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European Standard (Telecommunications series)

**Satellite Earth Stations and Systems (SES);
Satellite Digital Radio (SDR) Systems;
Part 1: Physical Layer of the Radio Interface;
Sub-part 2: Inner Physical Layer Single Carrier Modulation**



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Foreword

This European Standard (Telecommunications series) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

The present document is part 1, sub-part 2 of a multi-part deliverable. Full details of the entire series can be found in part 1, sub-part 1 [i.4].

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Introduction

An SDR system enables broadcast to fixed and mobile receivers through satellites and complementary terrestrial transmitters. Functionalities, architecture and technologies of such systems are described in TR 102 525 [i.5].

Several existing and planned ETSI standards specify parts of the SDR system, with the aim of interoperable implementations. The physical layer of the radio interface (air interface) is divided up into the outer physical layer, the inner physical layer with single carrier modulation, and the inner physical layer with multi carrier modulation. These parts can be used all together in SDR compliant equipment, or in conjunction with other existing and future specifications.

The present document specifies the inner physical layer with single carrier modulation. The inner physical layer with multi carrier modulation is specified in EN 302 550-1-3 [i.3], and the outer physical layer in EN 305 550-1-1 [i.4]. Guidelines for using the physical layer standard can be found in TR 102 604 [i.6].

The physical layer specifications have previously been published as "Technical Specification (TS)" type ETSI deliverables. The present document supersedes TS 102 551-1 [i.7] and is recommended for new implementations. The functional difference between the previous TS 102 551-1 [i.7] and the present document is that the exclusion of the IPL-MC Mode 1 is taken into account.

1 Scope

The present document concerns the radio interface of SDR broadcast receivers. It specifies functionality of the inner physical layer with single carrier modulation. It allows implementing this part of the system in an interoperable way.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

- For a specific reference, subsequent revisions do not apply.
- Non-specific reference may be made only to a complete document or a part thereof and only in the following cases:
 - if it is accepted that it will be possible to use all future changes of the referenced document for the purposes of the referring document;
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2.1 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

Not applicable.

2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area. For non-specific references, the latest version of the referenced document (including any amendments) applies.

- [i.1] ETSI EN 302 307 (V1.1.1): "Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications".
- [i.2] ITU-T Recommendation O.153 (1992): "Basic parameters for the measurement of error performance at bit rates below the primary rate".
- [i.3] ETSI EN 302 550-1-3: "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Part 1: Physical Layer of the Radio Interface; Sub-part 3: Inner Physical Layer Multi Carrier Modulation".
- [i.4] ETSI EN 302 550-1-1: "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Part 1: Physical Layer of the Radio Interface; Sub-part 1: Outer Physical Layer".
- [i.5] ETSI TR 102 525 (V1.1.1): "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) service; Functionalities, architecture and technologies".
- [i.6] ETSI TR 102 604: "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Guidelines for the use of the physical layer standards".

[i.7] ETSI TS 102 551-1 (V1.1.1): "Satellite Earth Stations and Systems (SES); Satellite Digital Radio (SDR) Systems; Inner Physical Layer of the Radio Interface; Part 1: Single Carrier Transmission".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

floor function: function that rounds number down, towards zero, to the nearest integer

3.2 Symbols

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

α roll off factor

3.3 Abbreviations

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

16APSK	16 Amplitude and Phase Shift Keying
8PSK	8 Phase Shift Keying
BW	BandWidth
C/N	Carrier to Noise ratio
C-TS	Channel Transport Stream
CU	Capacity Unit
DVB	Digital Video Broadcasting
I	In-phase
IPL	Inner Physical Layer
IPL-MC	Inner Physical Layer, Multi Carrier
IPL-SC	Inner Physical Layer, Single Carrier
ISI	Inter Symbol Interference
ksp	kilo symbols per second
LSB	Least Significant Bit
MSB	Most Significant Bit
Msp	Mega symbols per second
OPL	Outer Physical Layer
Q	Quadrature
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
RFU	Reserved for Future Use
SDR	Satellite Digital Radio
S-TS	Service Transport Stream
XOR	eXclusive OR

4 Inner physical layer - Single Carrier

The functionality of the Inner Physical Layer (Single Carrier), in the following denoted IPL-SC, is to provide a robust modulation scheme for single carrier transmissions. The single carrier modulation is mainly applicable to satellite signal transmission but may be reused in other transmission environments. However, certain parameters are especially designed and optimized for satellite requirements.

The IPL-SC is embedded between the OPL (C-TS delivery) and the RF frontend (modulation) as depicted in figure 1.

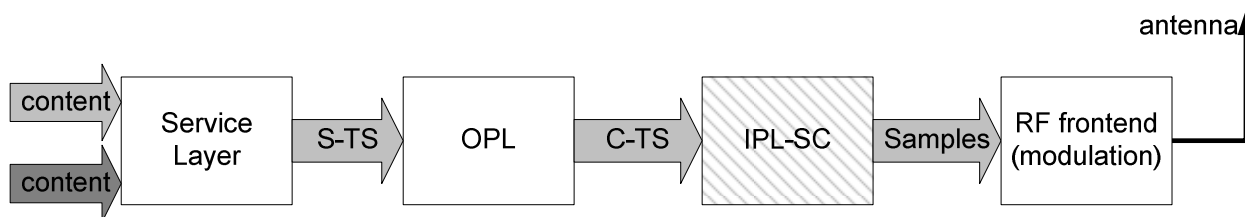


Figure 1: General block diagram of the ETSI SES SDR system concept with selection of IPL-SC

The general block diagram of the IPL-SC functionality is given in figure 2. Please notify that the generation of each Phy section can be handled individually (dashed box), whereas rolloff filtering is applied to the stream of mapped symbols of many Phy section (due to its dispersive nature).

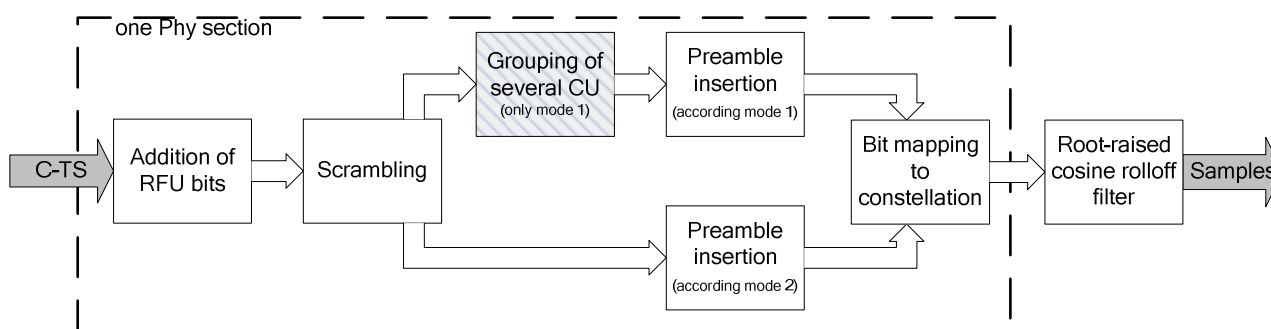


Figure 2: Block diagram of the ETSI SES SDR compliant IPL-SC

4.1 Interfacing to OPL (Outer Physical Layer)

Its interface to the OPL (Outer Physical Layer) is the C-TS (channel transport stream), which is defined in EN 302 550-1-1 [i.4]. For this special IPL-SC, the parameters which are passed to the OPL are derived within EN 302 550-1-1 [i.4].

This IPL-SC provides an input for only one single C-TS and generates the signal for one RF carrier. If more than one carrier needs to be supported, multiple instances of the IPL-SC need to be instantiated in parallel.

The parameters that are passed to the OPL are as follows:

- frame length in integer number of CU (capacity units).

One IPL-SC frame is composed by a number of Phy sections. Their parameters are denoted in clause 5.

As different modes are distinguished (see clause 4.3), the interfacing to the OPL is also slightly different for the two modes:

- For mode 1, it is mandatory to have integer numbers of CU which can be divided without remainder by 2 (for QPSK), by 3 (for 8PSK) and by 4 (for 16APSK). Other numbers of CU lead to Phy sections that miss some CU, and non-periodic preamble structure would be introduced.
- For mode 2, it is desirable to have integer numbers of CU which can be divided without remainder by 2 (for QPSK), by 3 (for 8PSK) and by 4 (for 16APSK). Other numbers of CU lead to non-periodic preamble structure for the different modulation orders.

Examples for a reasonable choice of parameters are given in clause 5.

With these parameters, the exact throughput of the IPL-SC can be derived in CU per time. The smallest unit to be processed by the IPL-SC is one CU.

To be able to benefit from the gain of hybrid configurations (e.g. using IPL-SC together with IPL-MC), it is mandatory to have equal frame lengths on both IPLs.

If modes 2, 2s, 3 or 4 of the IPL-MC [i.3] were used, the joint frame length of 432 ms is chosen for the IPL-MC frame length.

4.2 The profile approach - different single carrier modes

To cope with different design constraints that arise from the possible use scenarios of the IPL-SC, two modes (denoted mode 1 and mode 2) are defined which use a different share of pilots.

These modes are associated to profiles that are distinguished by their symbol rate and number of capacity units per inserted preamble, so that their adaptation to different channel bandwidths is easily possible. Profile IPL-SC-A is related to mode 1, and IPL-SC-B is related to mode 2, respectively.

For each profile, two examples are given.

To comply with the different profiles, profile IPL-SC-A needs to be capable to work with all symbol rates ranging from 3 Msps up to 12 Msps. A granularity (or step-size) of 88 kbps for the choice of symbol rates is provided in mode 1.

If compliance with profile IPL-SC-B is desired, symbol rates ranging from 1 Msps up to 3 Msps need to be supported. A granularity (or step-size) of 5 kbps for the choice of symbol rates is provided in mode 2.

The main target frequency bands and channel bandwidths are:

Table 1: Different examples for the two profiles IPL-SC-A and IPL-SC-B

	S-Band 4,31 Msps			L-Band 10,87 Msps	L-Band 1,84 Msps	L-Band or S-Band 1,49 Msps
Profile name	IPL-SC-A			IPL-SC-A	IPL-SC-B	IPL-SC-B
Supported modes	1			1	2	2
Carrier frequency	2,0 GHz to 2,3 GHz			1,4 GHz to 1,5 GHz	1,4 GHz to 1,5 GHz	1,4 GHz to 1,5 GHz 2,0 GHz to 2,3 GHz
Channel bandwidth	4,96 MHz			12,5 MHz	2,12 MHz	1,71 MHz
Symbol rate	4,31 Msps			10,87 Msps	1,84 Msps	1,49 Msps
min/max symbol rate	3 Msps/12 Msps			3 Msps / 12 Msps	1 Msps / 3 Msps	1 Msps / 3 Msps
IPL-SC frame length	432 ms			432 ms	432 ms	432 ms

The present document does not restrict its use to the application scenarios as denoted above. Other frequency bands or channel bandwidths may be used but the parameter selection may not be optimal.

4.3 Generation of one Phy section

4.3.1 Overview

One Phy section consists of the following 3 parts:

- preamble;
- data payload (capacity units, CU, etc.);
- signalling bits (RFU: reserved for future use).

Insertion of preambles is different for mode 1 and mode 2, therefore the preamble insertion is distinguished within the following clauses.

4.3.1.1 Overview of mode 1

Figure 3 displays the generation of one Phy section in mode 1.

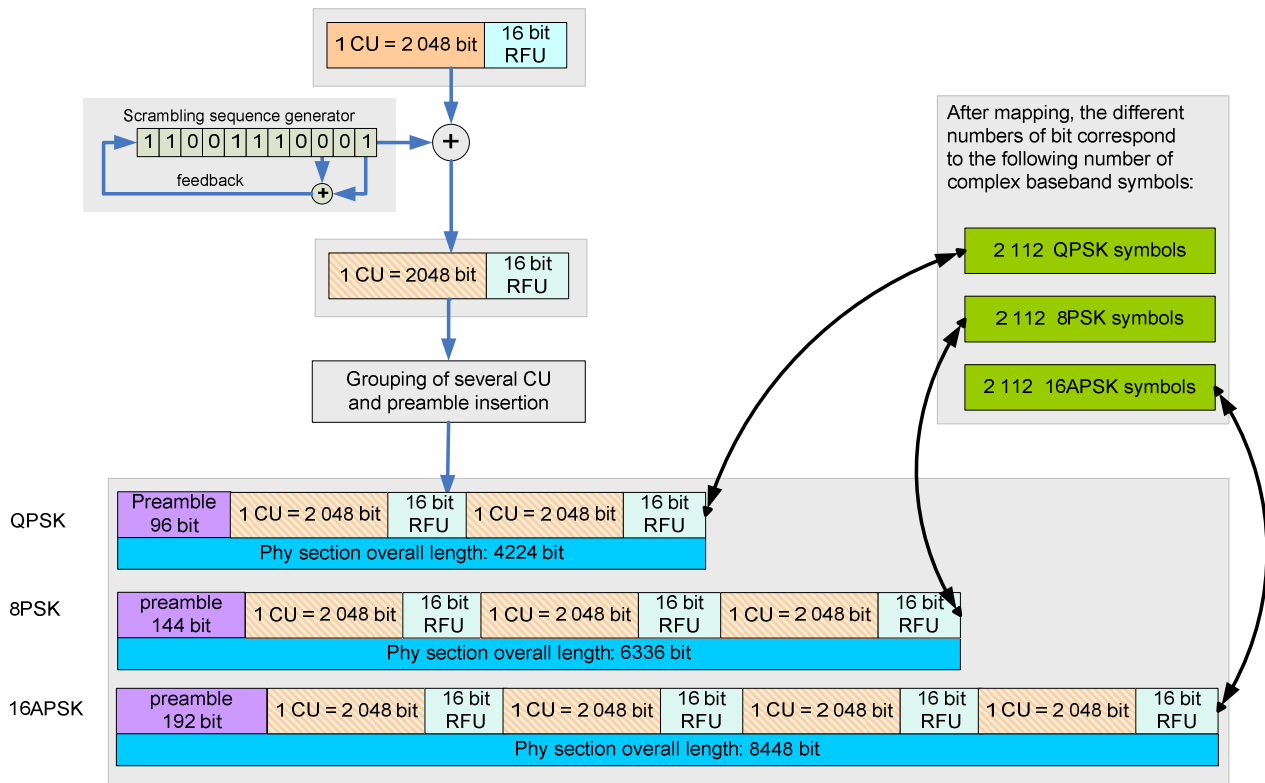


Figure 3: Overview of the generation of one Phy section in mode 1

The length of one Phy section (in bit) depends on the chosen modulation order. The number of complex baseband symbols after mapping is kept constant in mode 1 to be 2 112 symbols for all three modulation orders. The procedure to generate one Phy section is described below.

4.3.1.2 Overview of mode 2

Figure 4 displays the generation of one Phy section in mode 2.

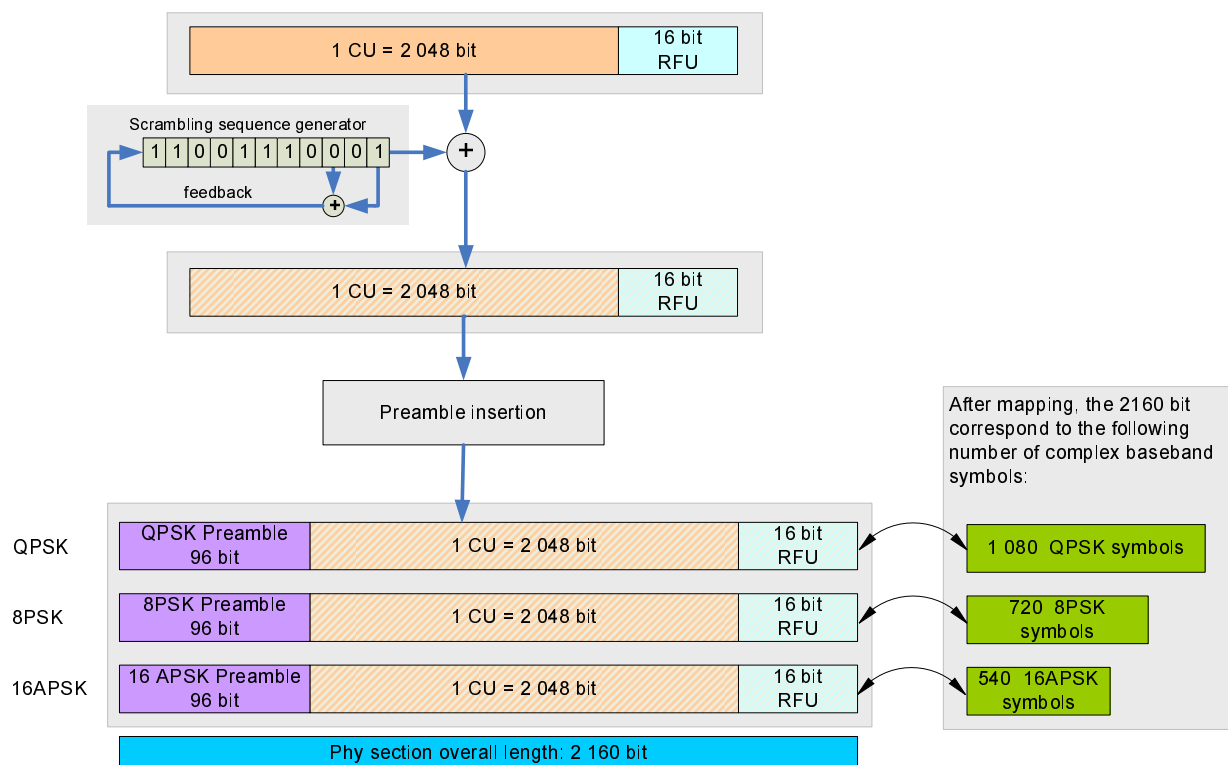


Figure 4: Overview of the generation of one Phy section in mode 2

The length of the Phy section is defined as 2160 bits as depicted in figure 4. The procedure to generate one Phy section is described in the following clauses.

4.3.2 IPL-SC signalling and padding

There is no signalling of transmission parameters of the IPL-SC. All transmission parameters (e.g. modulation order) can be derived from the preambles. To be able to distinguish different modulation modes, different preambles are selected.

Each CU is followed by 16 signalling bits which are currently not used but are reserved for future use. All bits are set to zero. Therefore, the block size for one CU after RFU insertion is 2064 bit. See also figure 3 and figure 4.

Bit padding at the end of one IPL-SC frame: Bit padding at the end of the IPL-SC frame is not required as the transport capability of one IPL-SC frame is always an integer number of Phy sections. This is ensured by the selection of the symbol rate and the frame length.

CU padding at the end of one C-TS frame: As it is a mandatory requirement of the C-TS multiplexer at the output of the OPL to adapt the number of CU to the transport capability of the IPL-SC, no additional padding of empty CU is necessary; however, padding of empty CU may be foreseen to support erroneous situations where the C-TS multiplexer does not provide entire C-TS frames.

Using different preamble lengths for the different modulation orders in mode 2 are justified by the following considerations: The lower the available C/N, the lower typically the modulation order is. With lower modulation orders, higher gain from longer preambles is necessary. On the other hand, due to the lower sensitivity of lower modulation orders to remaining phase noise, the distance of the preambles is higher. In total, the pilot overhead (in time) is constant for all modulation orders, approximately 4,4 % or 0,18 dB. Taking into account the slightly boosted preamble of 16APSK, this value changes to approximately 5,6 % or 0,25 dB, regarding the total share of energy spent on the pilots.

4.4 Bit mapping to constellation

The mapping of each Phy section is performed according to the following mapping schemes which have been adopted from the DVB-S2 standard EN 302 307 [i.1]. The notation of the bits is as follows:

The leftmost bit is to be extracted from the input bitstream first, whereas the rightmost bit is to be extracted from the input bitstream as the last one.

4.4.1 QPSK Modulation

The following mapping scheme is used in QPSK modulation mode, denoted as modulation index 2. See also figure 6. The transmission order is $\{\text{bit}[i] \text{ bit}[i+1]\}$ where i denotes the current time index.

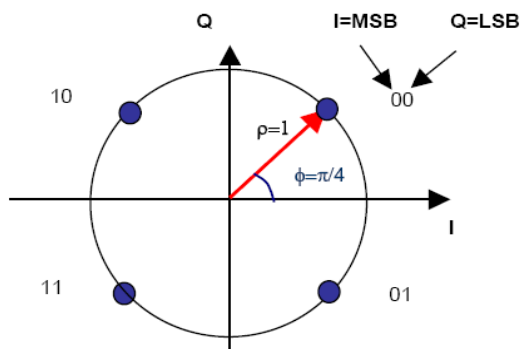


Figure 6: QPSK modulation

4.4.2 8PSK Modulation

The following mapping scheme is used in 8PSK modulation mode, denoted as modulation index 3. See also figure 7. The transmission order is $\{\text{bit}[i] \text{ bit}[i+1] \text{ bit}[i+2]\}$ where i denotes the current time index.

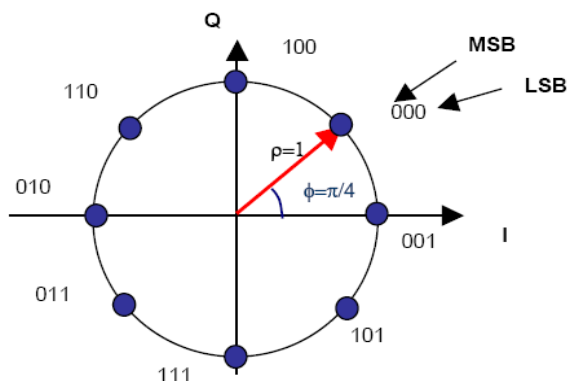


Figure 7: 8PSK Modulation

4.4.3 16APSK Modulation

The following mapping scheme is used in 16APSK modulation mode, denoted as modulation index 4. See also figure 8. The transmission order is {bit [i] bit [i+1] bit [i+2] bit [i+3]} where i denotes the current time index.

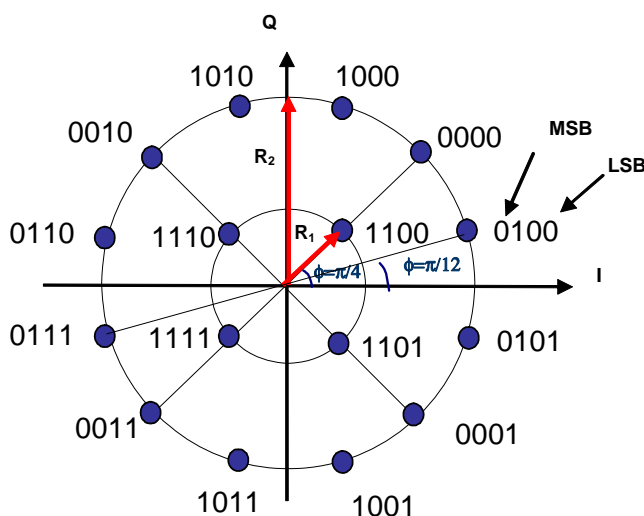


Figure 8: 16APSK modulation

In 16APSK mode, the radii of the two circles have to be chosen accordingly to table 4 to ensure equal mean power ratio between all modulation modes.

Table 4: Definition of radii for the two circles of the 16APSK constellation

Circle	Radius
Inner	$R_1 = 1/\sqrt{7}$
Outer	$R_2 = 3/\sqrt{7}$

4.5 Pulse shaping

Pulse shaping is performed on the whole mapped stream of symbols. To comply with regulatory bodies, the bandwidth of the transmitted signal needs to be band limited prior to digital-to-analog conversion, up conversion and amplification. Therefore, a (real-valued) root-raised cosine roll off filter is applied to the I and Q component, respectively. If the same filter was also applied at the receiver side, the signal could be detected ISI-free (free of inter symbol interference) in a non-dispersive channel.

The available roll off factor is $\alpha=0,15$. Any mismatch to existing roll off factors in the receivers (e.g. 0,20 or 0,25) is negligible, so other roll-off factors are not specified. However, other values of the roll-off factors may be considered optionally on the transmitter side. This would be the case if small overlaps of frequency bands are tolerated or the transmitters are already in situ.

For the pulse shaping, the following formula applies:

$$\begin{aligned}
 H(f) &= 1 & \text{for } |f| < f_N(1-\alpha) \\
 H(f) &= \left\{ \frac{1}{2} + \frac{1}{2} \sin \frac{\pi}{2f_N} \left[\frac{f_N - |f|}{\alpha} \right] \right\}^{1/2} & \text{for } f_N(1-\alpha) \leq |f| \leq f_N(1+\alpha) \\
 H(f) &= 0 & \text{for } |f| > f_N(1+\alpha),
 \end{aligned}$$

where $f_N = \frac{f_s}{2}$ denotes the Nyquist frequency, f_s the symbol frequency and α the roll-off factor.

5 Parameter selection

The following parameters have been derived for different scenarios:

- profile IPL-SC-A: symbol rate of 4,31 Msps (5 MHz channel grid, mode 1, frame length 432 ms);
- profile IPL-SC-A: symbol rate of 10,87 Msps (12,5 MHz channel grid, mode 1, frame length 432 ms);
- profile IPL-SC-B: symbol rate of 1,84 Msps (2,1 MHz channel grid, mode 2, compliant to existing satellites, frame length 432 ms);
- profile IPL-SC-B: symbol rate of 1,49 Msps (1,7 MHz channel grid, mode 2, compliant to EU 147 spectrum mask, frame length 432 ms).

The selection of the symbol rates has been made according to the following formulas providing means to avoid padding on the IPL-SC and to achieve maximum bandwidth occupation within the given frequency constraints:

For mode 1, the symbol rate has been derived as follows:

$$f_{\text{Symbol}} \text{ (kHz)} = (\text{nCUperFrame} / \text{modIndex}) \times 44 / 9;$$

$$\text{with nCUperFrame} = 18 \times \text{floor}(\text{BW} / (1 + \alpha) / 88) \times \text{modIndex} \text{ (BW denoted in kHz)}.$$

Achievable symbol rates in mode 1 have a granularity (step size) of 88 ksps. The smallest symbol rate that needs to be provided if mode 1 is supported is 3 080 ksps, the largest symbol rate for mode 1 is 11 968 ksps.

For mode 2, the symbol rate has been derived as follows:

$$f_{\text{Symbol}} \text{ (kHz)} = (\text{nCUperFrame} / \text{modIndex}) \times 5;$$

$$\text{with nCUperFrame} = \text{floor}(\text{BW} / (1 + \alpha) / 5) \times \text{modIndex} \text{ (BW denoted in kHz)}.$$

Achievable symbol rates in mode 2 have a granularity (step size) of 5 ksps. The smallest symbol rate that needs to be provided if mode 2 is supported is 1 000 ksps, the largest symbol rate is 3 000 ksps.

5.1 Example 1: profile IPL-SC-A: symbol rate of 4,31 Msps

To comply with profile IPL-SC-A, mode 1 must be supported due to the usage of a symbol rate larger than 3 Msps. This example has been designed to work in a channelization of 5 MHz. All three modulation orders (i.e. QPSK, 8PSK and 16APSK) are mandatory. The frame length is 432 ms.

Table 5: Parameters derived for profile IPL-SC-A with a symbol rate of 4,31 Msps and frame length of 432 ms

Parameter description	Parameter symbol	unit	QPSK	8PSK	16APSK
			mandatory	mandatory	mandatory
symbol rate	fSymbol	kHz	4 312	4 312	4 312
roll-off factor	a	percent	15	15	15
occupied bandwidth	BW	kHz	4 959	4 959	4 959
modulation index	modIndex		2	3	4
IPL-SC frame length	tFrame	ms	432	432	432
symbols per IPL-SC frame	nSymbolsPerFrame		1 862 784	1 862 784	1 862 784
CU length	CULength	bit	2 064	2 064	2 064
preamble length	PreaLength	bit	96	144	192
Phy section length	PhySecLength	bit	4 224	6 336	8 448
symbols per Phy section	nSymbolsPerPhySection		2 112	2 112	2 112
padding symbols per IPL-SC frame	nPaddingSymbolsPerFrame		0	0	0
padding bits per IPL-SC frame	nPaddingBitsPerFrame		0	0	0
CU per frame	nCUPerFrame		1 764	2 646	3 528
preamble overhead		percent	2,27	2,27	2,27
preamble distance		ms	0,49	0,49	0,49
preamble repetition rate		Hz	2 041	2 041	2 041

5.2 Example 2: profile IPL-SC-A: symbol rate of 10,87 Msps

To comply with profile IPL-SC-A, mode 1 must be supported due to the usage of a symbol rate larger than 3 Msps. This example has been designed to work in a channelization of 12,5 MHz. All three modulation orders (i.e. QPSK, 8PSK and 16APSK) are mandatory. The frame length is 432 ms.

Table 6: Parameters derived for profile IPL-SC-A with a symbol rate of 10,87 Msps and frame length of 432 ms

Parameter description	Parameter symbol	unit	QPSK	8PSK	16APSK
			mandatory	mandatory	mandatory
symbol rate	fSymbol	kHz	10 868	10 868	10 868
roll-off factor	a	percent	15	15	15
occupied bandwidth	BW	kHz	12 498	12 498	12 498
modulation index	modIndex		2	3	4
IPL-SC frame length	tFrame	ms	432	432	432
symbols per IPL-SC frame	nSymbolsPerFrame		4 694 976	4 694 976	4 694 976
CU length	CULength	bit	2 064	2 064	2 064
preamble length	PreaLength	bit	96	144	192
Phy section length	PhySecLength	bit	4 224	6 336	8 448
symbols per Phy section	nSymbolsPerPhySection		2 112	2 112	2 112
padding symbols per IPL-SC frame	nPaddingSymbolsPerFrame		0	0	0
padding bits per IPL-SC frame	nPaddingBitsPerFrame		0	0	0
CU per frame	nCUPerFrame		4 446	6 669	8 892
preamble overhead		percent	2,27	2,27	2,27
preamble distance		ms	0,19	0,19	0,19
preamble repetition rate		Hz	5 263	5 263	5 263

5.3 Example 3: profile IPL-SC-B: symbol rate of 1,84 Msps

To comply with profile IPL-SC-B, mode 2 must be supported due to the usage of a symbol rate smaller than 3 Msps. This example has been designed to work with a fixed symbol rate of 1,84 MHz. Only the two lower modulation orders (i.e. QPSK and 8PSK) are mandatory whereas 16APSK may be included as an option.

Table 7: Parameters derived for profile IPL-SC-B with a symbol rate of 1,84 Msps

Parameter description	Parameter symbol	unit	QPSK	8PSK	16APSK
			mandatory	mandatory	optional
symbol rate	fSymbol	kHz	1 840	1 840	1 840
roll-off factor	a	percent	15	15	15
occupied bandwidth	BW	kHz	2 116	2 116	2 116
modulation index	modIndex		2	3	4
IPL-SC frame length	tFrame	ms	432	432	432
symbols per IPL-SC frame	nSymbolsPerFrame		794 880	794 880	794 880
CU length	CULength	bit	2 064	2 064	2 064
preamble length	PreaLength	bit	96	96	96
Phy section length	PhySecLength	bit	2 160	2 160	2 160
symbols per Phy section	nSymbolsPerPhySection		1 080	720	540
padding symbols per IPL-SC frame	nPaddingSymbolsPerFrame		0	0	0
padding bits per IPL-SC frame	nPaddingBitsPerFrame		0	0	0
CU per frame	nCUPerFrame		736	1 104	1 472
preamble overhead		percent	4,44	4,44	4,44
preamble distance		ms	0,59	0,39	0,29
preamble repetition rate		Hz	1 695	2 564	3 448

5.4 Example 4: profile IPL-SC-B: symbol rate of 1,49 Msps

To comply with profile IPL-SC-B, mode 2 must be supported due to the usage of a symbol rate smaller than 3 Msps. This example has been designed to work in a channelization of 1,7 MHz, derived from spectrum constraints as described in EU 147. Only the two lower modulation orders (i.e. QPSK and 8PSK) are mandatory whereas 16APSK may be included as an option.

Table 8: Parameters derived for profile IPL-SC-B with a symbol rate of 1,49 Msps

Parameter description	Parameter symbol	unit	QPSK	8PSK	16APSK
			mandatory	mandatory	optional
symbol rate	fSymbol	kHz	1 485	1 485	1 485
roll-off factor	a	percent	15	15	15
occupied bandwidth	BW	kHz	1 708	1 708	1 708
modulation index	modIndex		2	3	4
IPL-SC frame length	tFrame	ms	432	432	432
symbols per IPL-SC frame	nSymbolsPerFrame		641 520	641 520	641 520
CU length	CULength	bit	2 064	2 064	2 064
preamble length	PreaLength	bit	96	96	96
Phy section length	PhySecLength	bit	2 160	2 160	2 160
symbols per Phy section	nSymbolsPerPhySection		1 080	720	540
padding symbols per IPL-SC frame	nPaddingSymbolsPerFrame		0	0	0
padding bits per IPL-SC frame	nPaddingBitsPerFrame		0	0	0
CU per frame	nCUPerFrame		594	891	1 188
preamble overhead		percent	4,44	4,44	4,44
preamble distance		ms	0,73	0,48	0,36
preamble repetition rate		Hz	1 370	2 083	2 778

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