequence \( \bar{w}_p(i) \)**

<table>
<thead>
<tr>
<th>Antenna port ( p )</th>
<th>( \bar{w}_p(0) )</th>
<th>( \bar{w}_p(1) )</th>
<th>( \bar{w}_p(2) )</th>
<th>( \bar{w}_p(3) )</th>
<th>( \bar{w}_p(4) )</th>
<th>( \bar{w}_p(5) )</th>
<th>( \bar{w}_p(6) )</th>
<th>( \bar{w}_p(7) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>2</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>4</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>5</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>6</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
</tr>
<tr>
<td>7</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>+1</td>
<td>-1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Resource elements \( (k, l) \) used for transmission of beam reference signals on any of the antenna ports shall be 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 xPBCCH 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 \( \bar{w}_p \) 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 xPBCCH

### 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>
<thead>
<tr>
<th>BRS configuration (Indication bits)</th>
<th>BRS transmission period</th>
<th>Maximum # of beam training opportunities</th>
<th>Logical beam index</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>1 slot &lt; 5ms</td>
<td>$P \cdot N_{symb}^{DL}$</td>
<td>$i = 0, ..., 1 \cdot P \cdot N_{symb}^{DL} - 1$</td>
</tr>
<tr>
<td>01</td>
<td>1 subframe = 5ms</td>
<td>$2 \cdot P \cdot N_{symb}^{DL}$</td>
<td>$i = 0, ..., 2 \cdot P \cdot N_{symb}^{DL} - 1$</td>
</tr>
<tr>
<td>10</td>
<td>2 subframes = 10ms</td>
<td>$4 \cdot P \cdot N_{symb}^{DL}$</td>
<td>$i = 0, ..., 4 \cdot P \cdot N_{symb}^{DL} - 1$</td>
</tr>
<tr>
<td>11</td>
<td>4 subframes = 20ms</td>
<td>$8 \cdot P \cdot N_{symb}^{DL}$</td>
<td>$i = 0, ..., 8 \cdot P \cdot N_{symb}^{DL} - 1$</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>BRS configuration</th>
<th>00</th>
<th>01</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st BRS Transmission Region</td>
<td>$b_i^P(i) = N_{symb}^{DL} \cdot p + i$, where $i = 0, ..., N_{symb}^{DL} - 1$</td>
<td>$b_i^P(i) = 2 \cdot N_{symb}^{DL} \cdot p + i$, where $i = 0, ..., 2 \cdot N_{symb}^{DL} - 1$</td>
</tr>
<tr>
<td>2nd BRS Transmission Region</td>
<td>$b_i^P(i) = 2 \cdot N_{symb}^{DL} \cdot p + i$, where $i = 0, ..., 2 \cdot N_{symb}^{DL} - 1$</td>
<td>$b_i^P(i) = 2 \cdot N_{symb}^{DL} \cdot p + i$, where $i = 0, ..., 2 \cdot N_{symb}^{DL} - 1$</td>
</tr>
<tr>
<td>3rd BRS Transmission Region</td>
<td>$b_i^P(i) = 4 \cdot N_{symb}^{DL} \cdot p + 2 \cdot N_{symb}^{DL} \cdot p + i$, where $i = 0, ..., 2 \cdot N_{symb}^{DL} - 1$</td>
<td>$b_i^P(i) = 4 \cdot N_{symb}^{DL} \cdot p + 2 \cdot N_{symb}^{DL} \cdot p + i$, where $i = 0, ..., 2 \cdot N_{symb}^{DL} - 1$</td>
</tr>
<tr>
<td>4th BRS Transmission Region</td>
<td>$b_i^P(i) = 6 \cdot N_{symb}^{DL} \cdot p + 2 \cdot N_{symb}^{DL} \cdot p + i$, where $i = 0, ..., 2 \cdot N_{symb}^{DL} - 1$</td>
<td>$b_i^P(i) = 6 \cdot N_{symb}^{DL} \cdot p + 2 \cdot N_{symb}^{DL} \cdot p + i$, where $i = 0, ..., 2 \cdot N_{symb}^{DL} - 1$</td>
</tr>
</tbody>
</table>

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, $p \in \{0, 1, 2, ..., 7\}$ is antenna port number, $b_i^P(i)$ 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 $b^p_l(0)$ for all $p \in \{0, 1, 2, \ldots, 7\}$ 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.

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

where $n_s$ is the slot number within a radio frame; $i$ 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:

$$c_{\text{init}} = 2^{10}(7(n_s + 1) + l + 1)(2N_{\text{ID}}^{\text{BRRS}} + 1) + 2N_{\text{id}}^{\text{BRRS}} + 1$$

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

The quantity $N_{\text{id}}^{\text{BRRS}}$ 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 $a^{(p)}_{k,l}$ on antenna port $p$ according to

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

where

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

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 [2]. On each Tx antenna port, BRRS may be transmitted with different Tx beam.
6.7.6 DL Phase noise compensation reference signal
Phase noise compensation reference signals associated with xPDSCH

- are transmitted on antenna port(s) \( p = 60 \) and/or \( p = 61 \) as signaled in DCI format in [2];
- 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 [2];
- 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
\[
    r(m) = \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m)) + j \frac{1}{\sqrt{2}} (1 - 2 \cdot c(2m + 1)), \quad m = 0,1,\ldots, \left\lfloor \frac{N_{\text{max,DL}}}{4} \right\rfloor - 1.
\]

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

\[
    c_{\text{init}} = \left(\lfloor \bar{n}_s / 2 \rfloor + 1\right) \cdot \left(2n_{\text{sc}}^{\text{(nscn)}} + 1\right) \cdot 2^{16} + n_{\text{SCID}}
\]

\[
    \bar{n}_s = n_s \mod 20
\]

at the start of each subframe.

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

- \( n_{\text{id}}^{(i)} = N_{\text{id}}^{\text{cdef}} \) if no value for \( n_{\text{id}}^{\text{PCRSj}} \) is provided by higher layers
- \( n_{\text{id}}^{(i)} = n_{\text{id}}^{\text{PCRSj}} \) otherwise

The value of \( n_{\text{SCID}} \) is zero unless specified otherwise. For a \( \text{xPDSCH} \) transmission, \( n_{\text{SCID}} \) is given by the DCI format in [2] associated with the \( \text{xPDSCH} \) 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 \( n_{\text{PRB}} \) assigned for the corresponding \( \text{xPDSCH} \) transmission, a part of the reference signal sequence \( r(m) \) shall be mapped to complex-valued modulation symbols \( a_{k,l}^{(p)} \) for all \( \text{xPDSCH} \) symbols in a subframe according to:

\[
    a_{k,l}^{(p)} = r(k^\prime). \]

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

\[
    k = N_{\text{sc}}^{\text{RB}} \cdot \left(n_{\text{PRB}}^{\text{xPDSCH}} + k^\prime \cdot 4\right) + k^\prime \cdot 4 + k^\prime\prime + 1
\]

\[
    k^\prime = \begin{cases} 
        24 & p = 60 \\
        23 & p = 61 
    \end{cases}
\]

\[
    k^\prime\prime = \left\lfloor m / 4 \right\rfloor
\]

\[
    l = \left\lfloor l_{\text{first}}^{\text{xPDSCH}}, \ldots, l_{\text{last}}^{\text{xPDSCH}} \right\rfloor
\]

\[
    m = 0,1,2,\ldots, N_{\text{PRB}}^{\text{xPDSCH}} - 1
\]
where \( l' \) is the symbol index within a subframe. \( l'_{\text{first}}^{xPDSCH} \) and \( l'_{\text{last}}^{xPDSCH} \) 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 6.7.6.2-1 illustrates the resource elements used for phase noise compensation reference signals for antenna ports 60 and 61 when \( xPDSCH \) is transmitted from \( l'_{\text{first}}^{xPDSCH} = 3 \) to \( l'_{\text{last}}^{xPDSCH} = 13 \).
Figure 6.7.6.2-1: Mapping of phase noise compensation reference signals, antenna ports 60 and 61 in case of $f_{\text{uPDSCH}}^{\text{first}}=3$ and $f_{\text{uPDSCH}}^{\text{last}}=13$.

6.7.6A Demodulation reference signal for xPBCH
BRS transmitted OFDM symbol $l$ is the demodulation reference signal associated with xPBCH in OFDM symbol $l$.

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 beams for reference signal transmission shall be identical with the beams for the ePBCH transmission in each OFDM symbol.

6.7.7.1 Sequence generation
The reference-signal sequence $r_{i,n}(m)$ is defined by

$$
r_{i,n}(m) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m)\right) + j \frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2m + 1)\right), \quad m = 0, 1, ..., 2 \cdot N_{RB}^{DL} - 1
$$

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 $l = 0, 1, 2, ..., 13$. The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

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

$$
\bar{n}_s = n_s \mod 20,
\bar{l} = l \mod 7
$$

at the start of each OFDM symbol.

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

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

- $k = 6 \cdot m + 2$
- $m = 0, 1, ..., 2 \cdot N_{RB}^{DL} - 1$
- $l = 0, 1, 2, ..., 12, 13$
- $m' = m \mod 2$
- $l' = l \mod 2$
where \( N_{DL}^{RB} = 100 \) and the sequence \( \bar{w}_p(i) \) is defined in Table 6.7.8.2-1.

Table 6.7.8.2-1: The sequence \( \bar{w}_{p0}(i) \) in odd OFDM symbol

<table>
<thead>
<tr>
<th>Antenna port ( p )</th>
<th>( \bar{w}_p(0) )</th>
<th>( \bar{w}_p(1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>501</td>
<td>+1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Table 6.7.8.2-2: The sequence \( \bar{w}_{p1}(i) \) in even OFDM symbol

<table>
<thead>
<tr>
<th>Antenna port ( p )</th>
<th>( \bar{w}_p(0) )</th>
<th>( \bar{w}_p(1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>+1</td>
<td>+1</td>
</tr>
<tr>
<td>501</td>
<td>-1</td>
<td>+1</td>
</tr>
</tbody>
</table>

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

UE may assume the angular power spectrum of the beam associated with the synchronization signals antenna port in any particular OFDM symbol has an equal or higher correlation with those of the beams associated with the xPBCH antenna ports in the same OFDM symbol than those of the beams associated with the xPBCH antenna ports in any other OFDM symbol.

#### 6.8.1 Primary synchronization signal (PSS)

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

**Sequence generation**

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

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

where the Zadoff-Chu root sequence index \( u \) is given by Table 6.8.1.1-1.

Table 6.8.1.1-1: Root indices for the primary synchronization signal
6.8.1.2 Mapping to resource elements

The UE shall not assume that the primary synchronization signal transmitted on any of the ports \( p = 300, \ldots, 313 \) is transmitted on the same antenna port as any of the downlink reference signals in that subframe. 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

\[
\begin{align*}
  a_{k,l}^{(p)} &= d(n), \quad n = 0, \ldots, 61 \\
  k &= n - 31 + \frac{N_{DL}^{RB} N_{sc}^{RB}}{2} \\
  l &= 0, 1, \ldots, 13 \\
  p &= 300 + l
\end{align*}
\]

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

\[
\begin{align*}
  k &= n - 31 + \frac{N_{DL}^{RB} N_{sc}^{RB}}{2} \\
  n &= -5, -4, \ldots, -1, 62, 63, \ldots, 66
\end{align*}
\]

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

6.8.2 Secondary synchronization signal (SSS)

The secondary synchronization signal is transmitted in symbol 0-13 in subframes 0 and 25 on antenna ports \( p = 300, \ldots, 313 \). 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 second synchronization signal is transmitted on antenna port \( p = 300, \ldots, 313 \).

The combination of two length-31 sequences defining the secondary synchronization signal differs between subframes according to
\[
d(2n) = \begin{cases} s_0^{(m_0)}(n)c_0(n) & \text{in subframe 0} \\ s_1^{(m_0)}(n)c_0(n) & \text{in subframe 25} \end{cases}
\]
\[
d(2n+1) = \begin{cases} s_1^{(m_1)}(n)c_1(n)z_1^{(m_1)}(n) & \text{in subframe 0} \\ s_0^{(m_1)}(n)c_1(n)z_1^{(m_1)}(n) & \text{in subframe 25} \end{cases}
\]

where \(0 \leq n \leq 30\). The indices \(m_0\) and \(m_1\) are derived from the physical-layer cell-identity group \(N_{ID}^{(1)}\) according to
\[
m_0 = m' \mod 31 \\
m_1 = (m_0 + \lfloor m'/31 \rfloor + 1) \mod 31 \\
m' = N_{ID}^{(1)} + q(q + 1)/2, \quad q = \left\lfloor \frac{N_{ID}^{(1)} + q'(q' + 1)/2}{30} \right\rfloor, \quad q' = \left\lfloor \frac{N_{ID}^{(1)}/30}{31} \right\rfloor
\]

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
\[
s_0^{(m_0)}(n) = \tilde{s}(n + m_0) \mod 31 \\
s_1^{(m_1)}(n) = \tilde{s}(n + m_1) \mod 31
\]

where \(\tilde{s}(i) = 1 - 2x(i)\), \(0 \leq i \leq 30\), is defined by
\[
x(i + 5) = (x(i + 2) + x(i)) \mod 2, \quad 0 \leq i \leq 25
\]
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
\[
c_0(n) = \tilde{c}((n + N_{ID}^{(2)}) \mod 31) \\
c_1(n) = \tilde{c}((n + N_{ID}^{(2)}/3) \mod 31)
\]

where \(N_{ID}^{(2)} \in \{0,1,2\}\) is the physical-layer identity within the physical-layer cell identity group \(N_{ID}^{(1)}\) and \(\tilde{c}(i) = 1 - 2x(i)\), \(0 \leq i \leq 30\), is defined by
\[
x(i + 5) = (x(i + 3) + x(i)) \mod 2, \quad 0 \leq i \leq 25
\]
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 \(z_0^{(m_0)}(n)\) and \(z_1^{(m_1)}(n)\) are defined by a cyclic shift of the m-sequence \(\tilde{z}(n)\) according to
\( z_i^{(m_0)}(n) = \bar{z}((n + (m_0 \mod 8)) \mod 31) \)

\( z_i^{(m_1)}(n) = \bar{z}((n + (m_1 \mod 8)) \mod 31) \)

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

\( x(\tilde{i} + 5) = (x(\tilde{i} + 4) + x(\tilde{i} + 2) + x(\tilde{i} + 1) + x(\tilde{i})) \mod 2, \quad 0 \leq \tilde{i} \leq 25 \)

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

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

<table>
<thead>
<tr>
<th>( N_{ID}^{(i)} )</th>
<th>( m_0 )</th>
<th>( m_1 )</th>
<th>( N_{ID}^{(i)} )</th>
<th>( m_0 )</th>
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<td>135</td>
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</table>

Table 6.8.2.1-1: Mapping between physical-layer cell-identity group \( N_{ID}^{(i)} \) and the indices \( m_0 \) and \( m_1 \)
### 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 \( p \in \{300,...,313\} \) 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

\[
d_{k,l}^{(p)} = d(n), \quad n = 0,...,61
\]

\[
k = n + 41 + \frac{N_{RB}N_{sc}}{2}
\]

\[
l = 0,1,...,12,13.
\]

\[
p = 300 + l
\]

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

\[
k = n + 41 + \frac{N_{RB}N_{sc}}{2}
\]

\[
n = -5,-4,...,-1,62,63,...,66
\]

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

### 6.8.3 Extended synchronization signal

The extended synchronization signal is used to identify the OFDM symbol index and transmitted in symbol 0-13 in subframes 0 and 25 on antenna ports \( p = 300,...,313 \).

#### 6.8.3.1 Sequence generation

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

\[
d(n) = e^{-j\frac{25\pi(n+1)}{63}}, \quad n = 0,1,...,62.
\]

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

\[
\hat{d}^l(n) = d((n + \Delta_l) \mod 63), \quad n = 0,1,...,62
\]

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

**Table 6.8.3.1-1:** Cyclic shifts for the extended synchronization signal
The sequence used for scrambling extended synchronization signal in subframe \( i \in \{0,25\} \) is defined by

\[
r_i(n) = \frac{1}{\sqrt{2}} \left( 1 - 2 \cdot c(2n) \right) + j \frac{1}{\sqrt{2}} \left( 1 - 2 \cdot c(2n + 1) \right), \quad n = 0, 1, \ldots, 62
\]

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

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

\[
d^l(n) = r_i(n) \cdot \bar{d}^l(n), \quad n = 0, \ldots, 62
\]

### 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

\[
a_{k,p}^{(n)} = d^l(n), \quad n = 0, 1, \ldots, 62
\]

\[
k = n - 104 + \frac{N_{\text{RB}}^{\text{DL}} N_{\text{RB}}^{\text{UL}}}{2}
\]

\[
l = 0, 1, \ldots, 12, 13.
\]

\[
p = 300 + l
\]

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

\[
k = n - 104 + \frac{N_{\text{RB}}^{\text{DL}} N_{\text{RB}}^{\text{UL}}}{2}
\]
are reserved and not used for transmission of the extended synchronization signal.

6.9 OFDM baseband signal generation

The time-continuous signal \( s_{i}^{(p)}(t) \) on antenna port \( p \) in OFDM symbol \( i \) in a downlink slot is defined by:

\[
s_{i}^{(p)}(t) = \sum_{k=-[N_{RB,sc}N_{s}] / 2}^{-1} a_{k}^{(p)} e^{j 2 \pi f \Delta f (t - N_{CP} T_{s})} + \sum_{k=1}^{[N_{RB,sc}N_{s}] / 2} a_{k}^{(p)} e^{j 2 \pi f \Delta f (t - N_{CP} T_{s})}
\]

for \( 0 \leq t < (N_{CP} + N) T_{s} \), where \( k^{(-)} = k + \left[ N_{DL,RB} N_{RB} / 2 \right] \) and \( k^{(+)} = k + \left[ N_{DL,RB} N_{RB} / 2 \right] - 1 \). The variable \( N \) equals 2048 and \( \Delta f = 75 \text{ kHz} \) subcarrier spacing.

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

Table 6.9-1 lists the value of \( N_{CP} \) 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

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Cyclic prefix length ( N_{CP} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal cyclic prefix</td>
<td>( \Delta f = 75 \text{ kHz} )</td>
</tr>
<tr>
<td></td>
<td>( 160 ) for ( l = 0 )</td>
</tr>
<tr>
<td></td>
<td>( 144 ) for ( l = 1,2,\ldots,6 )</td>
</tr>
</tbody>
</table>

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 \( x = I + jQ \) according to Table 7.1.1-1.

Table 7.1.1-1: BPSK modulation mapping

<table>
<thead>
<tr>
<th>( b(i) )</th>
<th>( I )</th>
<th>( Q )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>( \frac{1}{\sqrt{2}} )</td>
<td>( \frac{1}{\sqrt{2}} )</td>
</tr>
<tr>
<td>1</td>
<td>( -\frac{1}{\sqrt{2}} )</td>
<td>( -\frac{1}{\sqrt{2}} )</td>
</tr>
</tbody>
</table>

7.1.2  QPSK

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

Table 7.1.2-1: QPSK modulation mapping

<table>
<thead>
<tr>
<th>( b(i), b(i+1) )</th>
<th>( I )</th>
<th>( Q )</th>
</tr>
</thead>
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<tr>
<td>00</td>
<td>( \frac{1}{\sqrt{2}} )</td>
<td>( \frac{1}{\sqrt{2}} )</td>
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<tr>
<td>01</td>
<td>( \frac{1}{\sqrt{2}} )</td>
<td>( -\frac{1}{\sqrt{2}} )</td>
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<td>10</td>
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<tr>
<td>11</td>
<td>( -\frac{1}{\sqrt{2}} )</td>
<td>( -\frac{1}{\sqrt{2}} )</td>
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</table>

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
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
<table>
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<th>( b(i), b(i+1), b(i+2), b(i+3), b(i+4), b(i+5) )</th>
<th>( I )</th>
<th>( Q )</th>
<th>( b(i), b(i+1), b(i+2), b(i+3), b(i+4), b(i+5) )</th>
<th>( I )</th>
<th>( Q )</th>
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</table>
### 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 \( n = 0,1,\ldots,M_{PN} - 1 \), is defined by

\[
c(n) = (x_1(n + N_c) + x_2(n + N_c)) \mod 2
\]

\[
x_1(n + 31) = (x_1(n + 3) + x_1(n)) \mod 2
\]

\[
x_2(n + 31) = (x_2(n + 3) + x_2(n + 2) + x_2(n + 1) + x_2(n)) \mod 2
\]

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 \( c_{init} = \sum_{i=0}^{30} x_2(i) \cdot 2^i \) 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 \( (N_{TA} + N_{TA\text{ offset}}) \times T_s \) seconds before the start of the corresponding downlink radio frame at the UE, where \( 0 \leq N_{TA} \leq 1200 \).

\( N_{TA\text{ offset}} = 768 \) unless stated otherwise in [4].

Figure 8.1-1: Uplink-downlink timing relation