
**Information technology — MPEG
audio technologies —**

**Part 3:
Unified speech and audio coding**

*Technologies de l'information — Technologies audio MPEG —
Partie 3: Codage unifié parole et audio*



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Contents

Page

Foreword.....	vii
Introduction.....	viii
1 Scope.....	1
2 Normative references.....	1
3 Terms, definitions, symbols and abbreviated terms	1
3.1 Terms and definitions	1
3.2 Symbols and abbreviated terms.....	3
4 Technical overview	4
4.1 Decoder block diagram.....	4
4.2 Overview of the decoder tools.....	5
4.3 Combination of USAC with MPEG Surround and SAOC.....	9
4.4 Interface between USAC and systems.....	9
4.4.1 Decoder behaviour	10
4.5 USAC profiles and levels	10
4.5.1 General.....	10
4.5.2 MPEG-4 HE AACv2 compatibility	11
4.5.3 Baseline USAC profile	12
4.5.4 Extended high efficiency AAC profile.....	13
4.6 Combination of USAC with MPEG-D DRC	14
5 Syntax	15
5.1 General.....	15
5.2 Decoder configuration (UsacConfig).....	15
5.3 USAC bitstream payloads	20
5.3.1 Payloads for audio object type USAC	20
5.3.2 Subsidiary payloads.....	23
5.3.3 Payloads for enhanced SBR.....	34
5.3.4 Payloads for MPEG Surround.....	43
5.3.5 Payload of extension elements.....	53
6 Data structure	53
6.1 USAC configuration.....	53
6.1.1 Definition of elements.....	53
6.1.2 UsacConfig()	63
6.1.3 Usac Output Sampling Frequency	63
6.1.4 UsacChannelConfig()	63
6.1.5 UsacDecoderConfig()	64
6.1.6 UsacSingleChannelElementConfig().....	64
6.1.7 UsacChannelPairElementConfig()	64
6.1.8 UsacLfeElementConfig()	64
6.1.9 UsacCoreConfig().....	64
6.1.10 SbrConfig()	65
6.1.11 SbrDfltHeader()	65
6.1.12 Mps212Config()	65
6.1.13 UsacExtElementConfig().....	65
6.1.14 UsacConfigExtension()	65
6.1.15 Unique stream identifier (Stream ID)	66
6.2 USAC payload.....	66
6.2.1 Definition of elements.....	66
6.2.2 UsacFrame().....	68
6.2.3 UsacSingleChannelElement()	69
6.2.4 UsacExtElement().....	69
6.2.5 UsacChannelPairElement()	70
6.2.6 Low frequency enhancement (LFE) channel element, UsacLfeElement()	70
6.2.7 UsacCoreCoderData()	71

6.2.8	StereoCoreToolInfo()	71
6.2.9	fd_channel_stream() and ics_info()	72
6.2.10	lpd_channel_stream()	76
6.2.11	Spectral noiseless coder	79
6.2.12	Enhanced SBR	80
6.2.13	Definition of MPEG Surround 2-1-2 payloads	82
6.2.14	Buffer requirements	84
7	Tool descriptions	85
7.1	Quantization	85
7.1.1	Tool description	85
7.1.2	Definition of elements	85
7.1.3	Decoding process	85
7.2	Noise filling	85
7.2.1	Tool description	85
7.2.2	Definition of elements	86
7.2.3	Decoding process	86
7.2.4	Generation of random signs for spectral noise filling	87
7.3	Scale factors	87
7.4	Spectral noiseless coding	87
7.4.1	Tool description	87
7.4.2	Definition of elements	88
7.4.3	Decoding process	89
7.5	enhanced SBR tool (eSBR)	93
7.5.1	Modifications to SBR tool	93
7.5.2	Additional pre-processing in the MPEG-4 SBR within USAC	108
7.5.3	DFT based harmonic transposer	110
7.5.4	QMF based harmonic transposer	120
7.5.5	4:1 Structure for SBR in USAC	128
7.5.6	Predictive vector coding (PVC) decoding process	138
7.6	Inter-subband-sample temporal envelope shaping (inter-TES)	141
7.6.1	Tool Description	141
7.6.2	Definition of elements	142
7.6.3	Inter-TES	142
7.7	Joint stereo coding	144
7.7.1	M/S stereo	144
7.7.2	Complex stereo prediction	144
7.8	TNS	151
7.8.1	General	151
7.8.2	Definition of elements	151
7.8.3	Decoding process	152
7.8.4	Maximum TNS bandwidth	152
7.9	Filterbank and block switching	153
7.9.1	Tool description	153
7.9.2	Definition of elements	153
7.9.3	Decoding process	153
7.10	Time-warped filterbank and blockswitching	161
7.10.1	Tools description	161
7.10.2	Definition of elements	161
7.10.3	Decoding process	163
7.11	MPEG Surround for mono to stereo upmixing	169
7.11.1	Tool description	169
7.11.2	Decoding process	170
7.12	AVQ decoding	182
7.13	LPC-filter	189
7.13.1	Tool description	189
7.13.2	Definition of elements	189
7.13.3	Number of LPC filters	189
7.13.4	General principle of the inverse quantizer	189
7.13.5	Decoding of the LPC quantization mode	190

7.13.6	First-stage approximation	191
7.13.7	AVQ refinement	191
7.13.8	Reordering of quantized LSFs	193
7.13.9	Conversion into LSP parameters	193
7.13.10	Interpolation of LSP parameters	194
7.13.11	LSP to LP conversion	194
7.13.12	LPC initialization at decoder start-up	195
7.14	ACELP	196
7.14.1	General	196
7.14.2	Definition of elements	196
7.14.3	ACELP initialization at USAC decoder start-up	197
7.14.4	Setting of the ACELP excitation buffer using the past FD synthesis and LPC0	197
7.14.5	Decoding of CELP excitation	197
7.14.6	Excitation postprocessing	203
7.14.7	Synthesis	204
7.14.8	Writing in the output buffer	204
7.15	MDCT based TCX	205
7.15.1	Tool description	205
7.15.2	Decoding process	205
7.16	Forward aliasing cancellation (FAC) tool	209
7.16.1	Tool description	209
7.16.2	Definition of elements	209
7.16.3	Decoding process	210
7.16.4	Writing in the output buffer	211
7.17	Post-processing of the synthesis signal	212
7.18	Audio pre-roll	214
7.18.1	General	214
7.18.2	Semantics	214
7.18.3	Decoding process	215
8	Conformance testing	217
8.1	General	217
8.2	USAC conformance testing	217
8.2.1	Profiles	217
8.2.2	Conformance tools and test procedure	218
8.3	USAC bitstreams	222
8.3.1	General	222
8.3.2	USAC configuration	222
8.3.3	Framework	225
8.3.4	Frequency domain coding (FD mode)	226
8.3.5	Linear predictive domain coding (LPD mode)	228
8.3.6	Common core coding tools	229
8.3.7	Enhanced spectral band replication (eSBR)	230
8.3.8	eSBR – Predictive vector coding (PVC)	232
8.3.9	eSBR – Inter temporal envelope shaping (inter-TES)	233
8.3.10	MPEG Surround 2-1-2	233
8.3.11	Configuration Extensions	235
8.3.12	AudioPreRoll	235
8.3.13	DRC	236
8.3.14	Restrictions depending on profiles and levels	236
8.4	USAC decoders	238
8.4.1	General	238
8.4.2	FD core mode tests	238
8.4.3	LPD core mode tests	245
8.4.4	Combined core coding tests	250
8.4.5	eSBR tests	251
8.4.6	MPEG Surround 212 tests	260
8.4.7	Bitstream extensions	262
8.5	Decoder settings	265
8.5.1	General	265

8.5.2	Target loudness [Lou-<x>]	265
8.5.3	DRC effect type request [Eff-<x>]	265
8.6	Decoding of MPEG-4 file format parameters to support exact time alignment in file-to-file coding	265
9	Reference software	266
9.1	Reference software structure	266
9.1.1	General	266
9.1.2	Copyright disclaimer for software modules	266
9.2	Bitstream decoding software	268
9.2.1	General	268
9.2.2	USAC decoding software	268
Annex A (normative)	Tables	269
Annex B (informative)	Encoder tools	274
Annex C (normative)	Tables for arithmetic decoder	314
Annex D (normative)	Tables for predictive vector coding	320
Annex E (informative)	Adaptive time/frequency post-processing	329
Annex F (informative)	Audio/systems interaction	335
Annex G (informative)	Reference software	337
Annex H (normative)	Carriage of MPEG-D USAC in ISO base media file format	338
Bibliography		339

Foreword

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Introduction

As mobile appliances become multi-functional, multiple devices converge into a single device. Typically, a wide variety of multimedia content is required to be played on or streamed to these mobile devices, including audio data that consists of a mix of speech and music.

This document specifies unified speech and audio coding (USAC), which allows for coding of speech, audio or any mixture of speech and audio with a consistent audio quality for all sound material over a wide range of bitrates. It supports single and multi-channel coding at high bitrates and provides perceptually transparent quality. At the same time, it enables very efficient coding at very low bitrates while retaining the full audio bandwidth.

Where previous audio codecs had specific strengths in coding either speech or audio content, USAC is able to encode all content equally well, regardless of the content type.

In order to achieve equally good quality for coding audio and speech, the developers of USAC employed the proven MDCT-based transform coding techniques known from MPEG-4 audio and combined them with specialized speech coder elements like ACELP. Parametric coding tools such as MPEG-4 spectral band replication (SBR) and MPEG-D MPEG surround were enhanced and tightly integrated into the codec. The result delivers highly efficient coding and operates down to the lowest bit rates.

The main focus of this codec are applications in the field of typical broadcast scenarios, multimedia download to mobile devices, user-generated content such as podcasts, digital radio, mobile TV, audio books, etc.

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Information technology — MPEG audio technologies —

Part 3: Unified speech and audio coding

1 Scope

This document specifies a unified speech and audio codec which is capable of coding signals having an arbitrary mix of speech and audio content. The codec has a performance comparable to, or better than, the best known coding technology that might be tailored specifically to coding of either speech or general audio content. The codec supports single and multi-channel coding at high bitrates and provides perceptually transparent quality. At the same time, it enables very efficient coding at very low bitrates while retaining the full audio bandwidth.

This document incorporates several perceptually-based compression techniques developed in previous MPEG standards: perceptually shaped quantization noise, parametric coding of the upper spectrum region and parametric coding of the stereo sound stage. However, it combines these well-known perceptual techniques with a source coding technique: a model of sound production, specifically that of human speech.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 14496-3:2019, *Information technology — Coding of audio-visual objects — Part 3: Audio*

ISO/IEC 14496-26:2010, *Information technology — Coding of audio-visual objects — Part 26: Audio conformance*

ISO/IEC 23003-1, *Information technology — MPEG audio technologies — Part 1: MPEG Surround*

ISO/IEC 23003-4, *Information technology — MPEG audio technologies — Part 4: Dynamic range control*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 14496-3, ISO/IEC 23003-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1.1

algebraic codebook

fixed codebook where an algebraic code is used to populate the excitation vectors (innovation vectors)

Note 1 to entry: The excitation contains a small number of nonzero pulses with predefined interlaced sets of potential positions. The amplitudes and positions of the pulses of the k^{th} excitation codevector can be derived from its index k through a rule requiring no or minimal physical storage, in contrast with stochastic codebooks whereby the path from the index to the associated codevector involves look-up tables.

3.1.2

algebraic vector quantizer

AVQ

process associating, to an input block of 8 coefficients, the nearest neighbour from an 8-dimensional lattice and a set of binary indices to represent the selected lattice point

Note 1 to entry: This definition describes the encoder. At the decoder, AVQ describes the process to obtain, from the received set of binary indices, the 8-dimensional lattice point that was selected at the encoder.

3.1.3

closed-loop pitch

result of the adaptive codebook search, a process of estimating the pitch (lag) value from the weighted input speech and the long-term filter state

Note 1 to entry: In the closed-loop search, the lag is searched using error minimization loop (analysis-by-synthesis). In USAC, closed-loop pitch search is performed for every subframe.

3.1.4

fractional pitch

set of pitch lag values having sub-sample resolution

Note 1 to entry: In the LPD USAC, a sub-sample resolution of $1/4^{\text{th}}$ or $1/2^{\text{nd}}$ of a sample is used.

3.1.5

zero-input response

ZIR

output of a filter due to past inputs, i.e., due to the present state of the filter, given that an input of zeros is applied

3.1.6

immediate play-out frame

IPF

audio frame that contains an extension payload of type ID_EXT_ELE_AUDIOPREROLL

Note 1 to entry: The extension payload shall contain a Config() element as defined in 7.18, i.e., configLen > 0. It should also contain an adequate number of audio pre-roll frames, i.e., numPreRollFrames > 0, for pre-rolling the audio decoder.

3.1.7

independently decodable frame

IF

audio frame in which the bitstream element usacIndependencyFlag has a value of 1

3.1.8

bitstream

encoded audio data

3.1.9

conformance data

conformance test sequences and conformance tools

3.1.10

conformance tool

tool to check certain conformance criteria

3.1.11**conformance test sequence**

conformance test bitstreams and corresponding reference waveforms

3.1.12**conformance test bitstream**

USAC bitstream used for testing the conformance of a USAC decoder

3.1.13**conformance test condition**

condition which applies to properties of a conformance test bitstream in order to test a certain functionality of the USAC decoder

3.1.14**conformance test case**

combination of one or more conformance test conditions for which a set of conformance test sequences is provided

3.1.15**main audio channel**

audio channel conveyed by means of a `UsacSingleChannelElement` or `UsacChannelPairElement`

3.1.16**reference waveform**

decoded counterpart of a bitstream

3.1.17**USAC bitstream**

data encoded according to this document

3.2 Symbols and abbreviated terms

For the purposes of this document, the symbols and abbreviated terms given in ISO/IEC 14496-3 and the following apply.

ACELP algebraic code-excited linear predictor

PVC predictive vector coding

uclbf unary code, left bit first

NOTE "left bit first" refers to the order in which the unary codes are received. The value is encoded using a conventional unary code, where any decimal value d is represented by d '1' bits followed by one '0' stop-bit.

USAC unified speech and audio coding

UsacCPE `UsacChannelPairElement`

UsacEXT `UsacExtElement`

UsacLFE `UsacLfeElement`

UsacSCE `UsacSingleChannelElement`

$v[] = \{a\}$ This expression indicates that all elements of the array v shall be set to the value a .

4 Technical overview

4.1 Decoder block diagram

The block diagram of the USAC decoder as shown in Figure 1 reflects the general structure of MPEG-D USAC which can be described as follows (from bottom to top): There is a common pre/postprocessing stage consisting of an MPEG Surround functional unit to handle stereo processing (MPS212) and an enhanced SBR (eSBR) unit which handles the parametric representation of the higher audio frequencies in the input signal. Then there are two branches, one consisting of a modified advanced audio coding (AAC) tool path (frequency domain, "FD") and the other consisting of a linear prediction coding (LP or LPC domain, "LPD") based path. The latter can use either a frequency domain representation or a time domain representation of the LPC residual. All transmitted spectra for both FD and LPD path are represented in MDCT domain. The quantized spectral coefficients are coded using a context adaptive arithmetic coder. The time domain representation uses an ACELP excitation coding scheme.

In case of transmitted spectral information, the decoder shall reconstruct the quantized spectra, process the reconstructed spectra through whatever tools are active in the bitstream payload in order to arrive at the actual signal spectra as described by the input bitstream payload, and finally convert the frequency domain spectra to the time domain. Following the initial reconstruction and scaling of the spectrum, there are optional tools that modify one or more of the spectra in order to provide more efficient coding.

In case of transmitted time domain signal representation, the decoder shall reconstruct the quantized time signal, process the reconstructed time signal through whatever tools are active in the bitstream payload in order to arrive at the actual time domain signal as described by the input bitstream payload.

For each of the optional tools that operate on the signal data, the option to "pass through" is retained, and in all cases where the processing is omitted, the spectra or time samples at its input are passed directly through the tool without modification.

In places where the bitstream changes its signal representation from time domain to frequency domain representation or from LP domain to non-LP domain or vice versa, the decoder shall facilitate the transition from one domain to the other by means of an appropriate transition mechanism.

eSBR and MPS212 processing is applied in the same manner to both coding paths after transition handling.

The USAC specification offers in some instances multiple decoding options that serve to provide different quality/complexity trade-offs.

NOTE An informative overview of encoder tools is given by Annex B.

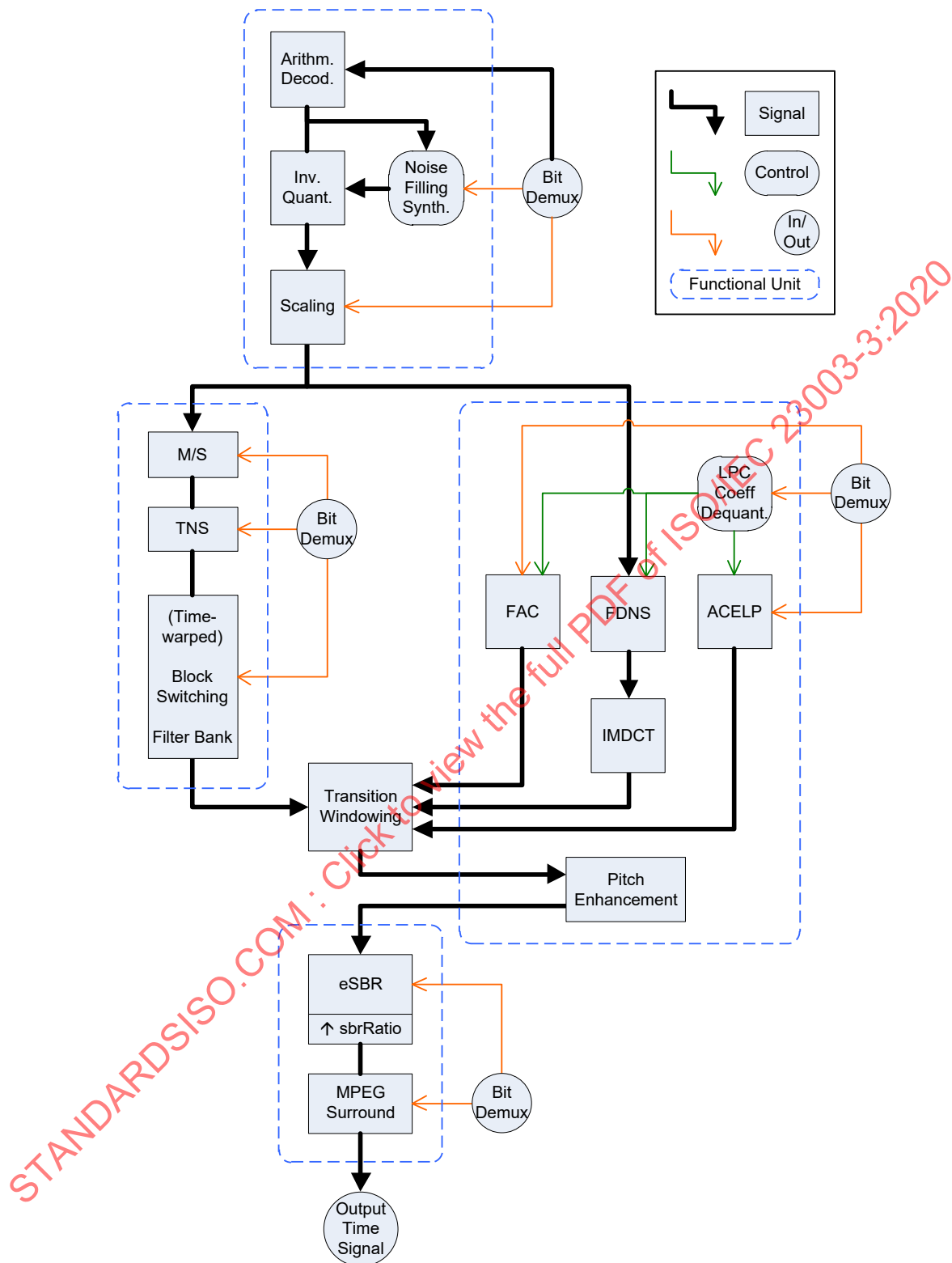


Figure 1 — Simplified block diagram of the typical USAC decoder configuration

4.2 Overview of the decoder tools

The input to the bitstream payload demultiplexer tool is the MPEG-D USAC bitstream payload. The demultiplexer separates the bitstream payload into the parts for each tool, and provides each of the tools with the bitstream payload information related to that tool.

The outputs from the bitstream payload demultiplexer tool are:

- depending on the core coding type in the current frame, either:
 - the quantized and noiselessly coded spectra represented by:
 - scalefactor information;
 - arithmetically coded spectral lines;
 - or: linear prediction (LP) parameters together with an excitation signal represented by either:
 - quantized and arithmetically coded spectral lines (transform coded excitation, TCX) or;
 - ACELP coded time domain excitation;
- the spectral noise filling information (optional);
- the M/S decision information (optional);
- the temporal noise shaping (TNS) information (optional);
- the filterbank control information;
- the time unwarping (TW) control information (optional);
- the enhanced spectral bandwidth replication (eSBR) control information (optional);
- the MPEG Surround 2-1-2 (MPS212) control information (optional).

The scalefactor noiseless decoding tool takes information from the bitstream payload demultiplexer, parses that information, and decodes the Huffman and DPCM coded scalefactors.

The input to the scalefactor noiseless decoding tool is:

- the scalefactor information for the noiselessly coded spectra.

The output of the scalefactor noiseless decoding tool is:

- the decoded integer representation of the scalefactors.

The context adaptive arithmetic decoding tool performs the spectral noiseless decoding step. It takes information from the bitstream payload demultiplexer, parses that information, decodes the context adaptive arithmetically coded data, and reconstructs the quantized spectra.

The input to this noiseless decoding tool is:

- the noiselessly coded spectra.

The output of this noiseless decoding tool is:

- the quantized values of the spectra.

The inverse quantizer tool takes the quantized values for the spectra, and converts the integer values to the non-scaled, reconstructed spectra. This quantizer is a companding quantizer, whose companding factor depends on the chosen core coding mode.

The input to the inverse quantizer tool is:

- the quantized values for the spectra.

The output of the inverse quantizer tool is:

- the un-scaled, inversely quantized spectra.

The noise filling tool is used to fill spectral gaps in the decoded spectra, which occur when spectral value are quantized to zero, e.g., due to a strong restriction on bit demand in the encoder.

The inputs to the noise filling tool are:

- the un-scaled, inversely quantized spectra;
- noise filling parameters;
- the decoded integer representation of the scalefactors.

The outputs to the noise filling tool are:

- the un-scaled, inversely quantized spectral values for spectral lines which were previously quantized to zero;
- modified integer representation of the scalefactors.

The rescaling tool converts the integer representation of the scalefactors to the actual values, and multiplies the un-scaled inversely quantized spectra by the relevant scalefactors.

The inputs to the scalefactors tool are:

- the decoded integer representation of the scalefactors;
- the un-scaled, inversely quantized spectra.

The output from the scalefactors tool is:

- the scaled, inversely quantized spectra.

For an overview over the M/S tool, refer to ISO/IEC 14496-3:2019, 4.1.1.2.

For an overview over the temporal noise shaping (TNS) tool, refer to ISO/IEC 14496-3:2019, 4.1.1.2.

The filterbank/block switching tool applies the inverse of the frequency mapping that was carried out in the encoder. An inverse modified discrete cosine transform (IMDCT) is used for the filterbank tool. The IMDCT can be configured to support 96, 128, 192, 256, 384, 512, 768, or 1024 spectral coefficients.

The inputs to the filterbank tool are:

- the (inversely quantized) spectra;
- the filterbank control information.

The output(s) from the filterbank tool is (are):

- the time domain reconstructed audio signal(s).

The time-warped filterbank/block switching tool replaces the normal filterbank/block switching tool when the time warping mode is enabled. The filterbank is the same (IMDCT) as for the normal filterbank, but in addition the windowed time domain samples are mapped from the warped time domain to the linear time domain by time-varying resampling.

The inputs to the time-warped filterbank tools are:

- the inversely quantized spectra;
- the filterbank control information;
- the time-warping control information.

The output(s) from the filterbank tool is (are):

- the linear time domain reconstructed audio signal(s).

The enhanced SBR (eSBR) tool regenerates the highband of the audio signal. It is based on replication of the sequences of harmonics, truncated during encoding. It adjusts the spectral envelope of the generated high-band and applies inverse filtering, and adds noise and sinusoidal components in order to recreate the spectral characteristics of the original signal.

The input to the eSBR tool is:

- the quantized envelope data;
- control data;
- a time domain signal from the frequency domain core decoder or the ACELP/TCX core decoder.

The output of the eSBR tool is either:

- a time domain signal or;
- a QMF-domain representation of a signal, e.g., in case MPS212 is used.

The MPEG Surround 2-1-2 (MPS212) tool produces multiple signals from one input signal by applying a sophisticated upmix procedure to the input signal controlled by appropriate spatial parameters. In the USAC context MPS212 is used for coding a stereo signal, by transmitting parametric side information alongside a transmitted downmixed signal.

The input to the MPS212 tool is:

- a downmixed time domain signal or;
- a QMF-domain representation of a downmixed signal from the eSBR tool.

The output of the MPS212 tool is:

- a two-channel time domain signal.

The ACELP tool provides a way to efficiently represent a time domain excitation signal by combining a long term predictor (adaptive codebook codeword) with a pulse-like sequence (innovation codebook codeword). The reconstructed excitation is sent through an LP synthesis filter to form a time domain signal.

The input to the ACELP tool is:

- adaptive and innovation codebook indices;

- adaptive and innovation codes gain values;
- other control data;
- inversely quantized and interpolated LPC filter coefficients.

The output of the ACELP tool is:

- the time domain reconstructed audio signal.

The MDCT based TCX decoding tool is used to turn the weighted LP residual representation from an MDCT-domain back to the time domain and outputs a time domain signal in which weighted LP synthesis filtering has been applied. The IMDCT can be configured to support 256, 512, or 1024 spectral coefficients.

The input to the TCX tool is:

- the (inversely quantized) MDCT spectra;
- inversely quantized and interpolated LPC filter coefficients.

The output of the TCX tool is:

- the time domain reconstructed audio signal.

4.3 Combination of USAC with MPEG Surround and SAOC

The output of the USAC decoder can be further processed by MPEG Surround (MPS) (ISO/IEC 23003-1) or spatial audio object coding (SAOC) (ISO/IEC 23003-2). If the SBR tool in USAC is active, a USAC decoder can typically be efficiently combined with a subsequent MPS/SAOC decoder by connecting them in the QMF domain in the same way as it is described for HE-AAC in ISO/IEC 23003-1:2007, 4.4. If a connection in the QMF domain is not possible, they need to be connected in the time domain.

If MPS/SAOC side information is embedded into a USAC bitstream by means of the `usacExtElement` mechanism (with `usacExtElementType` being `ID_EXT_ELE_MPEGS` or `ID_EXT_ELE_SAOC`), the time-alignment between the USAC data and the MPS/SAOC data assumes the most efficient connection between the USAC decoder and the MPS/SAOC decoder. If the SBR tool in USAC is active and if MPS/SAOC employs a 64 band QMF domain representation (see ISO/IEC 23003-1:2007, 6.6.3), the most efficient connection is in the QMF domain. Otherwise, the most efficient connection is in the time domain. This corresponds to the time-alignment for the combination of HE-AAC and MPS as defined in ISO/IEC 23003-1:2007, 4.4, 4.5, and 7.2.1.

The additional delay introduced by adding MPS decoding after USAC decoding is given by ISO/IEC 23003-1:2007, 4.5 and depends on whether HQ MPS or LP MPS is used, and whether MPS is connected to USAC in the QMF domain or in the time domain.

4.4 Interface between USAC and systems

This subclause clarifies the interface between USAC and MPEG systems. Every access unit delivered to the audio decoder from the systems interface shall result in a corresponding composition unit delivered from the audio decoder to the systems interface, i.e., the compositor. This shall include start-up and shut-down conditions, i.e., when the access unit is the first or the last in a finite sequence of access units.

For an audio composition unit, the ISO/IEC 14496-1:2010, 7.1.3.5 composition time stamp (CTS) specifies that the composition time applies to the n -th audio sample within the composition unit. For USAC, the value of n is always 1. Note that this applies to the output of the USAC decoder itself. In the case that a USAC decoder is, for example, being combined with an MPS decoder as described in 4.3, the additional delay caused by the MPS decoding process (see 4.3 and ISO/IEC 23003-1:2007, 4.5) needs to be taken into account for the composition units delivered at the output of the MPS decoder.

4.4.1 Decoder behaviour

4.4.1.1 General decoding process

The decoder shall operate in such a way that the decoding of one access unit shall always and immediately produce one full composition unit of audio signal data (one audio frame with outputFrameLength number of samples).

The decoder shall not discard any audio samples. In particular the decoder shall make no assumptions about encoder delay and shall also not attempt to compensate assumed encoder processing delay by removing audio samples from the composition unit buffer.

Discarding of audio samples due to the presence of an EditListBox as described in Annex F is not part of the normative USAC decoder but shall be applied by the MPEG-4 systems infrastructure.

4.4.1.2 Initialization and re-initialization of the USAC decoder

Upon (re-)initialization, all decoder internal signal buffers shall be set to zero.

Due to the initialized state of the decoder internal buffers, the decoder output may contain "start-up samples" when decoding the first access units of a given compressed data stream.

These start-up samples are samples that do not have a direct relation to the audio input data and are typically zero-valued and may be discarded by the systems infrastructure.

The number of start-up samples to be discarded may for example be transmitted by means of the media_time field in the EditListbox in an ISO base media file format environment. Note that this shall be done by the encoder.

If a given USAC decoder implementation produces more than the minimum number of start-up samples (i.e., it creates additional decoder delay), the number of additional samples shall be reported by the decoder to the systems infrastructure. Systems infrastructure shall then correctly apply delay compensation or time-alignment.

4.4.1.3 Decoding process of access unit with audio pre-roll

The decoding process of access units with embedded audio pre-roll frames is identical to the above description.

The presence of audio pre-roll in the first access unit prepares the decoder internal signal buffers. This allows an encoder to produce a compressed data stream, that will cause the decoder output buffer to contain less or no start-up samples.

The decoding description when changing from one configuration to another while employing audio pre-roll is described in 7.18.3.3.

If a given decoder implementation produces additional start-up samples (additional decoder delay), then the flushing of the old configuration (FlushDecoder()) shall be increased by the same amount of samples. The signal crossfade shall be delayed accordingly. The decoder shall ensure that the number of additional start-up samples (additional decoder delay) does not change when switching to another stream in the adaptation set.

4.5 USAC profiles and levels

4.5.1 General

This subclause defines profiles and their levels for unified speech and audio coding.

Complexity units are defined to give an approximation of the decoder complexity in terms of processing power and RAM usage required for the decoding process. The approximated processing power is given in "processor complexity units" (PCU), specified in MOPS. The approximated RAM usage is given in "RAM complexity units" (RCU), specified in kWords (1000 words).

4.5.2 MPEG-4 HE AACv2 compatibility

Large parts of the USAC codec are inherited from the codec tools and structure subsumed in the MPEG-4 HE AAC v2 profile. A few of these tools have been adopted into USAC as is. Many more have been adopted into USAC and greatly enhanced in terms of performance, capability and flexibility. Others were substituted with tools which provide a range of advantages over their MPEG-4 counterparts. As a result, USAC retains all *functionalities and performance features* that the AAC family of technologies – AAC, HE AAC, HE AAC v2 – can provide. However, it does not adopt all *tools*.

If a decoder is intended to provide full AAC family functionality, including the legacy MPEG-4 AAC tools, all coding tools listed in Table 1 shall be considered.

The following tools listed in Table 1 are normatively referenced in USAC:

Table 1 — Summary of the location of and normative reference to the definitions of all AAC, HE-AAC and USAC coding tools as employed in the extended high efficiency AAC profile

Module	Tool	defined in ISO/IEC	subclause	USAC	AAC LC	SBR	PS
block switching	block switching	14496-3	4.6.14	X	X		
window shapes	AAC based	14496-3	4.6.11	X	X		
	additional USAC	23003-3	6.2.9.3	X			
filter bank	AAC based	14496-3	4.6.11	X	X		
	additional USAC	23003-3	7.9	X			
TNS	TNS	14496-3	4.6.9	X	X		
intensity/ coupling	intensity	14496-3	4.6.8.2	^a	X		
	coupling	14496-3	4.6.8.3		X		
perceptual noise synthesis	PNS	14496-3	4.6.13	^b	X		
	noise filling	23003-3	7.2	X			
MS	basic mid/side coding	14496-3	4.6.8.1	X	X		
	MDCT-based complex prediction	23003-3	7.7.2	X			
quantization	non-uniform	14496-3	4.6.1	X	X		
	uniform	23003-3	7.1	X			
spectral noiseless coding	Huffman	14496-3	4.6.3	^c	X		
	context adaptive arithmetic coding	23003-3	7.4	X			
SBR	base	14496-3	4.6.18	X		X	X
	enhanced	23003-3	7.5	X			
parametric stereo extension	parametric stereo	14496-3	8.6.4/8.A	^d			X
	MPEG Surround 2-1-2 (incl. residual coding)	23003-3	6.2.13	X			
ACELP	ACELP	23003-3	7.14	X			
frequency domain noise shaping	scale factor based	14496-3	4.6.2	X	X		
	LPC based (as part of MDCT based TCX)	23003-3	7.15	X			
^a Functionality of the AAC LC intensity tool is fully provided by the MDCT-based complex prediction tool of USAC. ^b Functionality of the PNS tool is largely provided by the noise filling tool of USAC. ^c Functionality of the AAC LC Huffman coding tool is fully provided by the context adaptive arithmetic coding tool of USAC. ^d Functionality of the parametric stereo tool is fully provided by the MPEG Surround 2-1-2 tool of USAC.							

4.5.3 Baseline USAC profile

In the baseline USAC profile the following coding tools shall not be employed:

- time warped filterbank;
- DFT based harmonic transposer in enhanced spectral band replication;
- fractional delay decorrelator in MPEG Surround for mono to stereo upmixing (MPS212).

Four different hierarchical levels are defined with increasing number of audio channels and increasing complexity. The definition of the four levels of the baseline USAC profile is given in Table 2.

Table 2 — Levels for the baseline USAC profile

Level	Max. channels	Max. sampling rate [kHz]	Max. PCU	Max. RCU
1	1	48	7	6
2	2	48	12	11
3	5.1	48	31	28
4	5.1	96	62	28

Furthermore, restrictions on the sampling rate apply for the USAC baseline profile. The sampling rate signalled as part of the `UsacConfig()` shall be one out of those listed in Table 3. These sampling rates are chosen such that they can conveniently be resampled to 44100 Hz and 48000 Hz, respectively.

Table 3 — Allowed sampling rates for the baseline USAC profile

Sampling rates [Hz] and <code>usacSamplingFrequencyIndex</code>			
88200	0x01	96000	0x00
70560	n/a	76800	n/a
58800	n/a	64000	0x02
44100	0x04	48000	0x03
35280	n/a	38400	0x12
29400	n/a	32000	0x05
22050	0x07	24000	0x06
17640	n/a	19200	0x17
14700	n/a	16000	0x08
11760	n/a	12800	0x1a
11025	0x0a	12000	0x09
8820	n/a	9600	0x1b
7350	0x0c	8000	0x0b

Furthermore the following requirements apply:

- The number of pre-roll frames, `numPreRollFrames`, in an `AudioPreRoll()` extension payload shall not exceed 3.
- Decoders conforming to the baseline USAC profile shall support the full decoding and correct handling of the `AudioPreRoll()` extension.

NOTE The number of pre-roll frames required for seamless operation of the audio codec can be lower than the above mentioned number. See B.26 for encoder implementation guidelines.

4.5.4 Extended high efficiency AAC profile

The extended HE AAC profile contains the audio object types 42 (USAC), 5 (SBR), 29 (PS) and 2 (AAC LC) as defined in ISO/IEC 14496-3. In order for a decoder to support the extended HE AAC profile it shall implement all modules listed in Table 1. For some tools specific restrictions apply as outlined in the following.

The extended HE AAC profile is compatible with the MPEG-4 high efficiency AAC v2 profile as defined in ISO/IEC 14496-3. It warrants decodability of HE AAC v2 profile compliant bitstreams by extended HE AAC profile decoders.

A number of hierarchical levels are defined with increasing number of audio channels and increasing complexity. All levels shall support all tools required by the baseline USAC profile. Support for additional tools is optional. The definition of the levels of the extended HE AAC profile is given in Table 4. All notes in Table 4 and all restrictions listed in the columns 2, 3, 4, and 5 ("Max. channels/object", "Max. AAC sampling rate, SBR not present [kHz]", "Max. AAC sampling rate, SBR present [kHz]", "Max. SBR sampling rate [kHz] (in/out)", of Table 4 apply only when decoding HE AAC v2 profile compliant bitstreams.

Table 4 — Levels for the extended HE AAC profile

Level ^a	Max. channels/object	Max. AAC sampling rate, SBR not present [kHz]	Max. AAC sampling rate, SBR present [kHz]	Max. SBR sampling rate [kHz] (in/out)	Max. PCU	Max. RCU	Max. PCU HQ/LP SBR ^e	Max. RCU HQ/LP SBR ^e
1	NA	NA	NA	NA	NA	NA	NA	NA
2	2	48	24	24/48	12	11	12	11
3	2	48	24/48 ^c	48/48 ^b	15	11	15	11
4	5	48	24/48 ^d	48/48 ^b	25	28	20	23
5	5	96	48	48/96	49	28	39	23
6	7	48	24/48 ^d	48/48	34	37	27	30
7	7	96	48	48/96	67	37	53	30

NOTE A Level 6 or 7 decoder is not required to decode a Level 5 stream.

^a Level 2, 3, 4, 6 and 7 extended HE AAC profile decoders implement the baseline version of the parametric stereo tool. A level 5 decoder shall not be limited to the baseline version of the parametric stereo tool.

^b For level 3, 4 and 6 decoders, it is mandatory to operate the SBR tool in downsampled mode if the sampling rate of the AAC core is higher than 24kHz. Hence, if the SBR tool operates on a 48kHz signal, the internal sampling rate of the SBR tool will be 96kHz, however, the output signal will be downsampled by the SBR tool to 48kHz.

^c If parametric stereo data are present the maximum AAC sampling rate is 24kHz, if parametric stereo data are not present the maximum AAC sampling rate is 48kHz.

^d For one or two channels the maximum AAC sampling rate, with SBR present, is 48kHz. For more than two channels the maximum AAC sampling rate, with SBR present, is 24kHz.

^e The PCU/RCU number are given for a decoder operating the LP SBR tool whenever applicable.

For the MPEG-4 audio object type 2 (AAC LC), mono or stereo mixdown elements are not permitted.

For MPEG-4 audio object types 2, 5, and 29 the following restrictions apply:

- An extended HE AAC profile decoder shall operate the HQ SBR tool for bitstreams containing parametric stereo data.
- For bitstreams not containing parametric stereo data, the extended HE AAC profile decoder may operate the HQ SBR tool, or the LP SBR tool.

- Only bitstreams consisting of exactly one AAC single channel element may contain parametric stereo data. Bitstreams containing more than one channel in the AAC part shall not contain parametric stereo data.

4.6 Combination of USAC with MPEG-D DRC

The output of the USAC decoder can be further processed by MPEG-D DRC (ISO/IEC 23003-4). If the SBR tool in USAC is active, a USAC decoder can typically be efficiently combined with a subsequent MPEG-D DRC decoder by connecting them in the QMF domain in the same way as it is described in ISO/IEC 23003-4. If a connection in the QMF domain is not possible they shall be connected in the time domain.

The MPEG-D DRC payload shall be embedded into a USAC bitstream by means of the `usacExtElement` mechanism, with `usacExtElementType` of type `ID_EXT_ELE_UNI_DRC`. The loudness metadata shall be embedded by means of the `usacConfigExt` mechanism with `usacConfigExtType` of type `ID_CONFIG_EXT_LOUDNESS_INFO`. The time-alignment between the USAC data and the MPEG-D DRC data assumes the most efficient connection between the USAC decoder and the MPEG-D DRC decoder. If the SBR tool in USAC is active, the most efficient connection is in the QMF domain. Otherwise, the most efficient connection is in the time domain. The DRC tool is operated in regular delay mode and the DRC frame size has the same duration as the USAC frame size. The same holds for the DRC sampling rate, which is synchronized to the USAC sampling rate.

The time resolution of the DRC tool is specified by ΔT_{min} in units of the audio sample interval. It is calculated as specified in ISO/IEC 23003-4. Specific values are provided as examples based on the following formula:

$$\Delta T_{min} = 2^M$$

The applicable exponent M is found by looking up the audio sample rate range that fulfils:

$$f_{s,min} \leq f_s < f_{s,max}$$

Table 5 — Lookup table for the exponent M

$f_{s,min}$ [Hz]	$f_{s,max}$ [Hz]	M
8000	16000	3
16000	32000	4
32000	64000	5
64000	128000	6

Given the codec frame size N_{Codec} ($=outputFrameLength$), the DRC frame size in units of DRC samples at a rate of ΔT_{min} is:

$$N_{DRC} = N_{Codec} 2^{-M}$$

For USAC, MPEG-D DRC offers mandatory decoding capability of up to four DRC subbands using the time-domain DRC filter bank. More DRC subbands can be supported by operating in the QMF-domain. DRC sets that contain more than four DRC subbands shall contain gain sequences that are all aligned with the QMF-domain used for SBR. If the SBR tool in USAC is active, MPEG-D DRC shall always operate in the QMF-domain. The gain sequences are all aligned with the QMF domain in that case.

If no additional filter bank is required for the application of multiband DRC gains, MPEG-D DRC doesn't introduce any additional decoding delay.

The `drcLocation` parameter shall be encoded according to Table 6.

Table 6 — Encoding of drcLocation parameter

drcLocation n	Payload
1	uniDrcConfig() / uniDrcGain() (see ISO/IEC 23003-4)
2	<i>reserved</i>
3	<i>reserved</i>
4	<i>reserved</i>

5 Syntax

5.1 General

The bitstream syntax shall be based on ISO/IEC 14496-3:2019, 4.4.

The USAC bitstream syntax is shown in 5.2.

5.2 Decoder configuration (UsacConfig)

Table 7 — Syntax of UsacConfig()

Syntax	No. of bits	Mnemonic
UsacConfig() { usacSamplingFrequencyIndex ; if (usacSamplingFrequencyIndex == 0x1f) { usacSamplingFrequency ; } coreSbrFrameLengthIndex ; channelConfigurationIndex ; if (channelConfigurationIndex == 0) { UsacChannelConfig(); } UsacDecoderConfig(); if (usacConfigExtensionPresent ==1) { UsacConfigExtension(); } }	5 24 3 5 1	bslbf uimsbf uimsbf uimsbf uimsbf

Table 8 — Syntax of UsacChannelConfig()

Syntax	No. of bits	Mnemonic
UsacChannelConfig() { numOutChannels = escapedValue(5,8,16); for (i=0; i<numOutChannels; i++) { bsOutputChannelPos [i]; } }	5	uimsbf

Table 9 — Syntax of UsacDecoderConfig()

Syntax	No. of bits	Mnemonic
<pre> UsacDecoderConfig() { numElements = escapedValue(4,8,16) + 1; for (elemIdx=0; elemIdx<numElements; ++elemIdx) { usacElementType[elemIdx] switch (usacElementType[elemIdx]) { case: ID_USAC_SCE UsacSingleChannelElementConfig(sbrRatioIndex); break; case: ID_USAC_CPE UsacChannelPairElementConfig(sbrRatioIndex); break; case: ID_USAC_LFE UsacLfeElementConfig(); break; case: ID_USAC_EXT UsacExtElementConfig(); break; } } } </pre>	2	uimsbf
NOTE UsacSingleChannelElementConfig(), UsacChannelPairElementConfig(), UsacLfeElementConfig() and UsacExtElementConfig() signalled at position elemIdx refer to the corresponding elements in UsacFrame() at the respective position elemIdx.		

Table 10 — Syntax of UsacSingleChannelElementConfig()

Syntax	No. of bits	Mnemonic
<pre> UsacSingleChannelElementConfig(sbrRatioIndex) { UsacCoreConfig(); if (sbrRatioIndex > 0) { SbrConfig(); } } </pre>		

Table 11 — Syntax of UsacChannelPairElementConfig()

Syntax	No. of bits	Mnemonic
<pre> UsacChannelPairElementConfig(sbrRatioIndex) { UsacCoreConfig(); if (sbrRatioIndex > 0) { SbrConfig(); stereoConfigIndex; } else { stereoConfigIndex = 0; } if (stereoConfigIndex > 0) { Mps212Config(stereoConfigIndex); } } </pre>	2	uimsbf

Table 12 — Syntax of UsacLfeElementConfig()

Syntax	No. of bits	Mnemonic
UsacLfeElementConfig() { tw_mdct = 0; noiseFilling = 0; }		

Table 13 — Syntax of UsacCoreConfig()

Syntax	No. of bits	Mnemonic
UsacCoreConfig() { tw_mdct; noiseFilling; }	 1 1	 bslbf bslbf

Table 14 — Syntax of SbrConfig()

Syntax	No. of bits	Mnemonic
SbrConfig() { harmonicSBR; bs_interTes; bs_pvc; SbrDfltHeader(); }	 1 1 1	 bslbf bslbf bslbf

Table 15 — Syntax of SbrDfltHeader()

Syntax	No. of bits	Mnemonic
SbrDfltHeader() { dflt_start_freq; dflt_stop_freq; dflt_header_extra1; dflt_header_extra2; if (dflt_header_extra1 == 1) { dflt_freq_scale; dflt_alter_scale; dflt_noise_bands; } else { dflt_freq_scale = 2; dflt_alter_scale = 1; dflt_noise_bands = 2; } if (dflt_header_extra2 == 1) { dflt_limiter_bands; dflt_limiter_gains; dflt_interpol_freq; dflt_smoothing_mode; } else { dflt_limiter_bands = 2; dflt_limiter_gains = 2; dflt_interpol_freq = 1; dflt_smoothing_mode = 1; } }	 4 4 1 1 2 1 2 2 2 1 1	 uimsbf uimsbf uimsbf uimsbf uimsbf uimsbf uimsbf uimsbf uimsbf uimsbf uimsbf

Table 16 — Syntax of Mps212Config()

Syntax	No. of bits	Mnemonic
Mps212Config(stereoConfigIndex)		
{		
bsFreqRes;	3	uimsbf
bsFixedGainDMX	3	uimsbf
bsTempShapeConfig;	2	uimsbf
bsDecorrConfig;	2	uimsbf
bsHighRateMode;	1	uimsbf
bsPhaseCoding;	1	uimsbf
bsOttBandsPhasePresent;	1	uimsbf
if (bsOttBandsPhasePresent) {		^a
bsOttBandsPhase;	5	uimsbf
}		
if (bsResidualCoding) {		^b
bsResidualBands;	5	uimsbf
bsOttBandsPhase = max(bsOttBandsPhase,bsResidualBands);		
bsPseudoLr;	1	uimsbf
}		
if (bsTempShapeConfig == 2) {		
bsEnvQuantMode;	1	uimsbf
}		
}		

^a If bsOttBandsPhasePresent==0 bsOttBandsPhase is initialized according to Table 109.

^b bsResidualCoding depends on stereoConfigIndex according to Table 77.

Table 17 — Syntax of UsacExtElementConfig()

Syntax	No. of bits	Mnemonic
<pre> UsacExtElementConfig() { usacExtElementType = escapedValue(4,8,16); usacExtElementConfigLength= escapedValue(4,8,16); usacExtElementDefaultLengthPresent; if (usacExtElementDefaultLengthPresent) { usacExtElementDefaultLength = escapedValue(8,16,0) + 1; } else { usacExtElementDefaultLength = 0; } usacExtElementPayloadFrag; switch (usacExtElementType) { case ID_EXT_ELE_FILL: break; case ID_EXT_ELE_MPEGS: SpatialSpecificConfig(); break; case ID_EXT_ELE_SAOC: SaocSpecificConfig(); break; </pre>	1 1	uimsbf uimsbf

<pre> case ID_EXT_ELE_AUDIOPREROLL: /* No configuration element */ break; case ID_EXT_ELE_UNI_DRC: uniDrcConfig(); break; default: while (usacExtElementConfigLength--) { tmp; } break; } </pre>		
	a	
	8	uimbsf
^a The default entry for the usacExtElementType is used for unknown extElementTypes so that legacy decoders can cope with future extensions.		

Table 18 — Syntax of UsacConfigExtension()

Syntax	No. of bits	Mnemonic
<pre> UsacConfigExtension() { numConfigExtensions = escapedValue(2,4,8) + 1; for (confExtIdx=0; confExtIdx<numConfigExtensions; confExtIdx++) { usacConfigExtType[confExtIdx] = escapedValue(4,8,16); usacConfigExtLength[confExtIdx] = escapedValue(4,8,16); switch (usacConfigExtType[confExtIdx]) { case ID_CONFIG_EXT_FILL: while (usacConfigExtLength[confExtIdx]--) { fill_byte[i]; /* should be '10100101' */ } break; case ID_CONFIG_EXT_LOUDNESS_INFO: loudnessInfoSet(); break; case ID_CONFIG_EXT_STREAM_ID: streamId(); break; default: while (usacConfigExtLength[confExtIdx]--) { tmp; } break; } } } </pre>		
	8	uimbsf
	8	uimbsf

Table 19 — Syntax of escapedValue()

Syntax	No. of bits	Mnemonic
<pre> escapedValue(nBits1, nBits2, nBits3) { value; if (value == 2^{nBits1-1}) { value += valueAdd; if (valueAdd == 2^{nBits2-1}) { value += valueAdd; } } return value; } </pre>	nBits1 nBits2 nBits3	uimsbf uimsbf uimsbf

Table 20 — Syntax of streamId()

Syntax	No. of bits	Mnemonic
<pre> streamId() { streamIdentifier } </pre>	16	uimsbf

5.3 USAC bitstream payloads

5.3.1 Payloads for audio object type USAC

Table 21 — Syntax of UsacFrame(),
top level payload for audio object type USAC

Syntax	No. of bits	Mnemonic
<pre> UsacFrame() { usacIndependencyFlag; for (elemIdx=0; elemIdx<numElements; ++elemIdx) { switch (usacElementType[elemIdx]) { case: ID_USAC_SCE UsacSingleChannelElement(usacIndependencyFlag); break; case: ID_USAC_CPE UsacChannelPairElement(usacIndependencyFlag); break; case: ID_USAC_LFE UsacLfeElement(usacIndependencyFlag); break; case: ID_USAC_EXT UsacExtElement(usacIndependencyFlag); break; } } } </pre>	1	uimsbf

Table 22 — Syntax of UsacSingleChannelElement()

Syntax	No. of bits	Mnemonic
<pre> UsacSingleChannelElement(indepFlag) { UsacCoreCoderData(1, indepFlag); if (sbrRatioIndex > 0) { UsacSbrData(1, indepFlag); } } </pre>		

Table 23 — Syntax of UsacChannelPairElement()

Syntax	No. of bits	Mnemonic
<pre> UsacChannelPairElement(indepFlag) { if (stereoConfigIndex == 1) { nrCoreCoderChannels = 1; } else { nrCoreCoderChannels = 2; } UsacCoreCoderData(nrCoreCoderChannels, indepFlag); if (sbrRatioIndex > 0) { if (stereoConfigIndex == 0 stereoConfigIndex == 3) { nrSbrChannels = 2; } else { nrSbrChannels = 1; } UsacSbrData(nrSbrChannels, indepFlag); } if (stereoConfigIndex > 0) { Mps212Data(indepFlag); } } </pre>		

Table 24 — Syntax of UsacLfeElement()

Syntax	No. of bits	Mnemonic
<pre> UsacLfeElement(indepFlag) { fd_channel_stream(0,0,0,0, indepFlag); } </pre>		

Table 25 — Syntax of UsacExtElement()

Syntax	No. of bits	Mnemonic
UsacExtElement(indepFlag)		
{		
usacExtElementPresent	1	uimsbf
if (usacExtElementPresent==1) {		
usacExtElementUseDefaultLength;	1	uimsbf
if (usacExtElementUseDefaultLength) {		
usacExtElementPayloadLength = usacExtElementDefaultLength;		
} else {		
usacExtElementPayloadLength;	8	uimsbf
if (usacExtElementPayloadLength==255) {		
valueAdd	16	uimsbf
usacExtElementPayloadLength += valueAdd - 2;		
}		
}		
if (usacExtElementPayloadLength>0) {		
if (usacExtElementPayloadFrag) {		
usacExtElementStart;	1	uimsbf
usacExtElementStop;	1	uimsbf
} else {		
usacExtElementStart = 1;		
usacExtElementStop = 1;		
}		
for (i=0; i<usacExtElementPayloadLength; i++) {		
usacExtElementSegmentData[i];	8	uimsbf
}		
}		
}		

Table 26 — Syntax of ics_info()

Syntax	No. of bits	Mnemonic
ics_info()		
{		
window_sequence;	2	uimsbf
window_shape;	1	uimsbf
if (window_sequence == EIGHT_SHORT_SEQUENCE) {		
max_sfb;	4	uimsbf
scale_factor_grouping;	7	uimsbf
}		
else {		
max_sfb;	6	uimsbf
}		
}		

5.3.2 Subsidiary payloads

Table 27 — Syntax of UsacCoreCoderData()

Syntax	No. of bits	Mnemonic
<pre> UsacCoreCoderData(nrChannels, indepFlag) { for (ch=0; ch < nrChannels; ch++) { core_mode[ch]; } if (nrChannels == 2) { StereoCoreToolInfo(core_mode, indepFlag, stereoConfigIndex); } for (ch=0; ch<nrChannels; ch++) { if (core_mode[ch] == 1) { lpd_channel_stream(indepFlag); } else { if ((nrChannels == 1) (core_mode[0] != core_mode[1])) { tns_data_present[ch]; } fd_channel_stream(common_window, common_tw, tns_data_present[ch], noiseFilling, indepFlag); } } } </pre>	1 1	uimsbf a uimsbf b
^a Each channel shall have its own instance of lpd_channel_stream ^b Each channel shall have its own instance of fd_channel_stream		

Table 28 — Syntax of StereoCoreToolInfo()

Syntax	No. of bits	Mnemonic
<pre> StereoCoreToolInfo(core_mode, indepFlag, stereoConfigIndex) { if (core_mode[0] == 0 && core_mode[1] == 0) { tns_active; common_window; if (common_window) { ics_info(); common_max_sfb; if (common_max_sfb == 0) { if (window_sequence == EIGHT_SHORT_SEQUENCE) { max_sfb1; } else { max_sfb1; } } else { max_sfb1 = max_sfb; } } max_sfb_ste = max(max_sfb, max_sfb1); } } </pre>	1 1 1 4 6	uimsbf uimsbf uimsbf uimsbf uimsbf

ms_mask_present;	2	uimsbf
if (ms_mask_present == 1) {		
for (g = 0; g < num_window_groups; g++) {		
for (sfb = 0; sfb < max_sfb_ste; sfb++) {		
ms_used[g][sfb];	1	uimsbf
}		
}		
if ((ms_mask_present == 3) && (stereoConfigIndex == 0)) {		
cplx_pred_data(max_sfb_ste, indepFlag);		
} else {		
alpha_q_re[] = {0};		
alpha_q_im[] = {0};		
}		
}		
if (tw_mdct) {		
common_tw;	1	uimsbf
if (common_tw) {		
tw_data();		
}		
}		
if (tns_active) {		
if (common_window) {		
common_tns;	1	uimsbf
} else {		
common_tns = 0;		
}		
tns_on_lr;	1	uimsbf
if (common_tns) {		
tns_data();		
tns_data_present[0] = 0;		
tns_data_present[1] = 0;		
} else {		
tns_present_both;	1	uimsbf
if (tns_present_both) {		
tns_data_present[0] = 1;		
tns_data_present[1] = 1;		
} else {		
tns_data_present[1];	1	uimsbf
tns_data_present[0] = 1 - tns_data_present[1];		
}		
}		
} else {		
common_tns = 0;		
tns_data_present[0] = 0;		
tns_data_present[1] = 0;		
}		
} else {		
common_window = 0;		
common_tw = 0;		
}		
}		

Table 29 — Syntax of `fd_channel_stream()`

Syntax	No. of bits	Mnemonic
<code>fd_channel_stream(common_window, common_tw, tns_data_present, noiseFilling, indepFlag)</code>		
<code>{</code>		
global_gain;	8	uimsbf
if (noiseFilling) {		
noise_level;	3	uimsbf
noise_offset;	5	uimsbf
}		
else {		
noise_level = 0;		
}		
if (!common_window) {		
ics_info();		
}		
if (tw_mdct) {		
if (!common_tw) {		
tw_data();		
}		
}		
scale_factor_data ();		
if (tns_data_present) {		
tns_data ();		
}		
ac_spectral_data(indepFlag);		
fac_data_present;	1	uimsbf
if (fac_data_present) {		
fac_length = (window_sequence == EIGHT_SHORT_SEQUENCE) ? ccfl/16 : ccfl/8;		
fac_data(1, fac_length);		
}		
<code>}</code>		

Table 30 — Syntax of `cplx_pred_data()`

Syntax	No. of bits	Mnemonic
<code>cplx_pred_data(max_sfb_ste, indepFlag)</code>		
<code>{</code>		
cplx_pred_all;	1	uimsbf
if (cplx_pred_all == 0) {		
for (g = 0; g < num_window_groups; g++) {		
for (sfb = 0; sfb < max_sfb_ste; sfb += SFB_PER_PRED_BAND) {		
cplx_pred_used[g][sfb];	1	uimsbf
if ((sfb+1) < max_sfb_ste) {		
cplx_pred_used[g][sfb+1] = cplx_pred_used[g][sfb];		
}		
}		
}		
}		
else {		
for (g = 0; g < num_window_groups; g++) {		
for (sfb = 0; sfb < max_sfb_ste; sfb++) {		
cplx_pred_used[g][sfb] = 1;		
}		
}		
}		

pred_dir;	1	uimsbf
complex_coef;	1	uimsbf
if (complex_coef) { if (indepFlag) { use_prev_frame = 0; } else { use_prev_frame; } }	1	uimsbf
if (indepFlag) { delta_code_time = 0; } else { delta_code_time; }	1	uimsbf
for (g = 0; g < num_window_groups; g++) { for (sfb = 0; sfb < max_sfb_ste; sfb += SFB_PER_PRED_BAND) { if (cplx_pred_used[g][sfb]) { hcod_sf [dpcm_alpha_q_re[g][sfb]]; if (complex_coef) { hcod_sf [dpcm_alpha_q_im[g][sfb]]; } else { alpha_q_im[g][sfb] = 0; dpcm_alpha_q_im[g][sfb] = 60; } } else { alpha_q_re[g][sfb] = 0; alpha_q_im[g][sfb] = 0; } } }	1..19 1..19	vlclbf vlclbf

Table 31 — Syntax of tw_data()

Syntax	No. of bits	Mnemonic
tw_data() { tw_data_present; if (tw_data_present == 1) { for (i = 0 ; i < NUM_TW_NODES ; i++) { tw_ratio [i]; } } }	1 3	uimsbf uimsbf

Table 32 — Syntax of scale_factor_data()

Syntax	No. of bits	Mnemonic
<pre> scale_factor_data() { dpcm_sf[0][0] = 60; for (g = 0; g < num_window_groups; g++) { for (sfb = 0; sfb < max_sfb; sfb++) { if (g > 0 sfb > 0) { hcod_sf[dpcm_sf[g][sfb]]; } } } } </pre>	1..19	vlclbf

Table 33 — Syntax of tns_data()

Syntax	No. of bits	Mnemonic
<pre> tns_data() { for (w = 0; w < num_windows; w++) { n_filt[w]; if (n_filt[w]) { coef_res[w]; } for (filt = 0; filt < n_filt[w]; filt++) { length[w][filt]; order[w][filt]; if (order[w][filt]) { direction[w][filt]; coef_compress[w][filt]; for (i = 0; i < order[w][filt]; i++) { coef[w][filt][i]; } } } } } </pre>	1..2 1 {4;6} {3;4} 1 1 2..4	uimsbf uimsbf uimsbf uimsbf uimsbf uimsbf

Table 34 — Syntax of ac_spectral_data()

Syntax	No. of bits	Mnemonic
<pre> ac_spectral_data(indepFlag) { if (indepFlag) { arith_reset_flag = 1; } else { arith_reset_flag; } for (win = 0; win < num_windows; win++) { arith_data(lg, arith_reset_flag && (win==0)); } } </pre>	1	uimsbf
^a num_windows indicates the number of windows in the current window_sequence. In case window_sequence is EIGHT_SHORT_SEQUENCE num_windows equals 8. In all other cases num_windows equals 1.		

Table 35 — Syntax of `lpd_channel_stream()`

Syntax	No. of bits	Mnemonic
<pre> lpd_channel_stream(indepFlag) { acelp_core_mode; lpd_mode; bpf_control_info core_mode_last; fac_data_present; first_lpd_flag = !core_mode_last; first_tcx_flag=TRUE; k = 0; if (first_lpd_flag) { last_lpd_mode = -1; } while (k < 4) { if (k==0) { if ((core_mode_last==1) && (fac_data_present==1)) { fac_data(0, ccfl/8); } } else { if ((last_lpd_mode==0 && mod[k]>0) (last_lpd_mode>0 && mod[k]==0)) { fac_data(0, ccfl/8); } } if (mod[k] == 0) { acelp_coding(acelp_core_mode); last_lpd_mode=0; k += 1; } else { tcx_coding(lg(mod[k]), first_tcx_flag, indepFlag); last_lpd_mode=mod[k]; k += (1 << (mod[k]-1)); first_tcx_flag=FALSE; } } lpc_data(first_lpd_flag); if ((core_mode_last==0) && (fac_data_present==1)) { short_fac_flag; fac_length = short_fac_flag ? ccfl/16 : ccfl/8; fac_data(1, fac_length); } } </pre>	3 5 1 1 1 1 1	uimbsbf uimbsbf, a uimbsbf uimbsbf uimbsbf b c uimbsbf
^a lpd_mode defines the contents of the array <code>mod[]</code> as described in 6.2.10.2, Table 94. ^b <code>first_lpd_flag</code> is defined in 6.2.10.2. ^c The number of spectral coefficients, <code>lg</code>, depends on <code>mod[k]</code> according to Table 155.		

Table 36 — Syntax of `lpc_data()`

Syntax	No. of bits	Mnemonic
<pre> lpc_data(first_lpd_flag, mod[]) { lpc_set = 4; mode_lpc = get_mode_lpc(lpc_set); lpc_first_approximation_index[lpc_set] code_book_indices(lpc_set, nk_mode, 2); if (first_lpd_flag) { lpc_set = 0; mode_lpc = get_mode_lpc(lpc_set); if (mode_lpc == 0) { lpc_first_approximation_index[lpc_set] } code_book_indices(0, nk_mode, 2); } if (mod[0] != 3) { lpc_set = 2; mode_lpc = get_mode_lpc(lpc_set); if (mode_lpc == 0) { lpc_first_approximation_index[lpc_set] } code_book_indices(lpc_set, nk_mode, 2); } if (mod[0] < 2) { lpc_set = 1; mode_lpc = get_mode_lpc(lpc_set); if (mode_lpc == 0) { lpc_first_approximation_index[lpc_set] } if (mode_lpc != 1) { code_book_indices(lpc_set, nk_mode, 2); } } if (mod[2] < 2) { lpc_set = 3; mode_lpc = get_mode_lpc(lpc_set); if (mode_lpc == 0) { lpc_first_approximation_index[lpc_set] } code_book_indices(lpc_set, nk_mode, 2); } } </pre>	8 a 8 a 8 a 8 a 8 a	uimsbf uimsbf uimsbf uimsbf uimsbf
^a nk_mode is determined by the number of the currently decoded LPC Filter set, lpc_set, and the LPC quantization mode, mode_lpc, according to Table 148.		

Table 37 — Syntax of qn_data()

Syntax	No. of bits	Mnemonic
<pre> qn_data(nk_mode, no_qn) { switch (nk_mode) { case 1: for (k=0; k<no_qn; k++) { qn[k] if (qn[k] > 0) { qn[k] += 1 } } break; case 0: case 2: case 3: for (k=0; k<no_qn; k++) { qn_base qn[k] = qn_base + 2; } if (nk_mode == 2) { for (k=0; k<no_qn; k++) { if (qn[k] > 4) { qn[k] if (qn[k] > 0) { qn[k] += 4 } } } } else { for (k=0; k<no_qn; k++) { if (qn[k] > 4) { qn_ext switch (qn_ext) { case 0: qn[k] = 5; break; case 1: qn[k] = 6; break; case 2: qn[k] = 0; break; default: qn[k] = qn_ext + 4; break; } } } } break; } } } </pre>	1..n 2 1..n 1..n	uclbf uimbsf uclbf uclbf

Table 38 — Syntax of `get_mode_lpc()`

Syntax	No. of bits	Mnemonic
<pre> get_mode_lpc(lpc_set) { switch (lpc_set) { case 4: mode_lpc=0; break; case 0: case 2: mode_lpc = binary_code break; case 1: switch (binary_code) { case '0₂': mode_lpc = 2; break; case '10₂': mode_lpc = 0; break; case '11₂': mode_lpc = 1; break; } break; case 3: switch (binary_code) { case '0₂': mode_lpc = 1; break; case '10₂': mode_lpc = 0; break; case '110₂': mode_lpc = 2; break; case '111₂': mode_lpc = 3; break; } break; } return mode_lpc; } </pre>	1 1..2 1..3	vlclbf vlclbf
NOTE The mapping of binary code to mode_lpc can also be deduced from Table 148.		

Table 39 — Syntax `code_book_indices ()`

Syntax	No. of bits	Mnemonic
<pre> code_book_indices(idx, nk_mode, no_qn) { qn_data(nk_mode, no_qn); for (k=0; k<no_qn; k++) { if (qn[k] > 4) { nk = (qn[k]-3)/2; n = qn[k] - nk*2; } else { nk = 0; n = qn[k]; } } code_book_index[idx][k] kv[idx][k][0] kv[idx][k][1] kv[idx][k][2] kv[idx][k][3] kv[idx][k][4] </pre>	^a 4*n nk nk nk nk nk	uimbsf uimbsf uimbsf uimbsf uimbsf

kv[idx][k][5]	nk	uimsbf
kv[idx][k][6]	nk	uimsbf
kv[idx][k][7]	nk	uimsbf
}		
}		

^a idx can take values from 0 to 4 in case the syntax element is used in context of lpc_data(). In case of the use in the context of fac_data() idx can take values from 0 to 7 or from 0 to 15 depending on fac_length.

Table 40 — Syntax of acelp_coding()

Syntax	No. of bits	Mnemonic
acelp_coding(acelp_core_mode)		
{		
mean_energy;	2	uimsbf
nb_subfr = coreCoderFrameLength/256		
for (sfr=0; sfr<nb_subfr; sfr++) {		
if ((sfr==0) ((nb_subfr==4) && (sfr==2))) {		
acb_index[sfr];	9	uimsbf
} else {		
acb_index[sfr];	6	uimsbf
}		
ltp_filtering_flag[sfr];	1	bmsbf
switch (acelp_core_mode) {		
case 0		
icb_index[sfr];	20	uimsbf
break;		
case 1		
icb_index[sfr];	28	uimsbf
break;		
case 2		
icb_index[sfr];	36	uimsbf
break;		
case 3		
icb_index[sfr];	44	uimsbf
break;		
case 4		
icb_index[sfr];	52	uimsbf
break;		
case 5		
icb_index[sfr];	64	uimsbf
break;		
case 6		
icb_index[sfr];	12	uimsbf
break;		
case 7		
icb_index[sfr];	16	uimsbf
break;		
}		
gains[sfr];	7	uimsbf
}		

^a coreCoderFrameLength designates the core frame length in samples and is equal to either 1024 or 768. See also 6.1.1.2.

Table 41 — Syntax of tcx_coding()

Syntax	No. of bits	Mnemonic
tcx_coding(lg, first_tcx_flag, indepFlag)		
{		
noise_factor;	3	uimsbf
global_gain;	7	uimsbf
if (first_tcx_flag) {		
if (indepFlag) {		
arith_reset_flag = 1;		
} else {		
arith_reset_flag;	1	uimsbf
}		
}		
else {		
arith_reset_flag=0;		
}		
arith_data(lg, arith_reset_flag);		
}		

Table 42 — Syntax of arith_data()

Syntax	No. of bits	Mnemonic
arith_data(lg, arith_reset_flag)		
{		
c = arith_map_context(N, arith_reset_flag);		
for (i=0; i<lg/2; i++) {		
/* MSB decoding */		
c = arith_get_context (c,i,N);		
for (lev=esc_nb=0;;) {		
pki = arith_get_pk(c+(esc_nb<<17));		
acod_m [pki][m];	1..20	vlclbf
if (m != ARITH_ESCAPE)		
break;		
lev += 1;		
if ((esc_nb=lev)>7)		
esc_nb=7;		
}		
b = m>>2;		
a = m - (b<<2);		
/* ARITH_STOP symbol detection */		
if (m==0 && lev>0)		
break;		
/* LSB decoding */		
for (l=lev; l>0; l--) {		
lsbidx = (a==0)?1:((b==0)?0:2);		
acod_r [lsbidx][r];	1..20	vlclbf
a=(a<<1) (r&1);		
b=(b<<1) ((r>>1)&1);		
}		

<pre> x_ac_dec[2*i] = a; x_ac_dec[2*i+1] = b; arith_update_context(i,a,b); } arith_finish(x_ac_dec, i,N,lg); /* Signs decoding */ for (i=0; i<lg; i++) { if (x_ac_dec[i] != 0) { s; if (s==0) { x_ac_dec[i] *= -1; } } } </pre>	1	uimsbf
---	----------	---------------

Table 43 — Syntax of fac_data()

Syntax	No. of bits	Mnemonic
<pre> fac_data(useGain, fac_length) { if (useGain) { fac_gain; } for (i=0; i<fac_length/8; i++) { code_book_indices (i, 1, 1); } } </pre>	7	uimsbf
NOTE 1 This value is encoded using a modified unary code, where qn=0 is represented by one "0" bit, and any value qn greater or equal to 2 is represented by qn-1 "1" bits followed by one "0" stop bit.		
NOTE 2 qn=1 cannot be signalled, because the codebook Q_1 is not defined.		

5.3.3 Payloads for enhanced SBR

Table 44 — Syntax of UsacSbrData()

Syntax	No. of bits	Mnemonic
<pre> UsacSbrData(numberSbrChannels, indepFlag) { if (indepFlag) { sbrInfoPresent = 1; sbrHeaderPresent = 1; } else { sbrInfoPresent; if (sbrInfoPresent) { sbrHeaderPresent; } else { sbrHeaderPresent = 0; } } if (sbrInfoPresent) { SbrInfo(); } if (sbrHeaderPresent) { </pre>	1	uimsbf
	1	uimsbf

<pre> sbrUseDfltHeader; if (sbrUseDfltHeader) { /* copy all SbrDfltHeader() elements dlft_xxx_yyy to bs_xxx_yyy */ } else { SbrHeader(); } } sbr_data(bs_amp_res, numberSbrChannels, indepFlag); } </pre>	1	uimbsbf
---	----------	----------------

Table 45 — Syntax of SbrInfo

Syntax	No. of bits	Mnemonic
SbrInfo()		
{		
bs_amp_res;	1	uimbsbf
bs_xover_band;	4	uimbsbf
bs_sbr_preprocessing;	1	uimbsbf
if (bs_pvc) {		
bs_pvc_mode;	2	uimbsbf
}		
}		

Table 46 — Syntax of SbrHeader()

Syntax	No. of bits	Mnemonic
SbrHeader()		
{		
bs_start_freq;	4	uimbsbf , ^a
bs_stop_freq;	4	uimbsbf , ^a
bs_header_extra_1;	1	uimbsbf
bs_header_extra_2;	1	uimbsbf
if (bs_header_extra_1) {		^b
bs_freq_scale;	2	uimbsbf
bs_alter_scale;	1	uimbsbf
bs_noise_bands;	2	uimbsbf
}		
if (bs_header_extra_2) {		^b
bs_limiter_bands;	2	uimbsbf
bs_limiter_gains;	2	uimbsbf
bs_interpol_freq;	1	uimbsbf
bs_smoothing_mode;	1	uimbsbf
}		
}		
^a bs_start_freq and bs_stop_freq shall define a frequency band that does not exceed the limits defined in 7.5.5 and ISO/IEC 14496-3:2019, 4.6.18.3.6.		
^a If this bit is not set the default values for the underlying data elements shall be used disregarding any previous value.		

Table 47 — Syntax of sbr_data()

Syntax	No. of bits	Mnemonic
<pre>sbr_data(bs_amp_res, numberSbrChannels, indepFlag) { switch (numberSbrChannels) { case 1: sbr_single_channel_element(bs_amp_res, bs_pvc_mode, indepFlag); break; case 2: sbr_channel_pair_element(bs_amp_res, indepFlag); break; } }</pre>		

Table 48 — Syntax of sbr_single_channel_element()

Syntax	No. of bits	Mnemonic
<pre> sbr_single_channel_element(bs_amp_res, bs_pvc_mode, indepFlag) { if (harmonicSBR) { if (sbrPatchingMode[0] == 0) { sbrOversamplingFlag[0]; if (sbrPitchInBinsFlag[0]) sbrPitchInBins[0]; else sbrPitchInBins[0] = 0; } else { sbrOversamplingFlag[0] = 0; sbrPitchInBins[0] = 0; } } sbr_grid(0, bs_pvc_mode); sbr_dtdf(0, bs_pvc_mode, indepFlag); sbr_invf(0); if (bs_pvc_mode==0) { sbr_envelope(0, 0, bs_amp_res); } else { pvc_envelope(indepFlag); } sbr_noise(0, 0); if (bs_add_harmonic_flag[0]) { sbr_sinusoidal_coding(0, bs_pvc_mode); } } </pre>	1 1 1 7 1	uimbsbf uimbsbf uimbsbf uimbsbf uimbsbf

Table 49 — Syntax of sbr_channel_pair_element()

Syntax	No. of bits	Mnemonic
sbr_channel_pair_element(bs_amp_res, indepFlag)		
{		
if (bs_coupling==1) {	1	uimsbf
if (harmonicSBR) {		
if (sbrPatchingMode[0,1] == 0) {	1	uimsbf
sbrOversamplingFlag[0,1];	1	uimsbf
if (sbrPitchInBinsFlag[0,1])	1	uimsbf
sbrPitchInBins[0,1];	7	uimsbf
else		
sbrPitchInBins[0,1] = 0;		
} else {		
sbrOversamplingFlag[0,1] = 0;		
sbrPitchInBins[0,1] = 0;		
}		
}		
sbr_grid(0, 0);	a	
if (!bs_coupling) sbr_grid(1, 0);		
sbr_dtdf(0, 0, indepFlag);		
sbr_dtdf(1, 0, indepFlag);		
sbr_invf(0);		
if (!bs_coupling) sbr_invf(1);	a	
sbr_envelope(0,1, bs_amp_res);		
sbr_noise(0,1);		
sbr_envelope(1,1, bs_amp_res);		
sbr_noise(1,1);		
} else {		
if (harmonicSBR) {		
if (sbrPatchingMode[0] == 0) {	1	uimsbf
sbrOversamplingFlag[0];	1	uimsbf
if (sbrPitchInBinsFlag[0])	1	uimsbf
sbrPitchInBins[0];	7	uimsbf
else		
sbrPitchInBins[0] = 0;		
} else {		
sbrOversamplingFlag[0] = 0;		
sbrPitchInBins[0] = 0;		
}		
if (sbrPatchingMode[1] == 0) {	1	uimsbf
sbrOversamplingFlag[1];	1	uimsbf
if (sbrPitchInBinsFlag[1])	1	uimsbf
sbrPitchInBins[1];	7	uimsbf
else		
sbrPitchInBins[1] = 0;		
} else {		
sbrOversamplingFlag[1] = 0;		
sbrPitchInBins[1] = 0;		
}		
}		
sbr_grid(0, 0);		
sbr_grid(1, 0);		
sbr_dtdf(0,0, indepFlag);		

1 uimsbf
1 uimsbf

Table 50 — Syntax of sbr_grid()

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bs_var_bord_1[ch];	2	uimbsbf
bs_num_rel_0[ch];	2	uimbsbf
bs_num_rel_1[ch];	2	uimbsbf
bs_num_env[ch] = bs_num_rel_0[ch] + bs_num_rel_1[ch] + 1;		^a
for (rel = 0; rel < bs_num_rel_0[ch]; rel++)		
bs_rel_bord_0[ch][rel] = 2* tmp + 2;	2	uimbsbf
for (rel = 0; rel < bs_num_rel_1[ch]; rel++)		
bs_rel_bord_1[ch][rel] = 2* tmp + 2;	2	uimbsbf
ptr_bits = ceil (log(bs_num_env[ch] + 1) / log (2));		^b
bs_pointer[ch];	ptr_bits	uimbsbf
for (env = 0; env < bs_num_env[ch]; env++)		
bs_freq_res[ch][env];	1	uimbsbf
break;		
}		
if (bs_num_env[ch] > 1)	{ bs_num_noise[ch] = 2; }	
else	{ bs_num_noise[ch] = 1; }	
} else {		
bs_noise_position[ch];	4	uimbsbf
bs_var_len_hf[ch];	1,3	uimbsbf
if (bs_noise_position[ch] == 0) {		
bs_num_env[ch] = 1;		
bs_num_noise[ch] = 1;		
bs_freq_res[ch][0] = 0;		
} else {		
bs_num_env[ch] = 2;		
bs_num_noise[ch] = 2;		
for (env = 0; env < bs_num_env[ch]; env++) {		
bs_freq_res[ch][env] = 0;		
}		
}		
}		
}		

^a bs_num_env is restricted according to 7.5.1.3.

^b The division (/) is a float division without rounding or truncation.

Table 51 — Syntax of sbr_envelope()

Syntax	No. of bits	Mnemonic
<pre> sbr_envelope(ch, bs_coupling, bs_amp_res) { amp_res = bs_amp_res; if (bs_frame_class[ch] == FIXFIX && bs_num_env[ch] == 1) { amp_res = 0; } if (bs_coupling) { if (ch) { t_huff = t_huffman_env_bal_3_0dB; f_huff = f_huffman_env_bal_3_0dB; } else { t_huff = t_huffman_env_bal_1_5dB; f_huff = f_huffman_env_bal_1_5dB; } } } </pre>		

```

    } else {
        if (amp_res) {
            t_huff = t_huffman_env_3_0dB;
            f_huff = f_huffman_env_3_0dB;
        } else {
            t_huff = t_huffman_env_1_5dB;
            f_huff = f_huffman_env_1_5dB;
        }
    }
} else {
    if (amp_res) {
        t_huff = t_huffman_env_3_0dB;
        f_huff = f_huffman_env_3_0dB;
    } else {
        t_huff = t_huffman_env_1_5dB;
        f_huff = f_huffman_env_1_5dB;
    }
}

for (env = 0; env < bs_num_env[ch]; env++) {
    if (bs_df_env[ch][env] == 0) {
        if (bs_coupling && ch) {
            if (amp_res)
                bs_data_env[ch][env][0] = bs_env_start_value_balance;
            else
                bs_data_env[ch][env][0] = bs_env_start_value_balance;
        } else {
            if (amp_res)
                bs_data_env[ch][env][0] = bs_env_start_value_level;
            else
                bs_data_env[ch][env][0] = bs_env_start_value_level;
        }
        for (band = 1; band < num_env_bands[bs_freq_res[ch][env]]; band++)
            bs_data_env[ch][env][band] = sbr_huff_dec(f_huff, bs_codeword);
    } else {
        for (band = 0; band < num_env_bands[bs_freq_res[ch][env]]; band++)
            bs_data_env[ch][env][band] = sbr_huff_dec(t_huff, bs_codeword);
    }
    if (bs_interTes) {
        bs_temp_shape[ch][env];
        If (bs_temp_shape[ch][env]) {
            bs_inter_temp_shape_mode[ch][env];
        }
    }
}
}

```

^a num_env_bands[bs_freq_res[ch][env]] is derived from the header according to ISO/IEC 14496-3:2019, 4.6.18.3 and is named **n**.

^b sbr_huff_dec() is defined in ISO/IEC 14496-3:2019, 4.A.6.1.

Table 52 — Syntax of `sbr_dtdf()`

Syntax	No. of bits	Mnemonic
<pre> sbr_dtdf (ch, bs_pvc_mode, indepFlag) { if (bs_pvc_mode == 0) { if (indepFlag) { bs_df_env[ch][0] = 0 } else { bs_df_env[ch][0]; } for (env = 1; env < bs_num_env[ch]; env++) { bs_df_env[ch][env]; } } if (indepFlag) { bs_df_noise[ch][0] = 0 } else { bs_df_noise[ch][0]; } for (noise = 1; noise < bs_num_noise[ch]; noise++) { bs_df_noise[ch][noise]; } } </pre>	1 1 1 1	

Table 53 — Syntax of `sbr_sinusoidal_coding()`

Syntax	No. of bits	Mnemonic
<pre> sbr_sinusoidal_coding(ch, bs_pvc_mode) { for (n = 0; n < num_high_res[ch]; n++) bs_add_harmonic [ch][n]; if (bs_pvc_mode != 0) { bs_sinusoidal_position = 31; bs_sinusoidal_position_flag; if (bs_sinusoidal_position_flag == 1) bs_sinusoidal_position; } } </pre>	1 1 5	uimsbf

Table 54 — Syntax of pvc_envelope

Syntax	No. of bits	Mnemonic
pvc_envelope(indepFlag)		
{		
divMode;	3	uimsbf
nsMode;	1	uimsbf
if (divMode<=3) {		
num_length = divMode;		
if (indepFlag) {		
reuse_pvcID = 0;		
} else {		
reuse_pvcID;	1	uimsbf
}		
if (reuse_pvcID) {		
pvcID[0]=pvcID[-1];		
} else {		
pvcID[0];	7	uimsbf
}		
k=1;		
if (num_length) {		
sum_length=0;		
for (i=0; i<num_length; i++) {		
if (sum_length >= 13) {		
length;	1	uimsbf
} else if (sum_length >= 11) {		
length;	2	uimsbf
} else if (sum_length >= 7) {		
length;	3	uimsbf
} else {		
length;	4	uimsbf
}		
length += 1;		
sum_length += length;		
for (j=1; j<length; j++, k++) {		
pvcID[k] = pvcID[k-1];		
}		
pvcID[k++];	7	uimsbf
}		
}		
for (; k<16; k++) {		
pvcID[k]=pvcID[k-1];		
}		
} else {		
switch (divMode) {		
case 4:		
num_grid_info=2;		
fixed_length=8;		
break;		
case 5:		
num_grid_info=4;		
fixed_length=4;		
break;		

```

    case 6:
        num_grid_info=8;
        fixed_length=2;
        break;
    case 7:
        num_grid_info=16;
        fixed_length=1;
        break;
}
for (i=0, k=0; i<num_grid_info; i++) {
    if (indepFlag && i==0) {
        grid_info = 1;
    } else {
        grid_info;
    }
    if (grid_info) {
        pvcID[k++];
    } else {
        pvcID[k++] = pvcID[k-1];
    }
    for (j=1; j<fixed_length; j++, k++) {
        pvcID[k] = pvcID[k-1];
    }
}
}
}

```

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7 **uimsbf**

Table 55 — References to SBR syntactic elements

Syntax of	Refer to:
sbr_invf()	ISO/IEC 14496-3:2019, 4.4.2.8, Table 4.76
sbr_noise()	ISO/IEC 14496-3:2019, 4.4.2.8, Table 4.78

5.3.4 Payloads for MPEG Surround

Table 56 — Syntax of Mps212Data()

Syntax	No. of bits	Mnemonic
Mps212Data(indepFlag) { FramingInfo(); if (indepFlag) { bsIndependencyFlag = 1; } else { bsIndependencyFlag; } OttData(); SmgData(); TempShapeData(); if (bsTsdEnable == 1) { TsdData(); } }	1	uimsbf

Table 57 — Syntax of FramingInfo()

Syntax	No. of bits	Mnemonic
<pre> FramingInfo() { if (bsHighRateMode) { bsFramingType; bsNumParamSets; } else { bsFramingType = 0; bsNumParamSets = 1; } numParamSets = bsNumParamSets + 1; nBitsParamSlot = ceil(log2(numSlots)); if (bsFramingType) { for (ps=0; ps<numParamSets; ps++) { bsParamSlot[ps]; } } } </pre>	1 3 nBitsParamSlot	uimsbf uimsbf uimsbf

Table 58 — Syntax of OttData()

Syntax	No. of bits	Mnemonic
<pre> OttData() { EcData(CLD, 0, 0, numBands); EcData(ICC, 0, 0, numBands); if (bsPhaseCoding) { bsPhaseMode; if (bsPhaseMode) { bsOPDSmoothingMode; EcData(IPD, 0, 0, bsOttBandsPhase); } } } </pre>	1 1	a a uimsbf uimsbf
^a numBands is defined in ISO/IEC 23003-1:2007, 5.2, Table 39 and depends on bsFreqRes.		

Table 59 — Syntax of SmgData()

Syntax	No. of bits	Mnemonic
<pre> SmgData() { if (bsHighRateMode) { for (ps=0; ps<numParamSets; ps++) { bsSmoothMode[ps]; if (bsSmoothMode[ps] >= 2) { bsSmoothTime[ps]; } if (bsSmoothMode[ps] == 3) { bsFreqResStrideSmg[ps]; dataBands = (numBands-1)/pbStride+1; for (pg=0; pg<dataBands; pg++) { bsSmgData[ps][pg]; } } } } else { for (ps=0; ps<numParamSets; ps++) { bsSmoothMode[ps] = 0; } } } </pre>	2 2 2 1	^a uimsbf uimsbf ^b uimsbf uimsbf
^a numParamSets is defined by numParamSets = bsNumParamSets + 1. ^b pbStride is defined in ISO/IEC 23003-1:2007, 5.2, Table 70 and depends on bsFreqResStrideSmg. The division shall be interpreted as ANSI C integer division. numBands is defined in ISO/IEC 23003-1:2007, 5.2, Table 39 and depends on bsFreqRes.		

Table 60 — Syntax of TempShapeData()

Syntax	No. of bits	Mnemonic
<pre> TempShapeData() { bsTsdEnable = 0; if (bsTempShapeConfig == 3) { bsTsdEnable; } else if ((bsTempShapeConfig == 1) (bsTempShapeConfig == 2)) { bsTempShapeEnable; if (bsTempShapeEnable) { for (ch=0; ch< numTempShapeChan; ch++) { bsTempShapeEnableChannel[ch]; } if (bsTempShapeConfig == 2) { EnvelopeReshapeHuff(bsTempShapeEnableChannel); } } } } </pre>	1 1 1	uimsbf uimsbf ^a uimsbf
^a numTempShapeChan is 2 as defined 6.2.13.2.		

Table 61 — Syntax of TsdData()

Syntax	No. of bits	Mnemonic
<pre> TsdData() { bsTsdNumTrSlots; TsdSepData = TsdTrPos_dec(bsTsdCodedPos); for (ts=0; ts< numSlots; ts++) { if (TsdSepData[ts] == 1) { bsTsdTrPhaseData[ts] } else { bsTsdTrPhaseData[ts] = 0; } } } </pre>	nBitsTrSlots nBitsTsdCW 3	uimbsbf a vlclbf b, c uimbsbf
^a nBitsTrSlots depends on the frame length as defined in Table 110. ^b nBitTsdCW is calculated according to the rule described in 7.11.2.4. ^c TsdTrPos_dec() is defined in 7.11.2.4.		

Table 62 — Syntax of EcData()

Syntax	No. of bits	Mnemonic
<pre> EcData(dataType, paramIdx, startBand, stopBand) { dataSets = 0; for (ps=0; ps<numParamSets; ps++) { bsXXXdataMode[paramIdx][ps]; if (bsXXXdataMode[paramIdx][ps]==3) { dataSets++; } } setIdx = 0; while (setIdx < dataSets) { bsDataPairXXX[paramIdx][setIdx]; bsQuantCoarseXXX[paramIdx][setIdx]; bsFreqResStrideXXX[paramIdx][setIdx]; dataBands = (stopBand-startBand-1)/pbStride+1; EcDataPair(dataType, paramIdx, setIdx, dataBands, bsDataPairXXX[paramIdx][setIdx], bsQuantCoarseXXX[paramIdx][setIdx]); if (bsDataPairXXX[paramIdx][setIdx]) { bsQuantCoarseXXX[paramIdx][setIdx+1] = bsQuantCoarseXXX[paramIdx][setIdx]; bsFreqResStrideXXX[paramIdx][setIdx+1] = bsFreqResStrideXXX[paramIdx][setIdx]; } setIdx += bsDataPairXXX[paramIdx][setIdx]+1; } startBandXXX[paramIdx] = startBand; stopBandXXX[paramIdx] = stopBand; } </pre>	2 1 1 2	a b uimbsbf uimbsbf uimbsbf c
^a XXX is to be replaced by the value of dataType (CLD, ICC, IPD). ^b numParamSets is defined by numParamSets = bsNumParamSets + 1. ^c pbStride is defined in ISO/IEC 23003-1:2007, Table 70 and depends on bsFreqResStride[[]]. Furthermore the division shall be interpreted as ANSI C integer division.		

Table 63 — Syntax of EcDataPair()

Syntax	No. of bits	Mnemonic
EcDataPair(dataType, paramIdx, setIdx, dataBands, pairFlag, coarseFlag)		a
{		
mixedTimePair_flag = 0;		
bsPcmCodingXXX [paramIdx][setIdx];	1	uimbsbf
if (bsPcmCoding[paramIdx][setIdx]) {		
if (coarseFlag) {		
numQuantSteps = numQuantStepsXXXCoarse;		b
Else {		b
numQuantSteps = numQuantStepsXXXFine;		
}		
aaDataPair = GroupedPcmData(dataType, pairFlag,		
numQuantSteps, dataBands);		
}		
else {		
allowDiffTimeBack = (!bsIndependencyFlag) (setIdx>0);		
(aaDataPairMsbDiff, aPgOffset, mixedTimePair_flag) =		
DiffHuffData(dataType, pairFlag,		
allowDiffTimeBack, dataBands);		
aaDataPairLsb[0] = LsbData(dataType, coarseFlag, dataBands);		
if (pairFlag) {		
aaDataPairLsb[1] = LsbData(dataType, coarseFlag, dataBands);		
}		
}		
/* copy information read by EcDataPair() and its subfunctions		
into non-ambiguous variables for later delta decoding etc. */		
bsDiffTypeXXX[paramIdx][setIdx] = bsDiffType[0];		
bsDiffTimeDirectionXXX[paramIdx][setIdx] = bsDiffTimeDirection[0];		
mixedTimePairXXX[paramIdx][setIdx] = mixedTimePair_flag;		
if (pairFlag) {		
bsDiffTypeXXX[paramIdx][setIdx+1] = bsDiffType[1];		
bsDiffTimeDirectionXXX[paramIdx][setIdx+1] = bsDiffTimeDirection[1];		
bsPcmCodingXXX[paramIdx][setIdx+1] = bsPcmCodingXXX[paramIdx][setIdx];		
mixedTimePairXXX[paramIdx][setIdx+1] = mixedTimePair_flag;		
}		
for (pg=0; pg<dataBands; pg++) {		
if (bsPcmCodingXXX[paramIdx][setIdx]) {		
bsXXXpcm[paramIdx][setIdx][pg] = aaDataPair[0][pg];		
else {		
bsXXXmsbDiff[paramIdx][setIdx][pg] = aaDataPairMsbDiff[0][pg];		
bsXXXlsb[paramIdx][setIdx][pg] = aaDataPairLsb[0][pg];		
}		
if (pairFlag) {		
if (bsPcmCodingXXX[paramIdx][setIdx+1]) {		
bsXXXpcm[paramIdx][setIdx+1][pg] = aaDataPair[1][pg];		
}		

<pre> else { bsXXXmsbDiff[paramIdx][setIdx+1][pg] = aaDataPairMsbDiff[1][pg]; bsXXXlsb[paramIdx][setIdx+1][pg] = aaDataPairLsb[1][pg]; } } } } </pre>
^a XXX is to be replaced by the value of dataType. (CLD, ICC, IPD).
^b numQuantStepsXXXCoarse and numQuantStepsXXXFine are defined in Table 112 and depend on dataType.

Table 64 — Syntax of DiffHuffData()

Syntax	No. of bits	Mnemonic
<pre> DiffHuffData(dataType, pairFlag, allowDiffTimeBackFlag, dataBands) { mixedTimePair_flag = 0; bsDiffType[0] = DIFF_FREQ; bsDiffType[1] = DIFF_FREQ; if (pairFlag allowDiffTimeBackFlag) { bsDiffType[0]; } if (pairFlag && ((bsDiffType[0] == DIFF_FREQ) allowDiffTimeBackFlag)) { bsDiffType[1]; } bsCodingScheme; if (bsCodingScheme == HUFF_1D) { (aaHuffData[0]) = HuffData1D(dataType, aDiffType[0], dataBands); if (pairFlag) { (aaHuffData[1]) = HuffData1D(dataType, aDiffType[1], dataBands); } } else { /* HUFF_2D */ if (pairFlag) { bsPairing; } else { bsPairing = FREQ_PAIR; } if (bsPairing == FREQ_PAIR) { (aaHuffData[0]) = HuffData2DFreqPair(dataType, aDiffType[0], dataBands); if (pairFlag) { (aaHuffData[1]) = HuffData2DFreqPair(dataType, aDiffType[1], dataBands); } } else { /* TIME_PAIR */ (aaHuffData) = HuffData2DtimePair(dataType, aDiffType, dataBands); } } } </pre>	1 1 1 1	uimbsbf uimbsbf uimbsbf uimbsbf

```

        if ( bsDiffType[0] != bsDiffType[1] ) {
            mixedTimePair_flag = 1;
        }
    }
}

/* Inverse differential coding */
if ( (bsDiffType[0] == DIFF_TIME) || (bsDiffType[1] == DIFF_TIME) ) {
    if ( !allowDiffTimeBackFlag && (bsDiffType[0] == DIFF_TIME) ) {
        bsDiffTimeDirection[0] = FORWARDS;
    }
    else if ( !pairFlag || (pairFlag && (bsDiffType[1] == DIFF_TIME)) ) {
        bsDiffTimeDirection[0] = BACKWARDS;
    }
    else {
        bsDiffTimeDirection[0];
    }
    if ( pairFlag ) {
        bsDiffTimeDirection[1] = BACKWARDS;
    }
}

return (aaHuffData, aPgOffset, mixedTimePair_flag);
}

```

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Table 65 — Syntax of HuffData1D()

Syntax	No. of bits	Mnemonic
<pre> HuffData1D(dataType, diffType, dataBands) { pgOffset = 0; if (diffType == DIFF_FREQ) { aHuffData1D[0] = 1Dhuff_dec(hcodFirstBand_XXX, bsCodeW); pgOffset = 1; } for (i=pgOffset; i<dataBands; i++) { aHuffData1D[i] = 1Dhuff_dec(hcod1D_XXX_YY, bsCodeW); if (aHuffData1D[i] != 0 && dataType != IPD) { bsSign; if (bsSign) { aHuffData1D[i] = -aHuffData1D[i]; } } } return (aHuffData1D); } </pre>	1..x 1..x 1	vlclbf a, c vlclbf a, b, c uimsbf
^a XXX is to be replaced by the value of dataType (CLD, ICC, IPD). ^b YY is to be replaced by "DF", or "DT", depending on the value of diffType. ^c 1Dhuff_dec() is defined in ISO/IEC 23003-1:2007, A.1. IPD tables required for decoding shall be defined as shown in Annex A.3.		

Table 66 — Syntax of HuffData2DFreqPair()

Syntax	No. of bits	Mnemonic
HuffData2DFreqPair(dataType, diffType, dataBands)		
{		
LavIdx = 1Dhuff_dec(hcodLavIdx, bsCodeW);	1..3	vlclbf
lav = lavTabXXX[LavIdx];		a
pgOffset = 0;		
if (diffType == DIFF_FREQ) {		
aHuffData2D[0] = 1Dhuff_dec(hcodFirstBand_XXX, bsCodeW);	1..x	vlclbf
pgOffset = 1;		
}		
escapeCode = hcod2D_XXX_YY_FP_LL_escape;		b, c, d, e
/* specific escape code belonging to this Huffman table */		
escCntr = 0;		
for (i=pgOffset; i<dataBands; i+=2) {		
(aTmp[0], aTmp[1]) = 2Dhuff_dec(hcod2D_XXX_YY_FP_LL, bsCodeW);	1..x	vlclbf , c, d, e, f
if (bsCodeWord != escapeCode) {		
aTmpSym = SymmetryData(aTmp, dataType);		
aHuffData2D[i] = aTmpSym[0];		
aHuffData2D[i+1] = aTmpSym[1];		
}		
else {		
aEscList[escCntr++] = i;		
}		
}		
if (escCntr > 0) {		
aaEscData = GroupedPcmData(dataType, 1, 2*lav+1, escCntr);		
for (i=0; i<escCntr; i++) {		
aHuffData2D[aEscList[i]] = aaEscData[0][i] - lav;		
aHuffData2D[aEscList[i]+1] = aaEscData[1][i] - lav;		
}		
}		
if ((dataBands-pgOffset) % 2) {		g
aHuffData2D[dataBands-1] = 1Dhuff_dec(hcod1D_XXX_YY, bsCodeW);	1..x	vlclbf , c, d, f
if (aHuffData2D[dataBands-1] != 0 && dataType != IPD) {		
bsSign ;	1	uimbsf
if (bsSign) {		
aHuffData2D[dataBands-1] = -aHuffData2D[dataBands-1];		
}		
}		
}		
return (aHuffData2D);		
}		

- ^a lavTabXXX is defined in Table 113.
- ^b The escape code tables are defined in Table A.4 for IPD and in ISO/IEC 23003-1:2007, Table A.8 and Table A.9 for CLD, ICC. For some Huffman tables no escape code is needed since all possible values are covered by the Huffman table.
- ^c XXX is to be replaced by the value of dataType (CLD, ICC, IPD).
- ^d YY is to be replaced by “DF”, or “DT”, depending on the value of diffType.
- ^e LL is to be replaced by the value of lav.
- ^f 1Dhuff_dec() and 2Dhuff_dec() are defined in ISO/IEC 23003-1:2007, A.1. IPD tables required for decoding shall be defined as shown in Annex A.3.
- ^g % denotes the modulo operator (ANSI C integer math) and returns the remainder of the division.

Table 67 — Syntax of HuffData2DTimePair()

Syntax	No. of bits	Mnemonic
HuffData2DTimePair(dataType, aDiffType, dataBands)		
{		
LavIdx = 1Dhuff_dec(hcodLavIdx, bsCodeW);	1..3	vlclbf
lav = lavTabXXX[LavIdx];		^a
pgOffset = 0;		
if ((aDiffType[0] == DIFF_FREQ) (aDiffType[1] == DIFF_FREQ)) {		
aaHuffData2D[0][0] = 1Dhuff_dec(hcodFirstBand_XXX, bsCodeW);	1..x	vlclbf , ^{c, f}
aaHuffData2D[1][0] = 1Dhuff_dec(hcodFirstBand_XXX, bsCodeW);	1..x	vlclbf , ^{c, f}
pgOffset = 1;		
}		
escapeCode = hcod2D_XXX_YY_TP_LL_escape;		^{b, c, d, e}
/* specific escape code belonging to this Huffman table */		
escCntr = 0;		
if ((aDiffType[0] == DIFF_TIME) (aDiffType[1] == DIFF_TIME)) {		
diffType = DIFF_TIME;		
}		
else {		
diffType = DIFF_FREQ;		
}		
for (i=pgOffset; i<dataBands; i++) {		
(aTmp[0], aTmp[1]) = 2Dhuff_dec(hcod2D_XXX_YY_TP_LL, bsCodeW);	1..x	vlclbf , ^{c, d, e, f}
if (bsCodeW != escapeCode) {		
aTmpSym = SymmetryData(aTmp, dataType);		
aaHuffData2D[0][i] = aTmpSym[0];		
aaHuffData2D[1][i] = aTmpSym[1];		
}		
else {		
aEscList[escCntr++] = i;		
}		
}		

```

if ( escCntr > 0 ) {
    aaEscData = GroupedPcmData(dataType, 1, 2*lav+1, escCntr);
    for ( i=0; i<escCntr; i++ ) {
        aaHuffData2D[0][aEscList[i]] = aaEscData[0][i] - lav;
        aaHuffData2D[1][aEscList[i]] = aaEscData[1][i] - lav;
    }
}

return (aaHuffData2D);
}

```

^a lavTabXXX is defined in Table 113.

^b The escape code tables are defined in Table A.4 for IPD and in ISO/IEC 23003-1:2007, Table A.8 and Table A.9 for CLD, ICC. For some Huffman tables no escape code is needed since all possible values are covered by the Huffman table.

^c XXX is to be replaced by the value of dataType (CLD, ICC, IPD).

^d YY is to be replaced by “DF”, or “DT”, depending on the value of diffType.

^e LL is to be replaced by the value of lav.

^f 1Dhuff_dec() and 2Dhuff_dec() are defined in ISO/IEC 23003-1:2007, A.1. IPD tables required for decoding shall be defined as shown in Annex A.3.

Table 68 — Syntax of SymmetryData()

Syntax	No. of bits	Mnemonic
<pre> SymmetryData(aDataPair, dataType) { sumVal = aDataPair[0] + aDataPair[1]; diffVal = aDataPair[0] - aDataPair[1]; if (sumVal > lav) { aDataPair[0] = (2*lav+1) - sumVal; aDataPair[1] = - diffVal; } else { aDataPair[0] = sumVal; aDataPair[1] = diffVal; } if (aDataPair[0] + aDataPair[1] != 0 && dataType != IPD) { bsSymBit[0]; if (bsSymBit[0]) { aDataPair[0] = - aDataPair[0]; aDataPair[1] = - aDataPair[1]; } } if (aDataPair[0] - aDataPair[1] != 0) { bsSymBit[1]; if (bsSymBit[1]) { tmpVal = aDataPair[0]; aDataPair[0] = aDataPair[1]; aDataPair[1] = tmpVal; } } } </pre>	1 1	uimsbf uimsbf

Table 69 — Syntax of LsbData()

Syntax	No. of bits	Mnemonic
<pre> LsbData(dataType, coarseFlag, dataBands) { for (i=0; i<dataBands; i++) { bsLsb = 0; if ((dataType == IPD) && !coarseFlag) { bsLsb; } aDataOut[i] =bsLsb; } return (aDataOut); } </pre>	1	uimsbf

Table 70 — References to MPS syntactic elements

Syntax of	Please see
EnvelopeReshapeHuff()	ISO/IEC 23003-1:2007, 5.1, Table 21
GroupedPcmData()	ISO/IEC 23003-1:2007, 5.1, Table 25

5.3.5 Payload of extension elements

Table 71 — Syntax of AudioPreRoll()

Syntax	No. of bits	Mnemonic
<pre> AudioPreRoll() { configLen = escapedValue(4,4,8); Config() applyCrossfade; reserved; numPreRollFrames = escapedValue(2,4,0); for (frameIdx=0; frameIdx < numPreRollFrames; ++frameIdx) { auLen = escapedValue(16,16,0) AccessUnit() } } </pre>	4..16 8*configLen 1 1 2..6 16..32 8*auLen	uimsbf

6 Data structure

6.1 USAC configuration

6.1.1 Definition of elements

6.1.1.1 Data elements

UsacConfig()	This element contains information about the contained audio content as well as everything needed for the complete decoder set-up.
UsacChannelConfig()	This element give information about the contained bitstream elements and their mapping to loudspeakers.

UsacDecoderConfig()	This element contains all further information required by the decoder to interpret the bitstream. In particular the SBR resampling ratio is signalled here and the structure of the bitstream is defined here by explicitly stating the number of elements and their order in the bitstream.
UsacConfigExtension()	Configuration extension mechanism to extend the configuration for future configuration extensions for USAC.
UsacSingleChannelElementConfig()	Contains all information needed for configuring the decoder to decode one single channel. This is essentially the core coder related information and if SBR is used the SBR related information.
UsacChannelPairElementConfig()	In analogy to the above, this element configuration contains all information needed for configuring the decoder to decode one channel pair. In addition to the above mentioned core config and sbr configuration this includes stereo specific configurations like the exact kind of stereo coding applied (with or without MPS212, residual etc.). This element covers all kinds of stereo coding options currently available in USAC.
UsacLfeElementConfig()	The LFE element configuration does not contain configuration data as an LFE element has a static configuration.
UsacExtElementConfig()	This element configuration can be used for configuring any kind of existing or future extensions to the codec. Each extension element type has its own dedicated type value. A length field is included in order to be able to skip over configuration extensions unknown to the decoder.
UsacCoreConfig()	Contains configuration data which have impact on the core coder set-up.
SbrConfig()	Contains default values for the configuration elements of eSBR that are typically kept constant. Furthermore, static SBR configuration elements are also carried in SbrConfig(). These static bits include flags for en- or disabling particular features of the enhanced SBR, like harmonic transposition or inter TES.
SbrDfltHeader()	This element carries a default version of the elements of the SbrHeader() that can be referred to if no differing values for these elements are desired.
Mps212Config()	All set-up parameters for the MPEG Surround 2-1-2 tools are assembled in this configuration.
escapedValue()	This element implements a general method to transmit an integer value using a varying number of bits. It features a two level escape mechanism which allows to extend the representable range of values by successive transmission of additional bits.
usacSamplingFrequencyIndex	This index determines the sampling frequency of the audio signal after decoding. The value of usacSamplingFrequencyIndex and their associated sampling frequencies are described in Table 72.

Table 72 — Value and meaning of **usacSamplingFrequencyIndex**

usacSamplingFrequencyIndex	sampling frequency
0x00	96000
0x01	88200
0x02	64000
0x03	48000
0x04	44100
0x05	32000
0x06	24000
0x07	22050
0x08	16000
0x09	12000
0x0a	11025
0x0b	8000
0x0c	7350
0x0d	reserved
0x0e	reserved
0x0f	57600
0x10	51200
0x11	40000
0x12	38400
0x13	34150
0x14	28800
0x15	25600
0x16	20000
0x17	19200
0x18	17075
0x19	14400
0x1a	12800
0x1b	9600
0x1c	reserved
0x1d	reserved
0x1e	reserved
0x1f	escape value

NOTE The values of **UsacSamplingFrequencyIndex** 0x00 up to 0x0e are identical to those of the **samplingFrequencyIndex** 0x0 up to 0xe contained in the **AudioSpecificConfig()** specified in ISO/IEC 14496-3.

usacSamplingFrequency

Output sampling frequency of the decoder coded as unsigned integer value in case **usacSamplingFrequencyIndex** is equal to the escape value.

channelConfigurationIndex

This index determines the channel configuration. If **channelConfigurationIndex** > 0 the index unambiguously defines the number of channels, channel elements and associated loudspeaker mapping according to Table 73. The names of the loudspeaker positions, the used abbreviations and the general position of the available loudspeakers can be deduced from Table 74 and Figure 2.

Table 73 — Channel configurations, meaning of channelConfigurationIndex, mapping of channel elements to loudspeaker positions

value	audio syntactic elements, listed in order received	channel to speaker mapping	Speaker abbrev.	"Front/ Surr. LFE" notation
0	–	defined in UsacChannelConfig()	–	–
1	UsacSingleChannelElement()	center front speaker	C	1/0.0
2	UsacChannelPairElement()	left, right front speakers	L, R	2/0.0
3	UsacSingleChannelElement(), UsacChannelPairElement()	center front speaker, left, right front speakers	C L,R	3/0.0
4	UsacSingleChannelElement(), UsacChannelPairElement(), UsacSingleChannelElement()	center front speaker, left, right center front speakers, center rear speakers	C L, R Cs	3/1.0
5	UsacSingleChannelElement(), UsacChannelPairElement(), UsacChannelPairElement()	center front speaker, left, right front speakers, left surround, right surround speakers	C L, R Ls, Rs	3/2.0
6	UsacSingleChannelElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacLfeElement()	center front speaker, left, right front speakers, left surround, right surround speakers, center front LFE speaker	C L, R Ls, Rs LFE	3/2.1
7	UsacSingleChannelElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacLfeElement()	center front speaker left, right center front speakers, left, right outside front speakers, left surround, right surround speakers, center front LFE speaker	C Lc, Rc L, R Ls, Rs LFE	5/2.1
8	UsacSingleChannelElement(), UsacSingleChannelElement()	channel1 channel2	N.A. N.A.	1+1
9	UsacChannelPairElement(), UsacSingleChannelElement()	left, right front speakers, center rear speaker	L, R Cs	2/1.0
10	UsacChannelPairElement(), UsacChannelPairElement()	left, right front speaker, left, right rear speakers	L, R Ls, Rs	2/2.0
11	UsacSingleChannelElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacSingleChannelElement(), UsacLfeElement()	center front speaker, left, right front speakers, left surround, right surround speakers, center rear speaker, center front LFE speaker	C L, R Ls, Rs Cs LFE	3/3.1
12	UsacSingleChannelElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacLfeElement()	center front speaker left, right front speakers, left surround, right surround speakers, left, right rear speakers, center front LFE speaker	C L, R Ls, Rs Lsr, Rsr LFE	3/4.1

value	audio syntactic elements, listed in order received	channel to speaker mapping	Speaker abbrev.	"Front/ Surr. LFE" notation
13	UsacSingleChannelElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacSingleChannelElement(), UsacLfeElement(), UsacLfeElement(), UsacSingleChannelElement(), UsacChannelPairElement(), UsacChannelPairElement(), UsacSingleChannelElement(), UsacChannelPairElement(), UsacSingleChannelElement(), UsacSingleChannelElement(), UsacChannelPairElement()	center front speaker, left, right front speakers, left, right outside front speakers, left, right side speakers, left, right back speakers, back center speaker, left front low freq. effects speaker, right front low freq. effects speaker, top center front speaker, top left, right front speakers, top left, right side speakers, center of the room ceiling speaker, top left, right back speakers, top center back speaker, bottom center front speaker, bottom left, right front speakers	C Lc, Rc L, R Lss, Rss Lsr, Rsr Cs LFE LFE2 Cv Lv, Rv Lvss, Rvss Ts Lvr, Rvr Cvr Cb Lb, Rb	11/11. 2
14- 31	reserved	reserved	reserved	

NOTE The values of **channelConfigurationIndex** 1 up to 7 are identical to those of the **channelConfiguration** 1 up to 7 contained in the MPEG-4 AudioSpecificConfig().

bsOutputChannelPos

This index describes loudspeaker positions which are associated to a given channel according to Table 74. Figure 2 indicates the loudspeaker position in the 3D environment of the listener. In order to ease the understanding of loudspeaker positions Table 74 also contains loudspeaker positions according to IEC 100/1706/CDV which are listed here for information.

Table 74 — bsOutputChannelPos

bsOutput- Channel- Pos	Loudspeaker position		Loudspeaker position according to IEC 100/1706/CDV IEC 62574 (TC100)	
	Abbr.	Name	Abbr.	Name
0	L	left front	FL	front left
1	R	right front	FR	front right
2	C	center front	FC	front centre
3	LFE	low frequency enhancement	LFE1	low frequency effects-1
4	Ls	left surround	LS	left surround
5	Rs	right surround	RS	right surround
6	Lc	left front center	FLc	front left centre
7	Rc	right front center	FRc	front right centre
8	Lsr	rear surround left	BL	back left
9	Rsr	rear surround right	BR	back right
10	Cs	rear center	BC	back centre
11	Lsd	left surround direct	LSd	left surround direct
12	Rsd	right surround direct	RSd	right surround direct
13	Lss	left side surround	SL	side left
14	Rss	right side surround	SR	side right

bsOutput- Channel- Pos	Loudspeaker position		Loudspeaker position according to IEC 100/1706/CDV IEC 62574 (TC100)	
	Abbr.	Name	Abbr.	Name
15	Lw	left wide front	FLw	front left wide
16	Rw	right wide front	FRw	front right wide
17	Lv	left front vertical height	TpFL	top front left
18	Rv	right front vertical height	TpFR	top front right
19	Cv	center front vertical height	TpFC	top front centre
20	Lvr	left surround vertical height rear	TpBL	top back left
21	Rvr	right surround vertical height rear	TpBR	top back right
22	Cvr	center vertical height rear	TpBC	top back centre
23	Lvss	left vertical height side surround	TpSiL	top side left
24	Rvss	right vertical height side surround	TpSiR	top side right
25	Ts	top center surround	TpC	top centre
26	LFE2	low frequency enhancement 2	LFE2	low frequency effects-2
27	Lb	left front vertical bottom	BtFL	bottom front left
28	Rb	right front vertical bottom	BtFR	bottom front right
29	Cb	center front vertical bottom	BtFC	bottom front centre
30	Lvs	left vertical height surround	TpLS	top left surround
31	Rvs	right vertical height surround	TpRS	top right surround

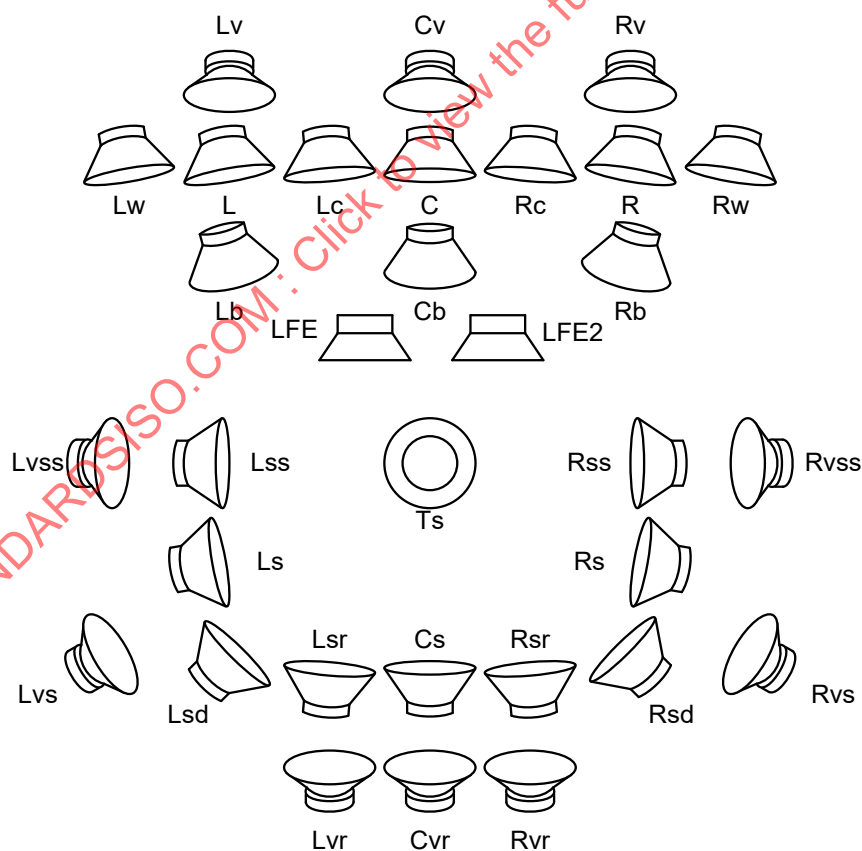


Figure 2 — Loudspeaker positions

coreSbrFrameLengthIndex This index determines the output frame length of the decoder, the sbrRatio and the sbrRatioIndex respectively, as well as the coreCoderFrameLength (ccfl) and the value of numSlots which is used in Mps212. The exact mapping can be found in Table 75:

Table 75 — Values of coreCoderFrameLength, sbrRatio, outputFrameLength and numSlots depending on coreSbrFrameLengthIndex

Index	coreCoder-FrameLength	sbrRatio (sbrRatioIndex)	output-FrameLength	Mps212 numSlots
0	768	no SBR (0)	768	N.A.
1	1024	no SBR (0)	1024	N.A.
2	768	8:3 (2)	2048	32
3	1024	2:1 (3)	2048	32
4	1024	4:1 (1)	4096	64
5...7	reserved			

usacConfigExtensionPresent Indicates the presence of extensions to the configuration.

numOutChannels If the value of channelConfigurationIndex indicates that none of the pre-defined channel configurations is used then this element determines the number of audio channels for which a specific loudspeaker position shall be associated.

numElements This field contains the number of elements that will follow in the loop over element types in the UsacDecoderConfig().

usacElementType[elemIdx] Defines the USAC channel element type of the element at position elemIdx in the bitstream. Four element types exist, one for each of the four basic bitstream elements: UsacSingleChannelElement(), UsacChannelPairElement(), UsacLfeElement(), UsacExtElement(). These elements provide the necessary top level structure while maintaining all needed flexibility. The meaning of usacElementType is defined in Table 76.

Table 76 — Value of usacElementType

usacElementType	Value
ID_USAC_SCE	0
ID_USAC_CPE	1
ID_USAC_LFE	2
ID_USAC_EXT	3

stereoConfigIndex This element determines the inner structure of a UsacChannelPairElement(). It indicates the use of a mono or stereo core, use of MPS212, whether stereo SBR is applied, and whether residual coding is applied in MPS212 according to Table 77. This element also defines the values of the helper elements **bsStereoSbr** and **bsResidualCoding**.

Table 77 — Values of stereoConfigIndex and its meaning and implicit assignment of bsStereoSbr and bsResidualCoding

stereoConfigIndex	meaning	bsStereoSbr	bsResidualCoding
0	regular CPE (no MPS212)	N/A	0
1	single channel + MPS212	N/A	0
2	two channels + MPS212	0	1
3	two channels + MPS212	1	1

tw_mdct	This flag signals the usage of the time-warped MDCT in this stream.
noiseFilling	This flag signals the usage of the noise filling of spectral holes in the FD core coder.
harmonicSBR	This flag signals the usage of the harmonic patching for the SBR.
bs_interTes	This flag signals the usage of the inter-TES tool in SBR.
bs_pvc	This flag signals the usage of the PVC tool in SBR.
dflt_start_freq	This is the default value for the bitstream element bs_start_freq, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_stop_freq	This is the default value for the bitstream element bs_stop_freq, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_header_extra1	This is the default value for the bitstream element bs_header_extra1, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_header_extra2	This is the default value for the bitstream element bs_header_extra2, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_freq_scale	This is the default value for the bitstream element bs_freq_scale, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_alter_scale	This is the default value for the bitstream element bs_alter_scale, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_noise_bands	This is the default value for the bitstream element bs_noise_bands, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_limiter_bands	This is the default value for the bitstream element bs_limiter_bands, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_limiter_gains	This is the default value for the bitstream element bs_limiter_gains, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.
dflt_interpol_freq	This is the default value for the bitstream element bs_interpol_freq, which is applied in case the flag sbrUseDfltHeader indicates that default values for the SbrHeader() elements shall be assumed.

- dflt_smoothing_mode** This is the default value for the bitstream element `bs_smoothing_mode`, which is applied in case the flag `sbrUseDfltHeader` indicates that default values for the `SbrHeader()` elements shall be assumed.
- usacExtElementType** this element allows to signal bitstream extensions types. The meaning of `usacExtElementType` is defined in Table 78.

Table 78 — Value of `usacExtElementType`

<code>usacExtElementType</code>	Value
ID_EXT_ELE_FILL	0
ID_EXT_ELE_MPEGS	1
ID_EXT_ELE_SAOC	2
ID_EXT_ELE_AUDIOPREROLL	3
ID_EXT_ELE_UNI_DRC	4
/* reserved for ISO use */	5-127
/* reserved for use outside of ISO scope */	128 and higher
NOTE Application-specific <code>usacExtElementType</code> values are mandated to be in the space reserved for use outside of ISO scope. These are skipped by a decoder as a minimum of structure is required by the decoder to skip these extensions.	

- usacExtElementConfigLength** Signals the length of the extension configuration in bytes (octets).
- usacExtElementDefaultLengthPresent** This flag signals whether a `usacExtElementDefaultLength` is conveyed in the `UsacExtElementConfig()`.
- usacExtElementDefaultLength** Signals the default length of the extension element in bytes. Only if the extension element in a given access unit deviates from this value, an additional length needs to be transmitted in the bitstream. If this element is not explicitly transmitted (`usacExtElementDefaultLengthPresent==0`) then the value of `usacExtElementDefaultLength` shall be set to zero.
- usacExtElementPayloadFrag** This flag indicates whether the payload of this extension element may be fragmented and send as several segments in consecutive USAC frames.
- numConfigExtensions** If extensions to the configuration are present in the `UsacConfig()` this value indicates the number of signalled configuration extensions.
- confExtIdx** Index to the configuration extensions.
- usacConfigExtType** This element allows to signal configuration extension types. The meaning of `usacConfigExtType` is defined in Table 79.

Table 79 — Value of `usacConfigExtType`

<code>usacConfigExtType</code>	Value
ID_CONFIG_EXT_FILL	0
/* reserved for ISO use */	1
ID_CONFIG_EXT_LOUDNESS_INFO	2
/* reserved for ISO use */	3...6
ID_CONFIG_EXT_STREAM_ID	7
/* reserved for ISO use */	8-127
/* reserved for use outside of ISO scope */	128 and higher

usacConfigExtLength Signals the length of the configuration extension in bytes (octets).

bsPseudoLr This flag signals that an inverse mid/side rotation should be applied to the core signal prior to Mps212 processing. Table 80 gives the allowed values and the corresponding meaning of bsPseudoLr.

Table 80 — bsPseudoLr

bsPseudoLr	Meaning
0	Core decoder output is DMX/RES
1	Core decoder output is Pseudo L/R

6.1.1.2 Helper Elements

coreCoderFrameLength Frame length of core-coder, i.e., number of valid samples output by FD/LPD core-decoder. coreCoderFrameLength is determined as outputFrameLength/sbrRatio.

bsStereoSbr This flag signals the usage of the stereo SBR in combination with MPEG Surround decoding. The value of bsStereoSbr is defined by stereoConfigIndex (see Table 77). Table 81 gives the allowed values and the corresponding meaning of bsStereoSbr.

Table 81 — bsStereoSbr

bsStereoSbr	Meaning
0	Mono SBR
1	Stereo SBR

bsResidualCoding Indicates whether residual coding is applied according to Table 82. The value of bsResidualCoding is defined by stereoConfigIndex (see Table 77).

Table 82 — bsResidualCoding

bsResidualCoding	Meaning
0	no residual coding, core coder is mono
1	residual coding, core coder is stereo

sbrRatioIndex Indicates the ratio between the core sampling rate and the sampling rate after eSBR processing. At the same time it indicates the number of QMF analysis and synthesis bands used in SBR according to the Table 83.

Table 83 — Definition of sbrRatioIndex

sbrRatioIndex	sbrRatio	QMF band ratio (analysis:synthesis)
0	no SBR	-
1	4:1	16:64
2	8:3	24:64
3	2:1	32:64

elemIdx Index to the elements present in the UsacDecoderConfig() and the UsacFrame().

6.1.2 UsacConfig()

The UsacConfig() contains information about output sampling frequency and channel configuration. This information shall be identical to the information signalled outside of this element, e.g., in an MPEG-4 AudioSpecificConfig().

6.1.3 Usac Output Sampling Frequency

If the sampling rate is not one of the rates listed in the right column in Table 84, the sampling frequency dependent tables (code tables, scale factor band tables etc.) shall be deduced in order for the bitstream payload to be parsed. Since a given sampling frequency is associated with only one sampling frequency table, and since maximum flexibility is desired in the range of possible sampling frequencies, Table 84 shall be used to associate an explicitly signalled sampling frequency (i.e., via usacSamplingFrequencyIndex) with the desired sampling frequency dependent tables.

Table 84 — Sampling frequency mapping

Frequency range (in Hz)	Use tables for sampling frequency (in Hz)
$f \geq 92017$	96000
$92017 > f \geq 75132$	88200
$75132 > f \geq 55426$	64000
$55426 > f \geq 46009$	48000
$46009 > f \geq 37566$	44100
$37566 > f \geq 27713$	32000
$27713 > f \geq 23004$	24000
$23004 > f \geq 18783$	22050
$18783 > f \geq 13856$	16000
$13856 > f \geq 11502$	12000
$11502 > f \geq 9391$	11025
$9391 > f$	8000

6.1.4 UsacChannelConfig()

The channel configuration table covers most common loudspeaker positions. For further flexibility channels can be mapped to an overall selection of 32 loudspeaker positions found in modern loudspeaker setups in various applications (see Table 74).

For each channel contained in the bitstream the UsacChannelConfig() specifies the associated loudspeaker position to which this particular channel shall be mapped. The loudspeaker positions which are indexed by bsOutputChannelPos are listed in Table 74. In case of multiple channel elements the index i of bsOutputChannelPos[i] indicates the position in which the channel appears in the bitstream. Figure 2 gives an overview over the loudspeaker positions in relation to the listener.

More precisely the channels are numbered in the sequence in which they appear in the bitstream starting with 0 (zero). In the trivial case of a UsacSingleChannelElement() or UsacLfeElement() the channel number is assigned to that channel and the channel count is increased by one. In case of a UsacChannelPairElement() the first channel in that element (with index $ch=0$) is numbered first, whereas the second channel in that same element (with index $ch=1$) receives the next higher number and the channel count is increased by two.

It follows that numOutChannels shall be equal to or smaller than the accumulated sum of all channels contained in the bitstream. The accumulated sum of all channels is equivalent to the number of all UsacSingleChannelElement()s plus the number of all UsacLfeElement()s plus two times the number of all UsacChannelPairElement()s.

All entries in the array bsOutputChannelPos shall be mutually distinct in order to avoid double assignment of loudspeaker positions in the bitstream.

In the special case that `channelConfigurationIndex` is 0 and `numOutChannels` is smaller than the accumulated sum of all channels contained in the bitstream, then the handling of the non-assigned channels is outside of the scope of this specification. Information about this can, e.g., be conveyed by appropriate means in higher application layers or by specifically designed (private) extension payloads.

6.1.5 `UsacDecoderConfig()`

The `UsacDecoderConfig()` contains all further information required by the decoder to interpret the bitstream. Firstly the value of `sbrRatioIndex` determines the ratio between core coder frame length (`ccfl`) and the output frame length. Following the `sbrRatioIndex` is a loop over all channel elements in the present bitstream. For each iteration the type of element is signalled in `usacElementType[]`, immediately followed by its corresponding configuration structure. The order in which the various elements are present in the `UsacDecoderConfig()` shall be identical to the order of the corresponding payload in the `UsacFrame()`.

Each instance of an element can be configured independently. When reading each channel element in `UsacFrame()`, for each element the corresponding configuration of that instance, ie. with the same `elemIdx`, shall be used.

6.1.6 `UsacSingleChannelElementConfig()`

The `UsacSingleChannelElementConfig()` contains all information needed for configuring the decoder to decode one single channel. SBR configuration data is only transmitted if SBR is actually employed.

6.1.7 `UsacChannelPairElementConfig()`

The `UsacChannelPairElementConfig()` contains core coder related configuration data as well as SBR configuration data depending on the use of SBR. The exact type of stereo coding algorithm is indicated by the `stereoConfigIndex`. In USAC a channel pair can be encoded in various ways. These are:

- a) Stereo core coder pair using traditional joint stereo coding techniques, extended by the possibility of complex prediction in the MDCT domain.
- b) Mono core coder channel in combination with MPEG Surround based MPS212 for fully parametric stereo coding. Mono SBR processing is applied on the core signal.
- c) Stereo core coder pair in combination with MPEG Surround based MPS212, where the first core coder channel carries a downmix signal and the second channel carries a residual signal. The residual may be band limited to realize partial residual coding. Mono SBR processing is applied only on the downmix signal *before* MPS212 processing.
- d) Stereo core coder pair in combination with MPEG Surround based MPS212, where the first core coder channel carries a downmix signal and the second channel carries a residual signal. The residual may be band limited to realize partial residual coding. Stereo SBR is applied on the reconstructed stereo signal *after* MPS212 processing.

Option c) and d) can be further combined with a pseudo LR channel rotation after the core decoder.

6.1.8 `UsacLfeElementConfig()`

Since the use of the time warped MDCT and noise filling is not allowed for LFE channels, there is no need to transmit the usual core coder flag for these tools. They shall be set to zero instead. Similarly the use of SBR is not allowed nor meaningful in an LFE context. Thus, SBR configuration data is not transmitted.

6.1.9 `UsacCoreConfig()`

The `UsacCoreConfig()` only contains flags to en- or disable the use of the time warped MDCT and spectral noise filling on a global bitstream level. If `tw_mdct` is set to zero, time warping shall not be applied. If `noiseFilling` is set to zero the spectral noise filling shall not be applied.

6.1.10 SbrConfig()

The SbrConfig() bitstream element serves the purpose of signalling the exact eSBR setup parameters. On one hand the SbrConfig() signals the general employment of eSBR tools. On the other hand it contains a default version of the SbrHeader(), the SbrDfltHeader(). The values of this default header shall be assumed if no differing SbrHeader() is transmitted in the bitstream. The background of this mechanism is, that typically only one set of SbrHeader() values are applied in one bitstream. The transmission of the SbrDfltHeader() then allows to refer to this default set of values very efficiently by using only one bit in the bitstream. The possibility to vary the values of the SbrHeader on the fly is still retained by allowing the in-band transmission of a new SbrHeader in the bitstream itself.

6.1.11 SbrDfltHeader()

The SbrDfltHeader() is what may be called the basic SbrHeader() template and should contain the values for the predominantly used eSBR configuration. In the bitstream this configuration can be referred to by setting the sbrUseDfltHeader flag to 1. The structure of the SbrDfltHeader() is identical to that of SbrHeader(). In order to be able to distinguish between the values of the SbrDfltHeader() and SbrHeader(), the bit fields in the SbrDfltHeader() are prefixed with "dflt_" instead of "bs_". If the use of the SbrDfltHeader() is indicated, then the SbrHeader() bit fields shall assume the values of the corresponding SbrDfltHeader(), i.e.:

```
bs_start_freq = dflt_start_freq;
bs_stop_freq = dflt_stop_freq;
etc.
(continue for all elements in SbrHeader(), like:
bs_xxx_yyy = dflt_xxx_yyy;
```

6.1.12 Mps212Config()

The Mps212Config() resembles the SpatialSpecificConfig() of MPEG Surround and was in large parts deduced from that. It is however reduced in extent to contain only information relevant for mono to stereo upmixing in the USAC context. Consequently MPS212 configures only one OTT box.

6.1.13 UsacExtElementConfig()

The UsacExtElementConfig() is a general container for configuration data of extension elements for USAC. Each USAC extension has a unique type identifier, usacExtElementType, which is defined in Table 78. For each UsacExtElementConfig() the length of the contained extension configuration is transmitted in the variable usacExtElementConfigLength and allows decoders to safely skip over extension elements whose usacExtElementType is unknown.

For USAC extensions which typically have a constant payload length, the UsacExtElementConfig() allows the transmission of a usacExtElementDefaultLength. Defining a default payload length in the configuration allows a highly efficient signalling of the usacExtElementPayloadLength inside the UsacExtElement(), where bit consumption needs to be kept low.

In case of USAC extensions where a larger amount of data is accumulated and transmitted not on a per frame basis but only every second frame or even more rarely, this data may be transmitted in fragments or segments spread over several USAC frames. This can be helpful in order to keep the bit reservoir more equalized. The use of this mechanism is signalled by the flag usacExtElementPayloadFrag flag. The fragmentation mechanism is further explained in the description of the usacExtElement in 6.2.4.

6.1.14 UsacConfigExtension()

The UsacConfigExtension() is a general container for extensions of the UsacConfig(). It provides a convenient way to amend or extend the information exchanged at the time of the decoder initialization or set-up. The presence of config extensions is indicated by usacConfigExtensionPresent. If config extensions are present (usacConfigExtensionPresent==1), the exact number of these extensions follows in the bit field numConfigExtensions. Each configuration extension has a unique type identifier, usacConfigExtType, which is defined in Table 79. For each UsacConfigExtension the length of the contained configuration extension is

transmitted in the variable `usacConfigExtLength` and allows the configuration bitstream parser to safely skip over configuration extensions whose `usacConfigExtType` is unknown.

6.1.15 Unique stream identifier (Stream ID)

6.1.15.1 Semantics

streamIdentifier A two byte unsigned integer stream identifier (stream ID) that shall uniquely identify a configuration of a stream within a set of associated streams that are intended for seamless switching between them. **streamIdentifier** can take values from 0 to 65535.
When being part of an MPEG-DASH adaptation set as defined in ISO/IEC 23009, all stream IDs of streams in that DASH adaptation set shall be pairwise distinct.

6.1.15.2 Stream identifier description

Configuration extensions of type `ID_CONFIG_EXT_STREAM_ID` provide a container for signalling a stream identifier (short: "stream ID"). The stream ID config extension allows attaching a unique integer number to a configuration structure such that audio bitstream configurations of two streams can be distinguished even if the rest of the configuration structure is (bit-) identical.

The `usacConfigExtLength` of a config extension of type `ID_CONFIG_EXT_STREAM_ID` shall have the value 2 (two).

Any given audio bitstream shall not have more than one configuration extension of type `ID_CONFIG_EXT_STREAM_ID`.

If a running decoder receives a new configuration structure, for example by means of a `Config()` in an `ID_EXT_ELE_AUDIOPREROLL` extension payload, it shall compare this new configuration structure with the currently active configuration as defined in 7.18.3.3. Such comparison may be conducted by means of a bit-wise comparison of the corresponding configuration structures.

If the configuration structures contain configuration extensions then all configuration extensions up to and including (with respect to the order in which they appear in the bitstream) the configuration extension of type `ID_CONFIG_EXT_STREAM_ID` shall be included in the comparison. Configuration extensions following the configuration extension of type `ID_CONFIG_EXT_STREAM_ID` are not required to be considered during the comparison.

NOTE The above rule allows an encoder to control whether changes in particular configuration extensions will cause a decoder reconfiguration or not.

6.2 USAC payload

6.2.1 Definition of elements

6.2.1.1 Top level and subsidiary data elements

UsacFrame() This block of data contains audio data for a time period of one USAC frame, related information and other data. As signalled in `UsacDecoderConfig()`, the `UsacFrame()` contains `numElements` elements. These elements can contain audio data, for one or two channels, audio data for low frequency enhancement or extension payload.

UsacSingleChannelElement() Abbreviation SCE. Syntactic element of the bitstream containing coded data for a single audio channel. A `single_channel_element()` basically consists of the `UsacCoreCoderData()`, containing data for either FD or LPD core coder. In case SBR is active, the `UsacSingleChannelElement` also contains SBR data.

UsacChannelPairElement()	Abbreviation CPE. Syntactic element of the bitstream payload containing data for a pair of channels. The channel pair can be achieved either by transmitting two discrete channels or by one discrete channel and related Mps212 payload. This is signalled by means of the stereoConfigIndex. The UsacChannelPairElement further contains SBR data in case SBR is active.
UsacLfeElement()	Abbreviation LFE. Syntactic element that contains a low sampling frequency enhancement channel. LFEs are always encoded using the fd_channel_stream() element.
UsacExtElement()	Syntactic element that contains extension payload. The length of an extension element is either signalled as a default length in the configuration (USACExtElementConfig()) or signalled in the UsacExtElement() itself. If present, the extension payload is of type usacExtElementType, as signalled in the configuration.
usacIndependencyFlag	indicates if the current UsacFrame() can be decoded entirely without the knowledge of information from previous frames according to the Table 85.

Table 85 — Meaning of usacIndependencyFlag

value of usacIndependencyFlag	Meaning
0	Decoding of data conveyed in UsacFrame() might require access to the previous UsacFrame().
1	Decoding of data conveyed in UsacFrame() is possible without access to the previous UsacFrame().

NOTE Refer to B.3 for recommendations on the use of the usacIndependencyFlag.

usacExtElementUseDefaultLength

Indicates whether the length of the extension element corresponds to usacExtElementDefaultLength, which was defined in the sacExtElementConfig().

usacExtElementPayloadLength

Shall contain the length of the extension element in bytes. This value should only be explicitly transmitted in the bitstream if the length of the extension element in the present access unit deviates from the default value, sacExtElementDefaultLength.

usacExtElementStart

Indicates if the present usacExtElementSegmentData *begins* a data block.

usacExtElementStop

Indicates if the present usacExtElementSegmentData *ends* a data block.

usacExtElementSegmentData

The concatenation of all usacExtElementSegmentData from UsacExtElement() of consecutive USAC frames, starting from the UsacExtElement() with usacExtElementStart==1 up to and including the UsacExtElement() with usacExtElementStop==1 forms one data block. In case a complete data block is contained in one UsacExtElement(), usacExtElementStart and usacExtElementStop shall both be set to 1. The data blocks are interpreted as a byte aligned extension payload depending on usacExtElementType according to Table 86.

Table 86 — Interpretation of data blocks for USAC extension payload decoding

usacExtElementType	Concatenated usacExtElementSegmentData represents:
ID_EXT_ELE_FIL	Series of fill_byte
ID_EXT_ELE_MPEGS	SpatialFrame()
ID_EXT_ELE_SAOC	SaocFrame()
ID_EXT_ELE_AUDIOPREROLL	AudioPreRoll()
ID_EXT_ELE_UNI_DRC	uniDrcGain() as defined in ISO/IEC 23003-4
unknown	unknown data. The data block shall be discarded.

fill_byte	Octet of bits which may be used to pad the bitstream with bits that carry no information. The exact bit pattern used for fill_byte should be '10100101'.
UsacCoreCoderData()	This block of data contains the core-coder audio data. The payload element contains data for one or two core-coder channels, for either FD or LPD mode. The specific mode is signalled per channel at the beginning of the element.
StereoCoreToolInfo()	All stereo related information is captured in this element. It deals with the numerous dependencies of bits fields in the stereo coding modes.
Mps212Data()	This block of data contains payload for the Mps212 stereo module. The presence of this data is dependent on the stereoConfigIndex.

6.2.1.2 Helper elements

nrCoreCoderChannels	In the context of a channel pair element this variable indicates the number of core coder channels which form the basis for stereo coding. Depending on the value of stereoConfigIndex this value shall be 1 or 2.
nrSbrChannels	In the context of a channel pair element this variable indicates the number of channels on which SBR processing is applied. Depending on the value of stereoConfigIndex this value shall be 1 or 2.

6.2.2 UsacFrame()

One UsacFrame() forms one access unit of the USAC bitstream. Each UsacFrame decodes into 768, 1024, 2048 or 4096 output samples according to the outputFrameLength determined from Table 75.

The first bit in the UsacFrame() is the usacIndependencyFlag, which determines if a given frame can be decoded without any knowledge of the previous frame. If the usacIndependencyFlag is set to 0, then dependencies to the previous frame may be present in the payload of the current frame.

The UsacFrame() is further made up of one or more syntactic elements which shall appear in the bitstream in the same order as their corresponding configuration elements in the UsacDecoderConfig(). The position of each element in the series of all elements is indexed by elemIdx. For each element the corresponding configuration, as transmitted in the UsacDecoderConfig(), of that instance, ie. with the same elemIdx, shall be used.

These syntactic elements are of one of four types, which are listed in Table 76. The type of each of these elements is determined by usacElementType. There may be multiple elements of the same type. Table 87 gives examples of straightforward combinations of different types of syntactic elements for typical loudspeaker layouts. Elements occurring at the same position elemIdx in different frames shall belong to the same stream.

Table 87 — Examples of simple possible bitstream payloads

	numElements	elemIdx	usacElementType[elemIdx]
mono output signal	1	0	ID_USAC_SCE
stereo output signal	1	0	ID_USAC_CPE
5.1 channel output signal	4	0	ID_USAC_SCE
		1	ID_USAC_CPE
		2	ID_USAC_CPE
		3	ID_USAC_LFE

If these bitstream payloads are to be transmitted over a constant rate channel then they may include an extension payload element with an usacExtElementType of ID_EXT_ELE_FILL to adjust the instantaneous bit rate. An example of such a coded stereo signal is shown in Table 88.

Table 88 — Example of simple stereo bitstream with extension payload for writing fill bits

	numElements	elemIdx	usacElementType[elemIdx]
stereo output signal	2	0	ID_USAC_CPE
		1	ID_USAC_EXT with usacExtElementType== ID_EXT_ELE_FILL

6.2.3 UsacSingleChannelElement()

The simple structure of the UsacSingleChannelElement() is made up of one instance of a UsacCoreCoderData() element with nrCoreCoderChannels set to 1. Depending on the sbrRatioIndex of this element a UsacSbrData() element follows with nrSbrChannels set to 1 as well.

6.2.4 UsacExtElement()

UsacExtElement() structures in a bitstream can be decoded or skipped by a USAC decoder. Every extension is identified by a usacExtElementType, conveyed in the UsacExtElement()'s associated UsacExtElementConfig(). For each usacExtElementType a specific decoder can be present.

If a decoder for the extension is available to the USAC decoder then the payload of the extension is forwarded to the extension decoder immediately after the UsacExtElement() has been parsed by the USAC decoder.

If no decoder for the extension is available to the USAC decoder, a minimum of structure is provided within the bitstream, so that the extension can be ignored by the USAC decoder.

The length of an extension element is either specified by a default length in octets, which can be signalled within the corresponding UsacExtElementConfig() and which can be overruled in the UsacExtElement(), or by an explicitly provided length information in the UsacExtElement(), which is either one or three octets long, using the syntactic element escapedValue().

Extension payloads that span one or more UsacFrame()s can be fragmented and their payload be distributed among several UsacFrame()s. In this case the usacExtElementPayloadFlag flag is set to 1 and a decoder shall collect all fragments from the UsacFrame() with usacExtElementStart set to 1 up to and including the UsacFrame() with usacExtElementStop set to 1. When usacExtElementStop is set to 1 then the extension is considered to be complete and is passed to the extension decoder.

Integrity protection for a fragmented extension payload is not provided by this specification and other means should be used to ensure completeness of extension payloads.

All extension payload data is assumed to be byte-aligned.

Each UsacExtElement() shall obey the requirements resulting from the use of the usacIndependencyFlag. Put more explicitly, if the usacIndependencyFlag is set (==1) the UsacExtElement() shall be decodable without knowledge of the previous frame (and the extension payload that may be contained in it).

6.2.5 UsacChannelPairElement()

6.2.5.1 Definition of elements

6.2.5.1.1 Data elements

common_max_sfb Signals the use of a common maximum scalefactor band for channels 0 and 1.

Table 89 — common_max_sfb

common_max_sfb	Meaning
0	max_sfb1 determines the maximum scalefactor band for channel 1
1	set max_sfb1 for channel 1 to the same maximum scalefactor band as for channel 0

common_window Indicates if channel 0 and channel 1 of a CPE use identical window parameters.

common_tw Indicates if channel 0 and channel 1 of a CPE use identical parameters for the time warped MDCT.

max_sfb1 Defines the number of scalefactor bands transmitted per group for channel 1.

6.2.5.1.2 Help elements

max_sfb_ste Maximum scalefactor bands transmitted for channels 0 and 1: max(max_sfb, max_sfb1).

6.2.5.2 Decoding process

The stereoConfigIndex, which is transmitted in the UsacChannelPairElementConfig(), determines the exact type of stereo coding which is applied in the given CPE. Depending on this type of stereo coding either one or two core coder channels are actually transmitted in the bitstream and the variable nrCoreCoderChannels needs to be set accordingly. The syntax element UsacCoreCoderData() then provides the data for one or two core coder channels.

Similarly there may be data available for one or two channels depending on the type of stereo coding and the use of eSBR (ie. if sbrRatioIndex>0). The value of nrSbrChannels needs to be set accordingly and the syntax element UsacSbrData() provides the eSBR data for one or two channels.

Finally Mps212Data() is transmitted depending on the value of stereoConfigIndex.

6.2.6 Low frequency enhancement (LFE) channel element, UsacLfeElement()

In order to maintain a regular structure in the decoder, the UsacLfeElement() is defined as a standard fd_channel_stream(0,0,0,0,x) element, i.e., it is equal to a UsacCoreCoderData() using the frequency domain coder. Thus, decoding can be done using the standard procedure for decoding a UsacCoreCoderData()-element.

In order to accommodate a more bit rate and hardware efficient implementation of the LFE decoder, however, several restrictions apply to the options used for the encoding of this element:

- The window_sequence field is always set to 0 (ONLY_LONG_SEQUENCE).
- Only the lowest 24 spectral coefficients of any LFE may be non-zero.
- No temporal noise shaping is used, i.e., tns_data_present is set to 0.
- Time warping is not active.
- No noise filling is applied.

6.2.7 UsacCoreCoderData()

6.2.7.1 Definition of elements

core_mode[ch] Indicates the core coding mode of the current frame for each channel according to Table 90.

Table 90 — Definition of core_mode

value of core_mode	Meaning
0	FD core coder mode
1	LPD core coder mode

6.2.7.2 Decoding process

The UsacCoreCoderData() contains all information for decoding one or two core coder channels.

The order of decoding is:

- get the core_mode[] for each channel;
- in case of two core coded channels (nrChannels==2), parse the StereoCoreToolInfo() and determine all stereo related parameters;
- depending on the signalled core_modes transmit an lpd_channel_stream() or an fd_channel_stream() for each channel.

As can be seen from the above list, the decoding of one core coder channel (nrChannels==1) results in obtaining the core_mode bit followed by one lpd_channel_stream or fd_channel_stream, depending on the core_mode.

In the two core coder channel case, some signalling redundancies between channels can be exploited in particular if the core_mode of both channels is 0. See 6.2.8 for details.

6.2.8 StereoCoreToolInfo()

The StereoCoreToolInfo() allows to efficiently code parameters, whose values may be shared across core coder channels of a CPE in case both channels are coded in FD mode (core_mode[0,1]==0). Table 91 gives the specific shared data elements when the appropriate flag in the bitstream is set to 1.

Table 91 — Bitstream elements shared across channels of a core coder channel pair

common_xxx flag is set to 1	channels 0 and 1 share the following elements:
common_window	ics_info()
common_window && common_max_sfb	max_sfb
common_tw	tw_data()
common_tns	tns_data()

If the appropriate flag is not set then the data elements are transmitted individually for each core coder channel either in StereoCoreToolInfo() (max_sfb, max_sfb1) or in the fd_channel_stream() which follows the StereoCoreToolInfo() in the the UsacCoreCoderData() element.

In case of common_window==1 the StereoCoreToolInfo() also contains the information about M/S stereo coding and complex prediction data in the MDCT domain (see 7.7).

6.2.9 fd_channel_stream() and ics_info()

6.2.9.1 Definition of elements

6.2.9.1.1 Data elements

fd_channel_stream() Contains data necessary to decode one frequency domain channel.

fac_data_present Flag which indicates the presence of the fac_data() syntax element in the bitstream, as used for transitions between two different core coding modes (LPD core coding mode, FD core coding mode). Table 92 gives the usage of fac_data() for each case of fac_data_present.

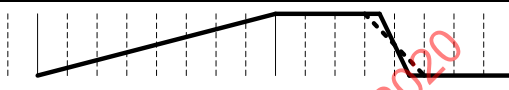
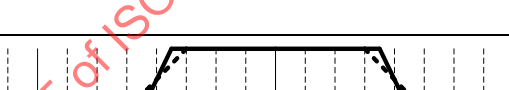
Table 92 — Definition of fac_data_present

value of fac_data_present	Meaning
0	fac_data() data element as used for transitions between two different core coding modes not present in current frame
1	fac_data() data element as used for transitions between two different core coding modes present in current frame

ics_info() Contains side information necessary to decode an fd_channel_stream() for SCE and CPE elements. The fd_channel_streams of a UsacChannelPairElement() may share one common ics_info. If **common_max_sfb** == 0, **max_sfb1** determines the maximum scalefactor band per group for channel 1 instead of **max_sfb** in ics_info().

window_sequence Indicates the sequence of windows as defined in Table 93.

Table 93 — Window sequences and transform windows dependent of coreCoderFrameLength (ccfl)

Value	Window	#coeffs	Window shape (schematic)
0	ONLY_LONG_SEQUENCE = LONG_WINDOW	ccfl	
1	LONG_START_SEQUENCE = LONG_START_WINDOW	ccfl	
2	EIGHT_SHORT_SEQUENCE = 8 * SHORT_WINDOW	8*(ccfl/8)	
3	LONG_STOP_SEQUENCE = LONG_STOP_WINDOW	ccfl	
1	STOP_START_SEQUENCE = STOP_START_WINDOW	ccfl	
NOTE Dashed lines indicate window shape when the adjacent window sequence is LPD_SEQUENCE.			

window_shape

A 1 bit field that determines what window is used for the right-hand part of this analysis window.

max_sfb

Number of scalefactor bands per group. If **common_window** == 1, **max_sfb** refers to channel 0 and **max_sfb1** is the maximum scalefactor band for channel 1.

scale_factor_grouping

A bit field that contains information about grouping of short spectral data.

fac_data()

Syntax element which contains all data for the forward aliasing cancellation (FAC) tool, which is operated at transitions between ACELP and transform coder.

6.2.9.1.2 Help elements

For the purpose of this clause, the definition of help elements given in ISO/IEC 14496-3:2019, 4.5.2.3.1.2, and the following apply:

lg

Number of quantized spectral coefficients output by the arithmetic decoder.

last_lpd_mode

See definition of last_lpd_mode in 6.2.10.2.

6.2.9.2 Decoding process

6.2.9.2.1 Decoding an fd_channel_stream (FCS)

In the fd_channel_stream, the order of decoding is:

- Get global_gain.
- Get noise filling, if present.

- Get ics_info (parse bitstream payload if common information is not present).
- Get tw_data (parse bitstream payload if common information is not present), if the time-warped filterbank tool is active.
- Get scale_factor_data, if present.
- Get tns_data, if present.
- Get ac_spectral_data, if present.

The process of recovering tns_data is described in ISO/IEC 14496-3:2019, 4.6.9. An overview of how to decode ics_info, scale_factor_data, and ac_spectral_data is given in 6.2.9.2.2 through 6.2.9.2.4.

6.2.9.2.2 Recovering ics_info()

For UsacSingleChannelElement()'s ics_info is located after the global_gain and optional noiseFilling data in the fd_channel_stream. For a channel pair element there are two possible locations for the ics_info.

In case of UsacChannelPairElement() if the common_window flag is set to 1 both channels share the same ics_info() (i.e., both have same window_sequence, same window_shape, same scale_factor_grouping, same max_sfb etc.). An exception to this occurs when **common_max_sfb** == 0. In this case **max_sfb1** determines the maximum scalefactor band per group for channel 1. Otherwise (i.e., common_window is set to 0) there is an ics_info after the global_gain and optional noiseFilling data for each of the two fd_channel_stream()s.

The ics_info() carries the window information associated with an FCS and thus permits channels in a channel_pair to switch separately if desired. The variable max_sfb_ste determines the number of ms_used[] bits that shall be transmitted. If the window_sequence is EIGHT_SHORT_SEQUENCE then scale_factor_grouping is transmitted. If a set of short windows form a group then they share scalefactors as well as M/S information. The first short window is always a new group so no grouping bit is transmitted. Subsequent short windows are in the same group if the associated grouping bit is 1. A new group is started if the associated grouping bit is 0. It is assumed that grouped short windows have similar signal statistics.

6.2.9.2.3 scale_factor_data() parsing and decoding

Since there is no section_data() in the bitstream, a standard sectioning has to be defined to ensure correct scalefactor decoding as describes in ISO/IEC 14496-3:2019, 4.4.2.7, Table 4.55:

```
section_data() {
    for ( g = 0 ; g < num_window_groups; g++ ) {
        k=0;
        for ( k = 0 ; k < max_sfb ; k++ ) {
            sfb_cb[g][k] = 11;
        }
    }
}
```

For channel 1, max_sfb is set equal to max_sfb1 if **common_window** == 1. For each scalefactor band a scalefactor is transmitted. global_gain, the first data element in an fd_channel_stream(), equals the value of the first scalefactor in that fd_channel_stream(). All scalefactors following the first scalefactor are transmitted using Huffman coded DPCM relative to the previous scalefactor. The DPCM value of the first scalefactor (relative to the global_gain) always represents zero and is thus not transmitted. The actual decoding of the scale factors remains identical to the description in ISO/IEC 14496-3. Once the scalefactors are decoded, the actual values are found via a power function.

6.2.9.2.4 ac_spectral_data() parsing and decoding

The value lg of quantized spectral coefficients is needed for parsing the spectral data syntax element. In `fd_channel_stream()` lg is determined by `max_sfb` according to the following formula:

$$lg = \begin{cases} \text{swb_offset_short_window}[\text{max_sfb}], & \text{in case of EIGHT_SHORT_SEQUENCE} \\ \text{swb_offset_long_window}[\text{max_sfb}], & \text{otherwise} \end{cases}$$

For further details on parsing and decoding of `ac_spectral_data()`, refer to 7.4.

6.2.9.3 Windows and window sequences

Quantization and coding is done in the frequency domain. For this purpose, the time signal is mapped into the frequency domain in the encoder. The decoder performs the inverse mapping as described in 7.9. Depending on the signal, the coder may change the time/frequency resolution by using two different windows sizes of size $2 \times \text{coreCoderFrameLength}$ and $2 \times \text{coreCoderFrameLength}/8$. To switch between windows, the transition windows LONG_START_WINDOW, LONG_STOP_WINDOW, and STOP_START_WINDOW are used. Table 93 lists the windows, specifies the corresponding transform length and shows the shape of the windows schematically. Two transform lengths are used: `coreCoderFrameLength` (referred to as long transform) and `coreCoderFrameLength/8` (referred to as short transform).

Window sequences are composed of windows in a way that a raw data block always contains data representing `coreCoderFrameLength` output samples. The data element **window sequence** indicates the window sequence that is actually used. Table 93 lists how the window sequences are composed of individual windows. Refer to 7.9 for more detailed information about the transform and the windows.

6.2.9.4 Scalefactor bands and grouping

See ISO/IEC 14496-3:2019, 4.5.2.3.4.

As explained in ISO/IEC 14496-3:2019, 4.5.2.3.4, the width of the scalefactor bands is built in imitation of the critical bands of the human auditory system. For that reason the number of scalefactor bands in a spectrum and their width depend on the transform length and the sampling frequency. ISO/IEC 14496-3:2009, 4.5.4, Tables 4.147 to 4.165 list the offset to the beginning of each scalefactor band on the transform lengths 1024 and 128 and on the sampling frequencies (window length of 2048 and 256).

For a transform length of 768 samples, the same 1024-based scalefactor band tables are used, but those corresponding to *4/3 sampling frequency*. In case a shorter transform length (dependent on `coreCoderFrameLength`) is used, `swb_offset_long_window` and `swb_offset_short_window` are limited to the size of the transform length, and `num_swb_long_window` and `num_swb_short_window` is determined according to the following pseudo code:

```
for (swb=0; swb<num_swb_long_window+1; swb++) {
    if (swb_offset_long_window[swb] > coreCoderFrameLength) {
        swb_offset_long_window[swb] = coreCoderFrameLength;
        break;
    }
}
num_swb_long_window = swb;

for (swb=0; swb<num_swb_short_window+1; swb++) {
    if (swb_offset_short_window[swb] > coreCoderFrameLength/8) {
        swb_offset_short_window[swb] = coreCoderFrameLength/8;
        break;
    }
}
num_swb_short_window = swb;
```

The tables originally designed for LONG_WINDOW, LONG_START_WINDOW and LONG_STOP_WINDOW are used also for STOP_START_WINDOW.

6.2.10 lpd_channel_stream()

6.2.10.1 General

The `lpd_channel_stream()` bitstream element contains all necessary information to decode one frame of “linear prediction domain” coded signal. It contains the payload for one frame of encoded signal which was coded in the LPC-domain, i.e., including an LPC filtering step. The residual of this filter (so-called “excitation”) is then represented either with the help of an ACELP module or in the MDCT transform domain (“transform coded excitation”, TCX). To allow close adaptation to the signal characteristics, one frame is broken down in to four smaller units of equal size, each of which is coded either with ACELP or TCX coding scheme.

This process is similar to the coding scheme described in 3GPP TS 26.290^[10], which is recommended for background reading. Inherited from this document is a slightly different terminology, where one “superframe” signifies a signal segment of `coreCoderFrameLength` samples, whereas a “frame” is exactly one fourth of that, i.e., `coreCoderFrameLength/4` samples. Each one of these frames is further subdivided into three or four “subframes” of equal length. In case of a `coreCoderFrameLength` of 768 samples, each frame is subdivided into three subframes. For every other `coreCoderFrameLength`, each frame is subdivided into four subframes. Note that this subclause adopts this terminology.

6.2.10.2 Definition of elements

acelp_core_mode This bitfield indicates the exact bit allocation scheme in case ACELP is used as a lpd coding mode.

lpd_mode The bit-field `lpd_mode` defines the coding modes for each of the four frames within one superframe of the `lpd_channel_stream()` (corresponds to one USAC frame). The coding modes are stored in the array `mod[]` and can take values from 0 to 3. The mapping from `lpd_mode` to `mod[]` can be determined from Table 94.

Table 94 — Mapping of coding modes for `lpd_channel_stream()`

lpd_mode	meaning of bits in bit-field lpd_mode					remaining mod[] entries
	bit 4	bit 3	bit 2	bit 1	bit 0	
0..15	0	mod[3]	mod[2]	mod[1]	mod[0]	
16..19	1	0	0	mod[3]	mod[2]	mod[1]=2 mod[0]=2
20..23	1	0	1	mod[1]	mod[0]	mod[3]=2 mod[2]=2
24	1	1	0	0	0	mod[3]=2 mod[2]=2 mod[1]=2 mod[0]=2
25	1	1	0	0	1	mod[3]=3 mod[2]=3 mod[1]=3 mod[0]=3
26..31						reserved

bpf_control_info

Bass-post filter control information which defines if bass-post filtering (low frequency enhancement) is enabled or disabled (see 7.17 and Table 95).

Table 95 — Bass-post filter modes

value of bpf_control_info	Bass-post filter operation
0	Bass-post filter disabled
1	Bass-post filter enabled

core_mode_last

Indicates the core coding mode of the previous frame as defined in Table 96. This value can also be determined from the history of the bitstream element core_mode.

Table 96 — Definition of core_mode_last

value of core_mode_last	Meaning
0	FD core coder mode used in previous frame
1	LPD core coder mode used in previous frame

mod[0..3]

The values in the array mod[] indicate the respective coding modes in each frame as defined in Table 97.

Table 97 — Coding modes indicated by mod[]

value of mod[x]	coding mode in frame	bitstream element
0	ACELP	acelp_coding()
1	short TCX (ccfl/4)	tcx_coding()
2	medium TCX (ccfl/2)	tcx_coding()
3	longTCX (ccfl)	tcx_coding()

acelp_coding()

Syntax element which contains all data to decode one frame of ACELP excitation.

tcx_coding()

Syntax element which contains all data to decode one frame of MDCT based transform coded excitation (TCX).

first_tcx_flag

Flag which indicates if the current processed TCX frame is the first in the superframe.

arith_reset_flag

see 6.2.11.2.

lpc_data()

Syntax element which contains all data to decode all LPC filter parameter sets required to decode the current superframe.

first_lpd_flag

Flag which indicates whether the current superframe is the first of a sequence of superframes which are coded in LPC domain. This flag can also be determined from the history of the bitstream element core_mode (core_mode0 and core_mode1 in case of a UsacChannelPairElement) according to Table 98.

Table 98 — Definition of first_lpd_flag

core_mode of previous frame (superframe)	core_mode of current frame (superframe)	first_lpd_flag
0	1	1
1	1	0

last_lpd_mode

Indicates the value of mod[x] of the previously decoded ACELP frame or TCX frame respectively (see Table 35) for the currently considered channel. At the beginning of the decoding process the value of this variable is assumed to be initialized to last_lpd_mode=-1. The variable is assumed to have a "static" characteristic, meaning that it carries over its value to the next frame after decoding of the current frame is finished.

short_fac_flag

Flag which indicates the length of the FAC transform fac_length for transitions between two different core coding modes. Table 99 defines the corresponding fac_length for each value of short_fac_flag.

Table 99 — Definition of short_fac_flag

value of short_fac_flag	fac_length
0	coreCoderFrameLength/8
1	coreCoderFrameLength/16

6.2.10.3 Decoding process

6.2.10.3.1 Decoding an lpd_channel_stream

In the lpd_channel_stream the order of decoding is:

- Get acelp_core_mode.
- Get lpd_mode and determine from it the content of the helper variable mod[].
- Get acelp_coding or tcx_coding data, depending on the content of the helper variable mod[].
- Get lpc_data.

Decoding of acelp_coding is described in 7.14.

Decoding of tcx_coding is described in 7.15.

Decoding of lpc_data is described in 7.13.

6.2.10.3.2 ACELP/TCX coding mode combinations

There are 26 allowed combinations of ACELP or TCX within one superframe of an lpd_channel_stream payload. One of these 26 mode combinations is signalled in the bitstream element lpd_mode. The mapping of lpd_mode to actual coding modes of each frame in a subframe is shown in Table 94 and Table 97.

6.2.11 Spectral noiseless coder

6.2.11.1 General

Spectral coefficients from both the “linear prediction-domain” coded signal and the “frequency-domain” coded signal are scalar quantized and then noiselessly coded by a context adaptive arithmetic coder.

The quantized coefficients are gathered together in 2-tuples before being transmitted from the lowest-frequency to the highest-frequency. Each 2-tuple is split into the sign s , the concatenated 2 most significant bit planes m , and the remaining least significant bit-planes r . The value m is coded according to a context, which is defined by the neighbouring spectral coefficients. The remaining least significant bit-planes r are entropy coded one by one with the context that is determined by the significance of the upper bit planes. Significance here means the information whether the upper bit planes decoded so far are zero or not. By means of m and r the amplitude of the spectral coefficients can be reconstructed on the decoder-side. For all non-null symbols the signs s are coded outside the context adaptive arithmetic coder using 1 bit per sign.

Detailed arithmetic decoding procedure is described in 7.4.3.

6.2.11.2 Definition of elements

6.2.11.2.1 Data elements

arith_data()	Data element to decode the spectral noiseless coder data.
arith_reset_flag	Flag which indicates if the spectral noiseless context shall be reset.
acod_m[pki][m]	Arithmetic codeword necessary for decoding of the 2 most significant bit planes m of the quantized spectral coefficients of a 2-tuple.
acod_r[lsbidx][r]	Arithmetic codeword necessary for decoding of the remaining least significant bit-planes r of the quantized spectral coefficient of a 2-tuple.
s	The coded sign of the non-null spectral quantized coefficient.

6.2.11.2.2 Helper elements

a,b	2-tuple corresponding to quantized spectral coefficients.
m	The concatenated 2 most significant bit planes of the 2-tuple to decode.
r	One of the least significant bit planes of the 2-tuple to decode.
lg	Number of quantized coefficients to decode.
N	Window length. For FD mode it is deduced from the window_sequence (see 7.9.3.1) and for TCX $N=2*lg$.
i	Index of 2-tuples to decode within the frame.
pki	Index of the cumulative frequencies table used by the arithmetic decoder for decoding m , where $0 \leq pki \leq 63$.
arith_get_pk ()	Function that returns the index pki of cumulative frequencies table necessary to decode the codeword acod_m[pki][m] .
c	State of context.
lsbidx	Index to the cumulative frequencies tables used by the arithmetic decoder for decoding r , where $0 \leq lsbidx \leq 2$.

lev	Number of least significant bit-planes to decode.
ARITH_ESCAPE	Escape symbol that indicates additional bit-planes to decode beyond the two most significant bit planes. ARITH_ESCAPE has the value 16.
esc_nb	Number of ARITH_ESCAPE symbol already decoded for the present 2-tuple. The value is bounded to 7. NOTE esc_nb is equal to lev, but limited to a maximum value of 7, i.e., $\text{esc_nb} = \min(\text{lev}, 7)$.
x_ac_dec[]	Element holding the decoded spectral coefficients.
arith_map_context()	Initializes the contexts needed for decoding the present frame.
arith_get_context()	Computes the context state for decoding the present 2-tuple m symbols.
arith_update_context()	Updates the context for the next 2-tuple.
arith_finish ()	Finish the noiseless decoding.

6.2.12 Enhanced SBR

6.2.12.1 General

The description of the bitstream elements for the SBR payload can be found in ISO/IEC 14496-3:2019, 4.5.2.8.

Deviations from these bitstream elements are listed below.

6.2.12.2 Definition of elements

bs_xover_band	Index to master frequency table. The index is coded with 4 bits allowing the xover band to be variable over a range of 0-15 bands.
UsacSbrData()	This block of data contains payload for the SBR bandwidth extension for one or two channels. The presence of this data is dependent on the sbrRatioIndex.
SbrInfo()	This element contains SBR control parameters which do not require a decoder reset when changed.
SbrHeader()	This element contains SBR header data with SBR configuration parameters, that typically do not change over the duration of a bitstream.
sbr_single_channel_element()	Syntactic element that contains data for an SBR single channel element.
sbr_channel_pair_element()	Syntactic element that contains data for an SBR channel pair element.
sbr_grid()	Syntactic element that contains the time frequency grid.
bs_num_env	Indicates the number of SBR envelopes in the current SBR frame. For USAC a maximum of 8 envelopes are allowed in a class FIXFIX frame.
bs_sbr_preprocessing	Signals the use of the additional preprocessing during HF generation according to Table 100.

Table 100 — bs_sbr_preprocessing

bs_sbr_preprocessing	Meaning
0	No pre-processing
1	Application of HF pre-processing as part of the MPEG-4 SBR HF generation as outlined in 7.5.2.2

bs_header_extra3 Indicates if optional header part3 is present.

bs_pvc_mode Indicates PVC mode according to Table 101.

Table 101 — bs_pvc_mode

bs_pvc_mode	Meaning
0	no PVC data present
1	PVC mode 1
2	PVC mode 2
3	reserved

bs_var_len Indicates the position of the trailing variable border according to Table 102.

Table 102 — bs_var_len

Length	bs_var_len_hf (hexadecimal)	bs_var_len
1	0x0	0
3	0x4	1
3	0x5	2
3	0x6	3
3	0x7	reserved

bs_noise_position Indicates the time slot border for noise floors. A value of zero means that there is one noise floor in the current SBR frame.

bs_sinusoidal_position_flag Indicates if bs_sinusoidal_position is present.

bs_sinusoidal_position Indicates the position of the starting time slot for sinusoidals. A value of 31 means that there is no sinusoid starting in the current SBR frame.

divMode Indicates the coding mode of the prediction coefficient matrix indices, pvcID.

nsMode Indicates the time-smoothing mode. The number of time slots for time-smoothing of $E_{sg}(k_{sg}, t)$, ns is derived from bs_pvc_mode and nsMode according to Table 103.

Table 103 — nsMode

bs_pvc_mode	nsMode	ns
1	0	16
	1	4
2	0	12
	1	3

reuse_pvcID Indicates if *pvcID* of the last time slot in the previous SBR frame is reused according to Table 104.

Table 104 — reuse_pvcID

reuse_pvcID	Meaning
0	pvcID[0] is unpacked from bitstream
1	pvcID[0] is copied from pvcID[-1]

pvcID Indicates the prediction coefficient matrix index, *pvcID*. The pvcID[-1] denotes *pvcID* of the last time slot in the previous SBR frame.

length Indicates the number of time slots in which the same prediction coefficient matrix index, pvcID is used.

grid_info Indicates if *pvcID* of previous time slot is reused according to Table 105.

Table 105 — grid_info

grid_info	Meaning
0	pvcID[k] is copied from pvcID[k-1]
1	pvcID[k] is unpacked from bitstream

6.2.12.3 SBR payload for USAC

In USAC the SBR payload is transmitted in UsacSbrData(), which is an integral part of each single channel element or channel pair element. UsacSbrData() follows immediately after UsacCoreCoderData(). There is no SBR payload for LFE channels.

6.2.13 Definition of MPEG Surround 2-1-2 payloads

6.2.13.1 General

The basic bitstream syntax shall be based on ISO/IEC 23003-1:2007, 5.2. Any modifications and amendments to the existing bitstream syntax are listed below.

6.2.13.2 Definition of elements

bsTempShapeConfig Indicates operation mode of temporal shaping (STP or GES) or activation of TSD in the decoder according to Table 106.

Table 106 — bsTempShapeConfig

bsTempShapeConfig	Meaning
0	do not apply temporal shaping
1	apply STP
2	apply GES
3	apply TSD

bsHighRateMode Indicates operation mode of Mps212Data() according to Table 107.

Table 107 — bsHighRateMode

bsHighRateMode	bit rate mode
0	LOW
1	HIGH

bsPhaseCoding

Indicates whether IPD coding is applied in Mps212Config() according to Table 108.

Table 108 — bsPhaseCoding

bsPhaseCoding	Meaning
0	no IPD data present
1	IPD data present

bsOttBandsPhasePresent

Indicates whether the number of IPD parameter bands is initialized to default values using Table 109 or transmitted explicitly by **bsOttBandsPhase**.

bsOttBandsPhase

Defines the number of MPS parameter bands where phase coding is used. If bsOttBandsPhasePresent==0, the value of bsOttBandsPhase is to be initialized according to Table 109.

Table 109 — Default value of bsOttBandsPhase

numBands	bsOttBandsPhase
4	2
5	2
7	3
10	5
14	7
20	10
28	10

bsResidualBands

Defines the number of MPS parameter bands where residual coding is used.

numSlots

The number of time slots in an Mps212Data frame.

bsPhaseMode

Indicates whether IPD parameters are available for the current Mps212Data frame.

bsOPDSmoothingMode

Indicates whether smoothing is applied to OPD parameters.

bsTsdEnable

Indicates that TSD is enabled in a frame.

numTempShapeChan

Indicates the number of channels on which a temporal shaping tool is applied. This value is 2 in the USAC context.

bsTsdNumTrSlots

Defines the number of TSD transients slots in a frame according to: $\text{number_of_TSD_transient_slots} = \text{bsTsdNumTrSlots} + 1$.

nBitsTrSlots

Defined according to Table 110.

Table 110 — nBitsTrSlots depending on MPS frame length

numSlots	nBitsTrSlots
32	4
64	5

bsTsdCodedPos Variable length code word containing position data for TSD transient slots.

bsTsdTrPhaseData Phase data for the transient steering of TSD according to Table 111.

Table 111 — Phase data for TSD

Index	0	1	2	3	4	5	6	7
TSD phase value	0	$\frac{\pi}{4}$	$\frac{\pi}{2}$	$\frac{3\pi}{4}$	π	$\frac{5\pi}{4}$	$\frac{3\pi}{2}$	$\frac{7\pi}{4}$

numQuantStepsXXX Defined according to Table 112.

Table 112 — numQuantStepsXXX depending on dataType

XXX (dataType)	numQuantStepsXXX Coarse	numQuantStepsXXX Fine
CLD	15	31
ICC	4	8
IPD	8	16

hcodLavIdx One-dimensional Huffman code (ISO/IEC 23003-1:2007, Table A.24) used for coding of the **lavIdx** data. This determines the largest absolute value in one or two data sets coded with two-dimensional Huffman codes according to Table 113.

Table 113 — lavTabXXX

LavIdx	lavTabCLD [LavIdx]	lavTabICC [LavIdx]	lavTabCPC [LavIdx]	lavTabIPD [LavIdx]
0	3	1	3	7
1	5	3	6	1
2	7	5	9	3
3	9	7	12	5

6.2.14 Buffer requirements

If USAC is employed by means of MPEG-4 audio object type 42, the buffer requirements for the USAC codec are the same as stated in ISO/IEC 14496-3:2019, 4.5.3. In the USAC context the number of considered channels (NCC) is equal to once the number of SCEs plus two times the number of CPEs.

Furthermore, unless explicitly specified differently, the buffer requirements for the USAC codec are the same as stated in ISO/IEC 14496-3:2019, 4.5.3.

7 Tool descriptions

7.1 Quantization

7.1.1 Tool description

For quantization of the FD core spectral coefficients in the encoder a non uniform quantizer is used. Therefore the decoder shall perform the inverse non uniform quantization after the Huffman decoding of the scalefactors (see 7.3) and the noiseless decoding of the spectral data (see 7.1).

For the quantization of the TCX spectral coefficients, a uniform quantizer is used. No inverse quantization is needed at the decoder after the noiseless decoding of the spectral data.

7.1.2 Definition of elements

Help elements:

<code>x_ac_quant[g][win][sfb][bin]</code>	Quantized FD spectral coefficient for group <code>g</code> , window <code>win</code> , scalefactor band <code>sfb</code> , coefficient <code>bin</code> .
<code>x_ac_invquant[g][win][sfb][bin]</code>	FD spectral coefficient for group <code>g</code> , window <code>win</code> , scalefactor band <code>sfb</code> , coefficient <code>bin</code> after inverse quantization.
<code>x_tcx_invquant[win][bin]</code>	TCX spectral coefficient for window <code>win</code> , and coefficient <code>bin</code> after noiseless decoding of the spectral data.

7.1.3 Decoding process

The inverse quantization of the FD spectral coefficients is described by the following formula:

$$x_ac_invquant = Sign(x_ac_quant) \cdot |x_ac_quant|^{\frac{4}{3}}$$

The inverse quantization is applied as follows:

```
for (g = 0; g < num_window_groups; g++) {
    for (sfb = 0; sfb < max_sfb; sfb++) {
        width = (swb_offset[sfb+1] - swb_offset[sfb]);
        for (win = 0; win < window_group_len[g]; win++) {
            for (bin = 0; bin < width; bin++) {
                x_ac_invquant[g][win][sfb][bin] =
                sign(x_ac_quant[g][win][sfb][bin]) * abs(x_ac_quant[g][win][sfb][bin]) ^ (4/3);
            }
        }
    }
}
```

For channel 1, `max_sfb` is set equal to `max_sfb1` if `common_window == 1`.

7.2 Noise filling

7.2.1 Tool description

In low bit rate coding noise filling can be used for two purposes:

- Coarse quantization of spectral values in low bit rate audio coding might lead to very sparse spectra after inverse quantization, as many spectral lines might have been quantized to zero. The sparse populated spectra will result in the decoded signal sounding sharp or instable (birdies).

By replacing the zeroed lines with “small” values in the decoder it is possible to mask or reduce these very obvious artefacts without adding obvious new noise artefacts.

- If there are noiselike signal parts in the original spectrum, a perceptually equivalent representation of these noisy signal parts can be reproduced in the decoder based on only few parametric information like the energy of the noisy signal part. The parametric information can be transmitted with fewer bits compared to the number of bits needed to transmit the coded waveform.

7.2.2 Definition of elements

7.2.2.1 Data elements

noise_offset	Additional offset to modify the scale factor of bands quantized to zero.
noise_level	Integer representing the quantization noise to be added for every spectral line quantized to zero.

7.2.2.2 Help elements

x_ac_invquant[g][win][sfb][bin]	FD spectral coefficient for group g, window win, scalefactor band sfb, coefficient bin after inverse quantization.
noiseFillingStartOffset[win]	A general offset or noise filling start frequency depending on coreCoderFrameLength (ccfl) and window_sequence according to Table 114.

Table 114 — Value of noiseFillingStartOffset[] as a function of window_sequence and coreCoderFrameLength

coreCoderFrameLength	window_sequence == EIGHT_SHORT_SEQUENCE	other window_sequence
768	15	120
other	20	160

noiseVal	The absolute noise Value that replaces every bin quantized to zero.
randomSign()	Function which returns a (pseudo) random sign. The function is defined in 7.2.4.
band_quantized_to_zero	Flag to signal whether a sfb is completely quantized to zero.

7.2.3 Decoding process

Noise filling process:

```

if (noise_level != 0) {
    noiseVal = pow(2, (noise_level-14)/3) ;
    noise_offset = noise_offset - 16;
}
else {
    noiseVal = 0;
    noise_offset = 0;
}
for (g = 0; g < num_window_groups; g++) {
    for (sfb = 0; sfb < max_sfb; sfb++) {
        band_quantized_to_zero = 1;
        width = (swb_offset [sfb+1] - swb_offset [sfb]);
        if (swb_offset [sfb] >= noiseFillingStartOffset) {
            for (win = 0; win < window_group_len[g]; win++) {
                for (bin = 0; bin < width; bin++) {
                    if (x_ac_invquant[g][win][sfb][bin] == 0) {

```

```

        x_ac_invquant[g][win][sfb][bin] = randomSign()*noiseVal;
    }
    else {
        band_quantized_to_zero = 0;
    }
}
}
}
else {
    band_quantized_to_zero = 0;
}
if (band_quantized_to_zero ) {
    scf[g][sfb] = scf[g][sfb] + noise_offset;
}
}
}

```

For channel 1, max_sfb is set equal to max_sfb1 if **common_window** == 1.

7.2.4 Generation of random signs for spectral noise filling

The random signs for the purpose of noise filling shall be produced according to the following pseudo code:

```

float randomSign(unsigned int *seed)
{
    float sign = 0.f;
    *seed = ((*seed) * 69069) + 5;
    if ( ((*seed) & 0x10000) > 0) {
        sign = -1.f;
    } else {
        sign = +1.f;
    }
    return sign;
}

```

The variable seed represents the "internal state" of the random sign generator. The seed shall be a 32 bit value. It is updated on every call to the function. For channel pair elements two seeds shall be employed, one for each channel. The seed for each channel is updated individually. Once at the beginning of the decoding process the seed shall be initialized to 0x3039 for the left channel of a channel pair and for a single channel element. The seed of the right channel of a channel pair shall be initialized to 0x10932.

7.3 Scale factors

For details on decoding of scale factor data, refer to ISO/IEC 14496-3:2019, 4.6.2 and 4.6.3.

For scale factor band tables, refer to ISO/IEC 14496-3:2019, 4.5.4, Table 4.147 to Table 4.165.

7.4 Spectral noiseless coding

7.4.1 Tool description

Spectral noiseless coding is used to further reduce the redundancy of the quantized spectrum.

The spectral noiseless coding scheme is based on an context adaptive arithmetic coder in conjunction with a dynamically adapted context. The spectral noiseless coding scheme is based on 2-tuples, that is two neighbouring spectral coefficients are combined. Each 2-tuple $\{a,b\}$ is split into the sign, the 2 most significant bit planes, and the remaining least significant bit planes. The noiseless coding for the concatenated 2 most significant bit planes m uses context dependent cumulative frequencies tables derived from four previously decoded 2-tuples. Neighbourhood in both, time and frequency is taken into account, as illustrated in Figure 3. The cumulative frequencies tables are then used by the arithmetic decoder to generate decoded values from the variable length binary code. The noiseless decoding for the remaining least significant bit planes r , uses context dependent cumulative frequencies tables derived from the significance of the upper bit planes in the 2-tuple.

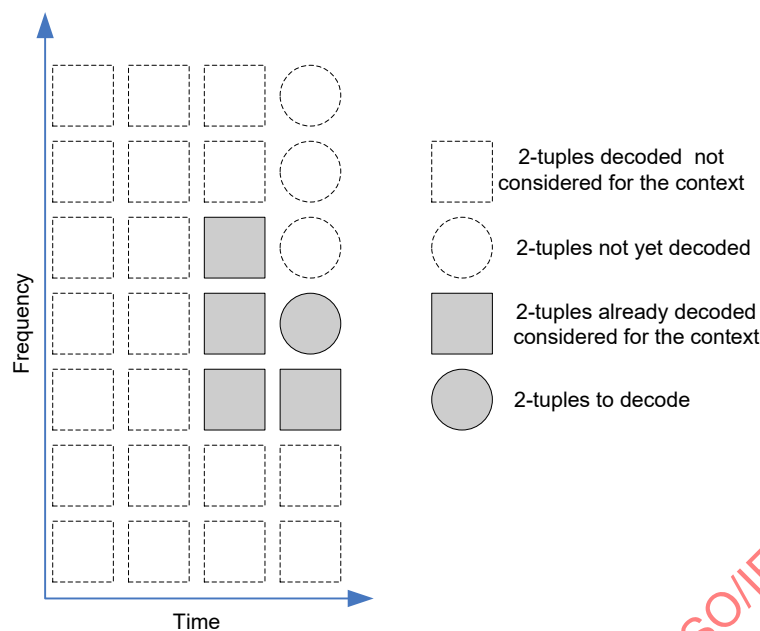


Figure 3 — Context for the state calculation

The arithmetic encoder produces a binary code for a given set of symbols and their respective probabilities. The binary code is generated by mapping a probability interval, where the set of symbols lies, to a codeword.

The relation between 2-tuple, the individual spectral values a and b of a 2-tuple, the most significant bit planes m and the remaining least significant bit planes r are illustrated in the example in Figure 4.

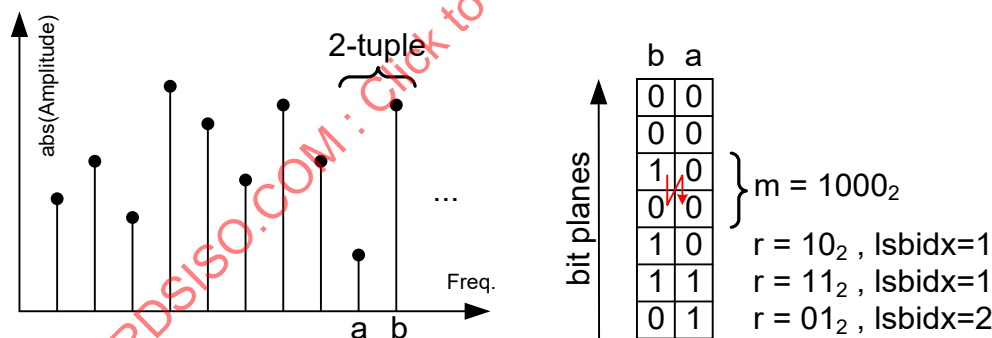


Figure 4 — Example of a coded pair (2-tuple) of spectral values a and b and their representation as m and r . In this example three ARITH_ESCAPE symbols are sent prior to the actual value m , indicating three transmitted least significant bit planes

7.4.2 Definition of elements

- a, b 2-tuple to decode.
- m The concatenated 2 most significant bit planes of the quantized spectral coefficient 2-tuple to decode.
- r A least significant bit plane of the quantized spectral coefficient 2-tuple to decode.

lev	Level of the remaining bit-planes. It corresponds to the number of least significant bit planes.
arith_hash_m[]	Hash table mapping context states to a cumulative frequencies table index pki (shall be defined as given in Annex C.2).
arith_lookup_m[]	Look-up table mapping group of context states to a cumulative frequencies table index pki (shall be defined as given in Annex C.1).
arith_cf_m[pki][17]	Models of the cumulative frequencies for the concatenated 2 most significant bit planes m and the ARITH_ESCAPE symbol (shall be defined as given in Annex C.3).
arith_cf_r[lsidx][4]	Models of the cumulative frequencies for the least significant bit planes symbol r (shall be defined as given in Annex C.4).
q[2][]	2-tuple context elements of the previous and current frame
x_ac_dec[]	Array which holds the decoded quantized spectral coefficients.
arith_reset_flag	Flag which indicates if the spectral noiseless context shall be reset.
ARITH_STOP	Stop symbol consisting of the succession of ARITH_ESCAPE symbol and m=0. When it occurs, the rest of the frame is decoded with zero values.
N	Window length. For FD mode it is deduced from the window_sequence (see 7.9.3.1) and for TCX $N=2 \cdot l_g$.
previous_N	Length of the previous window.

7.4.3 Decoding process

The quantized spectral coefficients `x_ac_dec[]` are noiselessly decoded starting from the lowest-frequency coefficient and progressing to the highest-frequency coefficient. They are decoded by groups of two successive coefficients *a* and *b* gathering in a so-called 2-tuple $\{a,b\}$.

The decoded coefficients `x_ac_dec[]` for FD are then stored in the array `x_ac_quant[g][win][sfb][bin]`. The order of transmission of the noiseless coding codewords is such that when they are decoded in the order received and stored in the array, *bin* is the most rapidly incrementing index and *g* is the most slowly incrementing index. Within a codeword the order of decoding is *a*, and then *b*.

The decoded coefficients `x_ac_dec[]` for the TCX are stored directly in the array `x_tcx_invquant[win][bin]`, and the order of the transmission of the noiseless coding codewords is such that when they are decoded in the order received and stored in the array, *bin* is the most rapidly incrementing index and *win* is the most slowly incrementing index. Within a codeword the order of decoding is *a*, and then *b*.

First, the flag `arith_reset_flag` determines if the context shall be reset.

The decoding process starts with an initialization phase where the context element vector *q* is updated by copying and mapping the context elements of the previous frame stored in `q[1][]` into `q[0][]`. The context elements within *q* are stored on 4 bits per 2-tuple.

If the context cannot be reliably determined, e.g., if the data of the previous frame is not available, and if the `arith_reset_flag` is not set, then the decoding of spectral data cannot be continued and the reading of the current `arith_data()` element should be skipped.

```
/*Input variables*/
N          /* Length of the current window */
arith_reset_flag /* Context adaptive arithmetic coder reset flag */

/*Global variables*/
previous_N  /* Length of the previous window */
```

```

c = arith_map_context(N, arith_reset_flag)
{
    if (arith_reset_flag) {
        for (j=0; j<N/4; j++) {
            q[0][j]=0;
        }
    } else {
        ratio = ((float)previous_N) / ((float) N);
        for (j=0; j<N/4; j++) {
            k = (int) ((float) j * ratio);
            q[0][j] = q[1][k];
        }
    }

    previous_N=N;

    return(q[0][0]<<12);
}

```

The noiseless decoder outputs 2-tuples of unsigned quantized spectral coefficients. At first, the state *c* of the context is calculated based on the previously decoded spectral coefficients surrounding the 2-tuple to decode. Therefore, the state is incrementally updated using the context state of the last decoded 2-tuple considering only two new 2-tuples. The state is coded on 17 bits and is returned by the function *arith_get_context()*.

```

/*Input variables*/
c      /* old state context */
i      /* Index of the 2-tuple to decode in the vector */
N      /* Window Length */
/*Output value*/
c      /*updated state context*/
c = arith_get_context(c,i,N) {
    c = (c & 0xFFFF)>>4;
    if (i<N/4-1)
        c = c + (q[0][i+1]<<12);
    c = (c&0xFFF0);
    if (i>0)
        c = c + (q[1][i-1]);
    if (i > 3) {
        if ((q[1][i-3] + q[1][i-2] + q[1][i-1]) < 5)
            return(c+0x10000);
    }
    return (c);
}

```

The context state *c* determines the cumulative frequency table used for decoding the most significant 2-bits wise plane *m*. The mapping from *c* to the corresponding cumulative frequency table index *pki* is performed by the function *arith_get_pk()*.

```

/*Input variable*/
c      /*State of the context*/

/*Output value*/
pki /*Index of the probability model */

pki = arith_get_pk(c) {
    i_min = -1;
    i = i_min;
    i_max = (sizeof(arith_lookup_m)/sizeof(arith_lookup_m[0]))-1;
    while ((i_max-i_min)>1) {
        i = i_min+((i_max-i_min)/2);
        j = arith_hash_m[i];
        if (c<(j>>8))
            i_max = i;
        else if (c>(j>>8))
            i_min = i;
        else

```

```

        return(j&0xFF);
    }

    return arith_lookup_m[i_max];
}

```

The value *m* is decoded using the function *arith_decode()* called with the cumulative frequencies table, *arith_cf_m[pki][i]*, where *pki* corresponds to the index returned by *arith_get_pk()*. The context adaptive arithmetic coder is an integer implementation using the method of tag generation with scaling [1]. The following pseudo C-code describes the used algorithm.

```

/*helper functions*/
bool arith_first_symbol(void);
/* Return TRUE if it is the first symbol of the sequence,
   FALSE otherwise */
Ushort arith_get_next_bit(void);
/* Get the next bit of the bitstream */

/* global variables */
low
high
value

/* input variables */
cum_freq[]; /* cumulative frequencies table */
cfl; /* length of cum_freq[] */

symbol = arith_decode(cum_freq, cfl) {
    if (arith_first_symbol()) {
        value = 0;
        for (i=1; i<=16; i++) {
            value = (value<<1) | arith_get_next_bit();
        }
        low = 0;
        high = 65535;
    }

    range = high-low+1;
    cum = (((int) (value-low+1))<<14)-((int) 1)/range;
    p = cum_freq-1;

    do {
        q = p + (cfl>>1);
        if ( *q > cum ) { p=q; cfl++; }
        cfl>>=1;
    }
    while ( cfl>1 );

    symbol = p-cum_freq+1;
    if (symbol)
        high = low + ((range*cum_freq[symbol-1])>>14) - 1;
    low += (range * cum_freq[symbol])>>14;

    for (;;) {
        if (high<32768) { }
        else if (low>=32768) {
            value -= 32768;
            low -= 32768;
            high -= 32768;
        }
        else if (low>=16384 && high<49152) {
            value -= 16384;
            low -= 16384;
            high -= 16384;
        }
        else break;
    }
}

```

```

        low += low;
        high += high+1;
        value = (value<<1) | arith_get_next_bit();
    }
    return symbol;
}

```

When the decoded value m is the escape symbol *ARITH_ESCAPE*, the variable *lev* and *esc_nb* are incremented by one and another value m is decoded. In this case, the function *arith_get_pk()* is called once again with the value $c + (\text{esc_nb} \ll 17)$ as input argument, where *esc_nb* is the number of escape symbols previously decoded for the same 2-tuple and bounded to 7.

Once the value m is not the escape symbol *ARITH_ESCAPE*, the decoder checks if the successive m forms an *ARITH_STOP* symbol. If the condition $(m=0 \ \&\& \ lev > 0)$ is true, the *ARITH_STOP* symbol is detected and the decoding process is ended. The condition indicates that the rest of the spectral data is composed of zero values. The decoder proceeds directly to the sign decoding described below.

If the *ARITH_STOP* symbol is not met, the remaining bit planes are then decoded if any exists for the present 2-tuple. The remaining bit planes are decoded from the most significant to the lowest significant level by calling *arith_decode()* *lev* number of times with the cumulative frequencies table *arith_cf_r[lsbidx][l]*. *lsbidx* is derived from the information indicating whether a, b to be currently decoded are zero or not. The decoded bit planes r permit to refine the previously decoded values a, b by the following way:

```

b = m>>2;
a = m - (b<<2);
for (j=0; j<lev; j++) {
    lsbidx = (a==0) ? 1 : ((b==0)?0:2);
    r = arith_decode(arith_cf_r[lsbidx], 4);
    a = (a<<1) | (r&1);
    b = (b<<1) | ((r>>1)&1);
}

```

At this point, the unsigned value of the 2-tuple $\{a, b\}$ is completely decoded. It is saved to the array holding the spectral coefficients:

```

x_ac_dec[2*i]    = a
x_ac_dec[2*i+1] = b

```

The context q is also updated for the next 2-tuple. Note that this context update has also to be performed for the last 2-tuple. This context update is performed by the function *arith_update_context()*:

```

/*input variables*/
a,b /* Decoded unsigned quantized spectral coefficients of the 2-tuple */
i /* Index of the quantized spectral coefficient to decode */

arith_update_context(i, a, b) {
    q[1][i] = a+b+1;
    if (q[1][i]>0xF)
        q[1][i] = 0xF;
}

```

The next 2-tuple of the frame is then decoded by incrementing i by one and by redoing the same process as described above starting from the function *arith_get_context()*. When $lg/2$ 2-tuples are decoded within the frame or when the stop symbol *ARITH_STOP* occurs, the decoding process of the spectral amplitude terminates and the decoding of the signs begins.

Once all unsigned quantized spectral coefficients are decoded, their signs are decoded. For each non-null quantized value of *x_ac_dec* a bit is read. If the read bit value is equal to one, the quantized value is positive, nothing is done and the signed value is equal to the previously decoded unsigned value. Otherwise, the decoded coefficient is negative and the two's complement is taken from the unsigned value. The sign bits are read from low to high frequencies.

The decoding is finished by calling the function *arith_finish()*. The remaining spectral coefficients are set to zero. The respective context states are updated correspondingly.

```
/*helper function*/
void arith_rewind_bitstream(offset);
/* move the bitstream position indicator backward by 'offset' bits*/

/*input variables*/
offset /* number of decoded 2-tuples */
N /* Window length */
x_ac_dec /* vector of decoded spectral coefficients */
arith_finish(x_ac_dec, offset, N, lg)
{
    if(lg>0) arith_rewind_bitstream(14);
    for (i=offset ;i<N/4;i++) {
        x_ac_dec[2*i] = 0;
        x_ac_dec[2*i+1] = 0;
        q[1][i] = 1;
    }
}
```

7.5 enhanced SBR tool (eSBR)

7.5.1 Modifications to SBR tool

The general description of the SBR tool can be found in ISO/IEC 14496-3:2019, 4.6.18.

The complex-exponential phase-shifting is outlined in ISO/IEC 14496-3:2019, 4.6.18.4.4. In USAC it shall be fixed to the default standard operation as defined in ISO/IEC 14496-3:2019, 4.6.18.4.1.

The SBR tool shall be modified as described below.

An optional tool for adaptive time/frequency ~~post~~-processing is described in Annex E.

7.5.1.1 Definition of elements

For the purposes of this clause, the terms and definitions in ISO/IEC 14496-3:2019, 4.6.18, and the following apply:

sbrPatchingMode[ch]	Indicates the transposer type used in eSBR: 1 indicates patching as described in ISO/IEC 14496-3:2019, 4.6.18. 0 indicates harmonic sbr patching as described 7.5.3 or 7.5.4.
sbrOversamplingFlag[ch]	Indicates the use of signal adaptive frequency domain oversampling used in eSBR in combination with the DFT-based harmonic SBR patching as described in 7.5.3. This flag controls the size of the DFTs that are utilized in the transposer. 1 indicates signal adaptive frequency domain oversampling enabled as described in 7.5.3.1. 0 indicates signal adaptive frequency domain oversampling disabled as described in 7.5.3.1.
sbrPitchInBinsFlag[ch]	Controls the interpretation of the sbrPitchInBins[ch] parameter: 1 indicates that the value in sbrPitchInBins[ch] is valid and greater than zero. 0 indicates that the value of sbrPitchInBins[ch] is set to zero.

sbrPitchInBins[ch] Controls the addition of cross product terms in the SBR harmonic transposer. **sbrPitchInBins[ch]** is an integer value in the range [0,127] and represents the distance measured in frequency bins for a 1536-line DFT acting on the sampling frequency of the core coder.

numTimeSlots number of SBR envelope time slots; is always 16.

7.5.1.2 Frequency band tables, offset

The lower frequency boundary of the master frequency table, k_0 , is defined in ISO/IEC 14496-3:2019, 4.6.18.3.2.1 as

$$k_0 = \text{startMin} + \text{offset}(bs_start_freq)$$

where **offset** is a sampling frequency dependent table of QMF subband indices. This table has been amended to include a row for an SBR sampling frequency of 40kHz by adding the following line to the definition of array **offset**:

$$\text{offset} = \begin{Bmatrix} \vdots \\ [-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 13, 15, 17, 19], F_{S_{SBR}} = 40000 \\ \vdots \end{Bmatrix}$$

For all other sampling rates $F_{S_{SBR}}$, the mapping as defined in Table 115 should be applied to build the master frequency table.

Table 115 — SBR sampling frequency mapping

Frequency range (in Hz)	Use tables for sampling frequency (in Hz)
$f \geq 92017$	96000
$92017 > f \geq 75132$	88200
$75132 > f \geq 55426$	64000
$55426 > f \geq 46009$	48000
$46009 > f \geq 42000$	44100
$42000 > f \geq 35777$	40000
$35777 > f \geq 27713$	32000
$27713 > f \geq 23004$	24000
$23004 > f \geq 18783$	22050
$18783 > f$	16000

7.5.1.3 Envelopes, L_E

In eSBR the requirements for the maximum allowed number of envelopes for $bs_frame_class = FIXFIX$ has been relaxed:

$$L_E \leq 8, bs_frame_class = FIXFIX$$

7.5.1.4 HF adjustment of SBR envelope scalefactors

If **bs_pvc_mode** is zero the SBR envelope time border vector of the current SBR frame, $\mathbf{t}_E(l)$, is calculated according to:

$$\mathbf{t}_E(l) = \begin{cases} \mathbf{absBordLead} & , \text{ if } l = 0 \\ \mathbf{absBordTrail} & , \text{ if } l = L_E \\ \mathbf{absBordLead} + \sum_{i=0}^{l-1} \mathbf{relBordLead}(i) & , \text{ if } l \leq l \leq n_{RelLead} \\ \mathbf{absBordTrail} - \sum_{i=0}^{L_E-l-1} \mathbf{relBordTrail}(i) & , \text{ if } n_{RelLead} < l < L_E \end{cases}$$

where $0 \leq l \leq L_E$ and $\mathbf{relBordLead}(l)$ and $\mathbf{relBordTrail}(l)$ are vectors containing the relative borders associated with the leading and trailing borders respectively. Both vectors are (if applicable) defined below.

$$\mathbf{relBordLead}(l) = \begin{cases} NINT\left(\frac{numTimeSlots}{L_E}\right) & , bs_frame_class = FIXFIX \\ NA & , bs_frame_class = FIXVAR \\ \mathbf{bs_rel_bord_0}(l) & , bs_frame_class = VARVAR \text{ or } VARFIX \end{cases}$$

where $0 \leq l < n_{RelLead}$

$$\mathbf{relBordTrail}(l) = \begin{cases} NA & , bs_frame_class = FIXFIX \text{ or } VARFIX \\ \mathbf{bs_rel_bord_1}(l) & , bs_frame_class = VARVAR \text{ or } FIXVAR \end{cases}$$

where $0 \leq l < n_{RelTrail}$

If **bs_pvc_mode** is not zero, the SBR envelope time border vector of the current SBR frame, $\mathbf{t}_E$ is calculated according to:

$$L_E = \begin{cases} 1 & , \text{ if } \mathbf{bs_noise_position} = 0 \\ 2 & , \text{ otherwise} \end{cases}$$

$$\mathbf{t}_E = \begin{cases} [\mathbf{var_len'} & , numTimeSlots + \mathbf{bs_var_len}] & , L_E = 1 \\ [\mathbf{var_len'} & , \mathbf{bs_noise_position} & , numTimeSlots + \mathbf{bs_var_len}] & , L_E = 2 \end{cases}$$

where

$\mathbf{var_len'} = \mathbf{t}'_E[L'_E] - numTimeSlots$ and $\mathbf{t}'_E$ is the time border vector $\mathbf{t}_E$ of the previous SBR frame and L'_E is the number of envelopes of the previous frame respectively. Note that if **bs_pvc_mode**'==1 (PVC active in previous frame), it follows that $\mathbf{var_len'}$ is $\mathbf{bs_var_len}$ of the previous SBR frame.

The **bs_var_len** and **bs_noise_position** are obtained from PVC bitstream. The **bs_var_len** indicates the position of the trailing variable border, and the **bs_noise_position** indicates the timeslot border for noise floors.

If bs_pvc_mode is not zero, the PVC SBR envelope time border vector of the current SBR frame, $\mathbf{t}_{EPVC}$, is calculated according to:

$$\mathbf{t}_{EPVC} = \begin{cases} [t_{first} & , numTimeSlots] & , L_E = 1 \\ [t_{first} & , bs_noise_position & , numTimeSlots] & , L_E = 2 \end{cases}$$

where

$$t_{first} = \begin{cases} \mathbf{var_len}' & , bs_pvc_mode' = 0 \text{ and } bs_pvc_mode \neq 0 \\ 0 & , \text{otherwise} \end{cases}$$

and $\mathbf{var_len}' = \mathbf{t}'_E[L'_E] - numTimeSlots$ and $\mathbf{t}'_E$ is the time border vector $\mathbf{t}_E$ of the previous SBR frame and L'_E is the number of envelopes of the previous frame respectively.

Where $bs_var_bord_l'$ is the trailing border of the previous frame and bs_pvc_mode' is the PVC mode of the previous frame. Independent of bs_pvc_mode within one SBR frame there can be either one or two noise floors. If bs_pvc_mode is zero, the noise floor time borders are derived from the SBR envelope time border vector according to:

$$L_Q = bs_num_noise$$

$$\mathbf{t}_Q = \begin{cases} [\mathbf{t}_E(0), \mathbf{t}_E(1)] & , L_E = 1 \\ [\mathbf{t}_E(0), \mathbf{t}_E(middleBorder), \mathbf{t}_E(L_E)] & , L_E > 1 \end{cases}$$

where $middleBorder = func(bs_frame_class, bs_pointer, L_E)$ is calculated according to ISO/IEC 14496-3:2019, Table 4.193.

If bs_pvc_mode is not zero, the noise floor time borders vectors of the current SBR frame, $\mathbf{t}_Q$ is calculated according to:

$$L_Q = L_E$$

$$\mathbf{t}_Q = \begin{cases} [\mathbf{t}_E(0), \mathbf{t}_E(1)] & , L_Q = 1 \\ [\mathbf{t}_E(0), \mathbf{t}_E(1), \mathbf{t}_E(2)] & , L_Q = 2 \end{cases}$$

7.5.1.5 HF adjustment

7.5.1.5.1 General

Same as ISO/IEC 14496-3:2019, 4.6.18.7.5.

7.5.1.5.2 Mapping

Some of the data extracted from the bitstream payload are vectors (or matrices) containing data elements representing a frequency range of several QMF subbands. In order to simplify the explanation below, and sometimes out of necessity, this grouped data is mapped to the highest available frequency resolution for the envelope adjustment, i.e., to the individual QMF subbands within the SBR range. This means that several adjacent subbands in the mapped vectors (or matrices) will have the same value.

The mapping of the envelope scalefactors and the noise floor scalefactors is outlined below. The SBR envelope is mapped to the resolution of the QMF bank, albeit with preserved time resolution. The noise floor scalefactors are also mapped to the frequency resolution of the filterbank, but with the time resolution of the envelope scalefactors.

If bs_pvc_mode is zero,

$$\begin{aligned} \mathbf{E}_{OrigMapped}(m - k_x, l) &= \mathbf{E}_{Orig}(i, l), \\ \mathbf{F}(i, \mathbf{r}(l)) &\leq m < \mathbf{F}(i + 1, \mathbf{r}(l)), \\ 0 &\leq i < \mathbf{n}(\mathbf{r}(l)), \\ 0 &\leq l < L_E \end{aligned}$$

$$\begin{aligned} \mathbf{Q}_{Mapped}(m - k_x, l) &= \mathbf{Q}_{Orig}(i, k(l)), \\ \mathbf{f}_{TableNoise}(i) &\leq m < \mathbf{f}_{TableNoise}(i + 1), \\ 0 &\leq i < N_Q, \\ 0 &\leq l < L_E \end{aligned}$$

else, bs_pvc_mode is not zero,

$$\begin{aligned} \mathbf{E}_{OrigMapped}(m - k_x, t) &= \hat{\mathbf{E}}(m, t), \\ \mathbf{F}(i, \mathbf{r}(l)) &\leq m < \mathbf{F}(i + 1, \mathbf{r}(l)), \\ 0 &\leq i < \mathbf{n}(\mathbf{r}(l)), \\ \mathbf{t}_{EPVC}(l) &\leq t < \mathbf{t}_{EPVC}(l + 1), \\ 0 &\leq l < L_E \end{aligned}$$

$$\mathbf{Q}_{PreMapped}(m - k_x, t) = \mathbf{Q}_{Orig}(i, k(l)),$$

$$\begin{aligned} \mathbf{f}_{TableNoise}(i) &\leq m < \mathbf{f}_{TableNoise}(i + 1), \\ 0 &\leq i < N_Q, \\ \mathbf{t}_E(l) &\leq t < \mathbf{t}_E(l + 1), \\ 0 &\leq l < L_E \end{aligned}$$

$$\mathbf{Q}_{Mapped}(m - k_x, t) = \begin{cases} \mathbf{Q}'_{PreMapped}(m - k_x, t + numTimeSlots) & , 0 \leq t < \mathbf{t}_E(0) \\ \mathbf{Q}_{PreMapped}(m - k_x, t) & , \mathbf{t}_E(0) \leq t < \mathbf{t}_E(L_E) \end{cases}$$

$$\begin{aligned} \mathbf{f}_{TableNoise}(0) &\leq m < \mathbf{f}_{TableNoise}(N_Q), \\ 0 &\leq t < \mathbf{t}_E(L_E), \end{aligned}$$

where $\mathbf{Q}'_{PreMapped}$ is the $\mathbf{Q}_{PreMapped}$ matrix of the previous SBR frame and $\mathbf{t}'_E$ is the time border vector, L'_E is the number of envelopes of the previous frame respectively and where $k(l)$ is defined by $RATE \cdot \mathbf{t}_E(l) \geq RATE \cdot \mathbf{t}_Q(k(l)), RATE \cdot \mathbf{t}_E(l + 1) \leq RATE \cdot \mathbf{t}_Q(k(l) + 1)$, and $\mathbf{F}(i, \mathbf{r}(l))$ is indexed as row, column, i.e., $\mathbf{F}(i, \mathbf{r}(l))$ gives $\mathbf{f}_{TableLow}(i)$ for $\mathbf{r}(l) = LO$ and $\mathbf{f}_{TableHigh}(i)$ for $\mathbf{r}(l) = HI$.

NOTE Remember that $\mathbf{t}_E(0) = \mathbf{t}'_E(L'_E) - numTimeSlots$.

The mapping of the additional sinusoids is done as indicated below. In order to simplify the mapping, two matrices are introduced, $\mathbf{S}_{IndexMapped}$ and $\mathbf{S}_{Mapped}$. The former is a binary matrix indicating in which QMF subbands sinusoids should be added, the latter is a matrix used to compensate the energy-values for the frequency bands where a sinusoid is added. If the bitstream payload indicates a sinusoid in a QMF subband where there was none present in the previous SBR frame, the generated sine should start at the position indicated by l_A (see Table 116) in the present SBR frame if PVC is not used ($bs_pvc_mode=0$) or at the position indicated by $bs_sinusoidal_position$ in the present SBR frame if PVC is used ($bs_pvc_mode \neq 0$). The generated sinusoid is placed in the middle of the high frequency resolution band, according to the following.

Let,

$$\mathbf{S}_{Index}(i) = \begin{cases} bs_add_harmonic(i) & , bs_add_harmonic_flag = 1 \\ 0 & , bs_add_harmonic_flag = 0 \end{cases}, 0 \leq i < N_{High}$$

If bs_pvc_mode is zero,

$$\mathbf{S}_{IndexMapped}(m - k_x, l) = \begin{cases} 0 & , \text{if } m \neq INT\left(\frac{\mathbf{f}_{TableHigh}(i+1) + \mathbf{f}_{TableHigh}(i)}{2}\right) \\ \mathbf{S}_{Index}(i) \cdot \delta_{Step}(m - k_x, l) & , \text{if } m = INT\left(\frac{\mathbf{f}_{TableHigh}(i+1) + \mathbf{f}_{TableHigh}(i)}{2}\right) \end{cases}$$

with $\mathbf{f}_{TableHigh}(i) \leq m < \mathbf{f}_{TableHigh}(i+1)$, $0 \leq i < N_{High}$, $0 \leq l < L_E$

where

$$\delta_{Step}(m, l) = \begin{cases} 1 & , \text{if } (l \geq l_A) OR (\mathbf{S}'_{IndexMapped}(m, L'_E - 1) = 1) \\ 0 & , \text{otherwise} \end{cases}$$

else, if bs_pvc_mode is not zero,

$$\mathbf{S}_{IndexPreMapped}(m - k_x, t) = \begin{cases} 0 & , \text{if } m \neq INT\left(\frac{\mathbf{f}_{TableHigh}(i+1) + \mathbf{f}_{TableHigh}(i)}{2}\right) \\ \mathbf{S}_{Index}(i) \cdot \delta_{Step}(m - k_x, t) & , \text{if } m = INT\left(\frac{\mathbf{f}_{TableHigh}(i+1) + \mathbf{f}_{TableHigh}(i)}{2}\right) \end{cases}'$$

$$\mathbf{f}_{TableHigh}(i) \leq m < \mathbf{f}_{TableHigh}(i+1),$$

$$0 \leq i < N_{High},$$

$$\mathbf{t}_E(0) \leq t < \mathbf{t}_E(L_E)$$

$$\mathbf{S}_{IndexMapped}(m - k_x, t) = \begin{cases} \mathbf{S}'_{IndexPreMapped}(m - k_x, t + numTimeSlots) & , 0 \leq t < \mathbf{t}_E(0) \\ \mathbf{S}_{IndexPreMapped}(m - k_x, t) & , \mathbf{t}_E(0) \leq t < \mathbf{t}_E(L_E) \end{cases}$$

$$\begin{aligned} \mathbf{f}_{TableHigh}(0) \leq m < \mathbf{f}_{TableHigh}(N_{High}), \\ 0 \leq t < \mathbf{t}_E(L_E) \end{aligned}$$

NOTE Remember that $\mathbf{t}_E(0) = \mathbf{t}'_E(L'_E) - numTimeSlots$.

where $\mathbf{S}'_{IndexPreMapped}$ is the $\mathbf{S}_{IndexPreMapped}$ matrix of the previous SBR frame and $\mathbf{t}'_E$ is the time border vector, L'_E is the number of envelopes of the previous frame respectively and where

$$\delta_{Step}(m, t) = \begin{cases} 1 & , \text{if } (t \geq bs_sinusoidal_position) \text{ OR } (\mathbf{S}'_{IndexMapped}(m, \mathbf{t}'_E(L'_E)) - 1) = 1 \\ 0 & , \text{otherwise} \end{cases}$$

and where l_A is defined according to Table 116,

Table 116 — Table for calculation of l_A

bs_pointer	bs_frame_class		
	<i>FIXFIX</i>	<i>FIXVAR, VARVAR</i>	<i>VARFIX</i>
=0	-1	-1	-1
=1	-1	$L_E + 1 - bs_pointer$	-1
>1	-1	$L_E + 1 - bs_pointer$	$bs_pointer - 1$

and $\mathbf{S}'_{IndexMapped}$ is $\mathbf{S}_{IndexMapped}$ of the previous SBR frame for the same frequency range. If the frequency range is larger for the current frame, the entries for the QMF subbands not covered by the previous $\mathbf{S}_{IndexMapped}$ are assumed to be zero. $\mathbf{t}'_E$ and L'_E are $\mathbf{t}_E$ and L_E of the previous SBR frame, respectively.

If bs_pvc_mode is not zero, l_A is defined as follows:

$$l_A = -1$$

The frequency resolution of the transmitted information on additional sinusoids is constant, therefore the varying frequency resolution of the envelope scalefactors needs to be considered. Since the frequency resolution of the envelope scalefactors is always coarser or as fine as that of the additional sinusoid data, the varying frequency resolution is handled as below.

If bs_pvc_mode is zero,

$$\mathbf{S}_{Mapped}(m - k_x, l) = \delta_S(i, l), l_i \leq m < u_i, \begin{cases} u_i = \mathbf{F}(i + 1, \mathbf{r}(l)) \\ l_i = \mathbf{F}(i, \mathbf{r}(l)) \end{cases}$$

for $0 \leq i < \mathbf{n}(\mathbf{r}(l)), 0 \leq l < L_E$

where

$$\delta_S(i, l) = \begin{cases} 1, & 1 \in \{S_{IndexMapped}(j - k_x, l) : F(i, r(l)) \leq j < F(i + 1, r(l))\} \\ 0, & \text{otherwise} \end{cases}.$$

else, bs_pvc_mode is not zero,

$$S_{Mapped}(m - k_x, t) = \delta_S(i, t), \quad l_i \leq m < u_i, \quad \begin{cases} u_i = F(i + 1, r(l)) \\ l_i = F(i, r(l)) \end{cases}$$

For $0 \leq i < n(r(l)), t_{EPVC}(l) \leq t < t_{EPVC}(l + 1), 0 \leq l < L_E$

where

$$\delta_S(i, t) = \begin{cases} 1, & \text{if } 1 \in \{S_{IndexMapped}(j - k_x, t) : F(i, r(l)) \leq j < F(i + 1, r(l)), t_{EPVC}(l) \leq t < t_{EPVC}(l + 1), 0 \leq l < L_E\} \\ 0, & \text{otherwise} \end{cases}$$

The $\delta_S(i, l)$ function returns 1 if any entry in the $S_{IndexMapped}$ matrix is one within the given boundaries, i.e., if an additional sinusoid is present within the present frequency band. The S_{Mapped} matrix is hence one for all QMF subbands in the scalefactor bands where an additional sinusoid shall be added.

7.5.1.5.3 Estimation of current envelope

In order to adjust the envelope of the present SBR frame, the envelope of the current SBR signal needs to be estimated. This is done as shown below, and depends on the value of the data element bs_interp_freq . The SBR envelope is estimated by averaging the squared complex subband samples over different time and frequency regions, given by the time/frequency grid represented by t_E and r or t_{EPVC} in case of $bs_pvc_mode \neq 0$ respectively.

If interpolation ($bs_interp_freq = 1$) is used:

$$E_{Curr}(m, l) = \frac{\sum_{i=RATE \cdot t_E(l) + t_{HFAdj}}^{RATE \cdot t_E(l+1) - 1 + t_{HFAdj}} |X_{High}(m + k_x, i)|^2}{(RATE \cdot t_E(l+1) - RATE \cdot t_E(l))}, \quad 0 \leq m < M, 0 \leq l < L_E,$$

if $bs_pvc_mode = 0$

$$E_{curr}(m, t) = \frac{\sum_{i=t_{HFAdj}}^{RATE - 1 + t_{HFAdj}} |X_{High}(m + k_x, RATE \cdot t + i)|^2}{RATE}, \quad 0 \leq m < M, t_{EPVC}(l) \leq t < t_{EPVC}(l + 1), 0 \leq l < L_E,$$

if $bs_pvc_mode \neq 0$

else, no interpolation ($bs_interp_freq = 0$):

$$E_{Curr}(k - k_x, l) = \frac{\sum_{i=RATE \cdot t_E(l) + t_{HFAdj}}^{RATE \cdot t_E(l+1) - 1 + t_{HFAdj}} \sum_{j=k_l}^{k_h} |X_{High}(j, i)|^2}{(RATE \cdot t_E(l+1) - RATE \cdot t_E(l)) \cdot (k_h - k_l + 1)},$$

$$k_l \leq k \leq k_h, \begin{cases} k_l = F(p, \mathbf{r}(l)) \\ k_h = F(p+1, \mathbf{r}(l)) - 1 \end{cases}, 0 \leq p < \mathbf{n}(\mathbf{r}(l)), 0 \leq l < L_E,$$

if $bs_pvc_mode = 0$

$$\mathbf{E}_{Curr}(k - k_x, t) = \frac{\sum_{i=t_{HFAdj}}^{RATE-1+t_{HFAdj}} \sum_{j=k_l}^{k_h} |\mathbf{X}_{High}(j, RATE \cdot t + i)|^2}{RATE \cdot (k_h - k_l + 1)},$$

$$k_l \leq k \leq k_h, \begin{cases} k_l = F(p, \mathbf{r}(l)) \\ k_h = F(p+1, \mathbf{r}(l)) - 1 \end{cases}, 0 \leq p < (\mathbf{n}(\mathbf{r}(l)), \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E,$$

if $bs_pvc_mode \neq 0$.

If interpolation is used, the energies are averaged over every QMF filterbank subband, else the energies are averaged over every frequency band. In either case, the energies are stored with the frequency resolution of the QMF filterbank. Hence the $\mathbf{E}_{Curr}$ matrix has L_E columns (one for every SBR envelope) and M rows (the number of QMF subbands covered by the SBR range).

7.5.1.5.4 Calculation of levels of additional HF signal components

The noise floor scalefactor is the ratio between the energy of the noise to be added to the envelope adjusted HF generated signal $\mathbf{X}_{High}$ and the energy of the same. Hence, in order to add the correct amount of noise, the noise floor scalefactor needs to be converted to a proper amplitude value, according to the following.

If bs_pvc_mode is zero,

$$\mathbf{Q}_M(m, l) = \sqrt{\mathbf{E}_{OrigMapped}(m, l) \cdot \frac{\mathbf{Q}_{Mapped}(m, l)}{1 + \mathbf{Q}_{Mapped}(m, l)}}, \quad 0 \leq m < M, 0 \leq l < L_E$$

else, bs_pvc_mode is not zero,

$$\mathbf{Q}_M(m, t) = \sqrt{\mathbf{E}_{OrigMapped}(m, t) \cdot \frac{\mathbf{Q}_{Mapped}(m, t)}{1 + \mathbf{Q}_{Mapped}(m, t)}},$$

$$0 \leq m < M,$$

$$\mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1),$$

$$0 \leq l < L_E$$

The level of the sinusoids are derived from the SBR envelope scalefactors according to the following.

If bs_pvc_mode is zero,

$$\mathbf{S}_M(m, l) = \sqrt{\mathbf{E}_{OrigMapped}(m, l) \cdot \frac{\mathbf{S}_{IndexMapped}(m, l)}{1 + \mathbf{Q}_{Mapped}(m, l)}}, \quad 0 \leq m < M, 0 \leq l < L_E$$

else, bs_pvc_mode is not zero,

$$S_M(m, t) = \sqrt{E_{OrigMapped}(m, l) \cdot \frac{S_{IndexMapped}(m, t)}{1 + Q_{Mapped}(m, t)}} ,$$

$$0 \leq m < M ,$$

$$t_{EPVC}(l) \leq t < t_{EPVC}(l+1) ,$$

$$0 \leq l < L_E$$

7.5.1.5.5 Calculation of gain

The gain to be applied for the subband samples in order to retain the correct envelope is calculated as shown below. The level of additional sinusoids, as well as the level of the additional added noise, are taken into account.

If bs_pvc_mode is zero,

$$G(m, l) = \begin{cases} \sqrt{\frac{E_{OrigMapped}(m, l)}{(\varepsilon + E_{Curr}(m, l)) \cdot (1 + \delta(l) \cdot Q_{Mapped}(m, l))}} , & \text{if } S_{Mapped}(m, l) = 0 \\ \sqrt{\frac{E_{OrigMapped}(m, l)}{(\varepsilon + E_{Curr}(m, l))}} \cdot \frac{Q_{Mapped}(m, l)}{(1 + Q_{Mapped}(m, l))} , & \text{if } S_{Mapped}(m, l) \neq 0 \end{cases} , 0 \leq m < M , 0 \leq l < L_E$$

where

$$\delta(l) = \begin{cases} 0 & , \text{if } l = l_A \text{ OR } l = l_{APrev} \\ 1 & , \text{otherwise} \end{cases} ,$$

and where

$$l_{APrev} = \begin{cases} 0 & , \text{if } l'_A = L'_E \\ -1 & , \text{otherwise} \end{cases}$$

is introduced, derived from l'_A and L'_E , which are the l_A and L_E values of the previous SBR frame.

else, bs_pvc_mode is not zero,

$$G(m, t) = \begin{cases} \sqrt{\frac{E_{OrigMapped}(m, t)}{(\varepsilon + E_{Curr}(m, t)) \cdot (1 + Q_{Mapped}(m, t))}} , & \text{if } S_{Mapped}(m, t) = 0 \\ \sqrt{\frac{E_{OrigMapped}(m, t)}{(\varepsilon + E_{Curr}(m, t))}} \cdot \frac{Q_{Mapped}(m, t)}{(1 + Q_{Mapped}(m, t))} , & \text{if } S_{Mapped}(m, t) \neq 0 \end{cases}$$

with $0 \leq m < M , t_{EPVC}(l) \leq t < t_{EPVC}(l+1) , 0 \leq l < L_E$

In order to avoid unwanted noise substitution, the gain values are limited according to the following. Furthermore, the total level of a particular limiter band is adjusted in order to compensate for the energy-loss imposed by the limiter.

If bs_pvc_mode is zero,

$$\mathbf{G}_{MaxTemp}(k,l) = \sqrt{\frac{\varepsilon_0 + \sum_{i=f_{TableLim}(k)-k_x}^{f_{TableLim}(k+1)-1-k_x} \mathbf{E}_{OrigMapped}(i,l)}{\varepsilon_0 + \sum_{i=f_{TableLim}(k)-k_x}^{f_{TableLim}(k+1)-1-k_x} \mathbf{E}_{Curr}(i,l)}} \cdot \mathbf{limGain}(bs_limiter_gains)}, \quad 0 \leq k < N_L, 0 \leq l < L_E$$

$$\mathbf{G}_{Max}(m,l) = \min(\mathbf{G}_{MaxTemp}(k(m),l), 10^5), \quad 0 \leq m < M, 0 \leq l < L_E$$

else, bs_pvc_mode is not zero,

$$\mathbf{G}_{MaxTemp}(k,t) = \sqrt{\frac{\varepsilon_0 + \sum_{i=f_{TableLim}(k)-k_x}^{f_{TableLim}(k+1)-1-k_x} \mathbf{E}_{OrigMapped}(i,t)}{\varepsilon_0 + \sum_{i=f_{TableLim}(k)-k_x}^{f_{TableLim}(k+1)-1-k_x} \mathbf{E}_{Curr}(i,t)}} \cdot \mathbf{limGain}(bs_limiter_gains)}$$

with $0 \leq k < N_L, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$

$$\mathbf{G}_{Max}(m,t) = \min(\mathbf{G}_{MaxTemp}(k(m),t), 10^5), \quad 0 \leq m < M, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$$

where $k(m)$ is defined by $\mathbf{f}_{TableLim}(k(m)) \leq m + k_x < \mathbf{f}_{TableLim}(k(m)+1)$,

and where $\mathbf{limGain} = [0.70795, 1.0, 1.41254, 10^{10}]$, and where $\varepsilon_0 = 10^{-12}$.

The additional noise added to the HF generated signal is limited in proportion to the energy lost due to the limitation of the gain values, according to the following.

If bs_pvc_mode is zero,

$$\mathbf{Q}_{M_{Lim}}(m,l) = \min\left(\mathbf{Q}_M(m,l), \mathbf{Q}_M(m,l) \cdot \frac{\mathbf{G}_{Max}(m,l)}{\mathbf{G}(m,l)}\right), \quad 0 \leq m < M, 0 \leq l < L_E$$

else, bs_pvc_mode is not zero,

$$\mathbf{Q}_{M_{Lim}}(m,t) = \min\left(\mathbf{Q}_M(m,t), \mathbf{Q}_M(m,t) \cdot \frac{\mathbf{G}_{Max}(m,t)}{\mathbf{G}(m,t)}\right), \quad 0 \leq m < M, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$$

The gain values are limited according to the following.

If bs_pvc_mode is zero,

$$\mathbf{G}_{Lim}(m,l) = \min(\mathbf{G}(m,l), \mathbf{G}_{Max}(m,l)), \quad 0 \leq m < M, 0 \leq l < L_E$$

else, bs_pvc_mode is not zero,

$$\mathbf{G}_{Lim}(m,t) = \min(\mathbf{G}(m,t), \mathbf{G}_{Max}(m,t)), \quad 0 \leq m < M, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$$

As mentioned above, the limiter is compensated for by adjusting the total gain for a limiter band, in proportion to the lost energy due to limitation. This is calculated according to the following.

If bs_pvc_mode is zero,

$$\mathbf{G}_{BoostTemp}(k,l) = \sqrt{\frac{\varepsilon_0 + \sum_{i=\mathbf{f}_{TableLim}(k)-k_x}^{\mathbf{f}_{TableLim}(k+1)-1-k_x} \mathbf{E}_{OrigMapped}(i,l)}{\varepsilon_0 + \sum_{i=\mathbf{f}_{TableLim}(k)-k_x}^{\mathbf{f}_{TableLim}(k+1)-1-k_x} (\mathbf{E}_{Curr}(i,l) \cdot \mathbf{G}_{Lim}^2(i,l) + \mathbf{S}_M^2(i,l) + \delta(\mathbf{S}_M(i,l),l) \cdot \mathbf{Q}_{M_{Lim}}^2(i,l))}}$$

$$\text{for } 0 \leq k < N_L, 0 \leq l < L_E \text{ where, } \delta(\mathbf{S}_M(i,l),l) = \begin{cases} 0 & , \mathbf{S}_M(i,l) \neq 0 \text{ OR } l = l_A \text{ OR } l = l_{A_{Prev}} \\ 1 & , \text{otherwise} \end{cases}$$

else, bs_pvc_mode is not zero,

$$\mathbf{G}_{BoostTemp}(k,t) = \sqrt{\frac{\varepsilon_0 + \sum_{i=\mathbf{f}_{TableLim}(k)-k_x}^{\mathbf{f}_{TableLim}(k+1)-1-k_x} \mathbf{E}_{OrigMapped}(i,t)}{\varepsilon_0 + \sum_{i=\mathbf{f}_{TableLim}(k)-k_x}^{\mathbf{f}_{TableLim}(k+1)-1-k_x} (\mathbf{E}_{Curr}(i,t) \cdot \mathbf{G}_{Lim}^2(i,t) + \mathbf{S}_M^2(i,t) + \delta(\mathbf{S}_M(i,t),t) \cdot \mathbf{Q}_{M_{Lim}}^2(i,t))}}$$

$$\text{for } 0 \leq k < N_L, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$$

$$\text{where } \delta(\mathbf{S}_M(i,t),t) = \begin{cases} 0 & , \mathbf{S}_M(i,t) \neq 0 \\ 1 & , \text{otherwise} \end{cases}$$

The compensation, or boost factor, is limited in order not to get too high energy values, according to:

If bs_pvc_mode is zero,

$$\mathbf{G}_{Boost}(m,l) = \min(\mathbf{G}_{BoostTemp}(k(m),l), 1.584893192), \quad 0 \leq m < M, 0 \leq l < L_E$$

else, bs_pvc_mode is not zero,

$$\mathbf{G}_{Boost}(m,t) = \min(\mathbf{G}_{BoostTemp}(k(m),t), 1.584893192), \quad 0 \leq m < M, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$$

where $k(m)$ is defined by $\mathbf{f}_{TableLim}(k(m)) \leq m + k_x < \mathbf{f}_{TableLim}(k(m)+1)$, and where $\varepsilon_0 = 10^{-12}$.

This compensation is applied to the gain, the noise floor scalefactors and the sinusoid levels, according to the following.

If bs_pvc_mode is zero,

$$\mathbf{G}_{LimBoost}(m, l) = \mathbf{G}_{Lim}(m, l) \cdot \mathbf{G}_{Boost}(m, l), \quad 0 \leq m < M, 0 \leq l < L_E$$

$$\mathbf{Q}_{M_{LimBoost}}(m, l) = \mathbf{Q}_{M_{Lim}}(m, l) \cdot \mathbf{G}_{Boost}(m, l), \quad 0 \leq m < M, 0 \leq l < L_E$$

$$\mathbf{S}_{MBoost}(m, l) = \mathbf{S}_M(m, l) \cdot \mathbf{G}_{Boost}(m, l), \quad 0 \leq m < M, 0 \leq l < L_E$$

else, bs_pvc_mode is not zero,

$$\mathbf{G}_{LimBoost}(m, t) = \mathbf{G}_{Lim}(m, t) \cdot \mathbf{G}_{Boost}(m, t), \quad 0 \leq m < M, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$$

$$\mathbf{Q}_{M_{LimBoost}}(m, t) = \mathbf{Q}_{M_{Lim}}(m, t) \cdot \mathbf{G}_{Boost}(m, t), \quad 0 \leq m < M, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$$

$$\mathbf{S}_{MBoost}(m, t) = \mathbf{S}_M(m, t) \cdot \mathbf{G}_{Boost}(m, t), \quad 0 \leq m < M, \mathbf{t}_{EPVC}(l) \leq t < \mathbf{t}_{EPVC}(l+1), 0 \leq l < L_E$$

7.5.1.5.6 Assembling HF signals

Analogous to the mapping of SBR envelope data and noise floor data to a higher time and frequency resolution, the gain values, representing a time-span of several QMF subsamples, are mapped to the highest time-resolution available for the envelope adjustment, i.e., to the individual QMF subsamples within the current SBR frame.

The gain values to be applied to the subband samples are smoothed using the filter $\mathbf{h}_{Smooth}$. The variable h_{SL} is used to control whether smoothing is applied or not, according to:

$$h_{SL} = \begin{cases} 4, & bs_smoothing_mode = 0 \\ 0, & bs_smoothing_mode = 1 \end{cases}$$

and the filter used is defined as following:

$$\mathbf{h}_{Smooth} = \begin{bmatrix} 0.33333333333333 \\ 0.30150283239582 \\ 0.21816949906249 \\ 0.11516383427084 \\ 0.03183050093751 \end{bmatrix}.$$

The smoothed gain values $\mathbf{G}_{Filt}$ are calculated with the help of the temporary matrix $\mathbf{G}_{Temp}$ according to the following equation.

If bs_pvc_mode is zero,

$$\mathbf{G}_{Temp}(m, i + h_{SL}) = \mathbf{G}_{LimBoost}(m, l)$$

$$0 \leq m < M,$$

$$RATE \cdot \mathbf{t}_E(l) \leq i < RATE \cdot \mathbf{t}_E(l+1),$$

$$0 \leq l < L_E$$

else, bs_pvc_mode is not zero,

$$\mathbf{G}_{Temp}(m, i + h_{SL}) = \mathbf{G}_{LimBoost}(m, (INT)(i / RATE)),$$

$$0 \leq m < M,$$

$$RATE \cdot t_{EPVC}(l) \leq t < RATE \cdot t_{EPVC}(l+1),$$

$$0 \leq l < L_E$$

The calculation of $\mathbf{G}_{Fill}$ itself and all further processing for assembling the HF signal shall be done in accordance with ISO/IEC 14496-3:2019, 4.6.18.7.6.

7.5.1.6 24 band analysis QMF filterbank

In case of $coreCoderFrameLength=768$, the 32 band analysis QMF as specified in ISO/IEC 14496-3:2009, 4.6.18.4.1 is replaced by a 24 band analysis filterbank in the SBR tool. This QMF bank is used to split the time domain signal output from the core decoder into 24 subband signals. The output from the filterbank, i.e., the subband samples, are complex-valued and thus oversampled by a factor two compared to a regular QMF bank. The flowchart of this operation is given in Figure 5. The filtering involves the following steps, where an array $\mathbf{x}$ consisting of 240 time domain input samples is assumed. A higher index into the array corresponds to older samples.

- Shift the samples in the array $\mathbf{x}$ by 24 positions. The oldest 24 samples are discarded and 24 new samples are stored in positions 0 to 23.
- Multiply the samples of array $\mathbf{x}$ by the coefficients of window $\mathbf{c}_i$. The window coefficients $\mathbf{c}_i$ are obtained by linear interpolation of the coefficients $\mathbf{c}$, i.e., through the equation:

$$c_i(n) = \rho(n)c(\mu(n)+1) + (1 - \rho(n))c(\mu(n)), \quad 0 \leq n < 240$$

where $\mu(n)$ and $\rho(n)$ are defined as the integer and fractional parts of $64 \cdot n / 24$, respectively. The window coefficients of $\mathbf{c}$ can be found in ISO/IEC 14496-3:2019, Table 4.A.89.

- Sum the samples according to the formula in the flowchart to create the 24-element array $\mathbf{u}$.

Calculate 24 new subband samples by the matrix operation $\mathbf{Mu}$, where:

$$\mathbf{M}(k, n) = 8 / 3 \cdot \exp \left(\frac{i \cdot \pi \cdot (k + 0.5) \cdot (2 \cdot n - 0.375)}{48} \right), \quad \begin{cases} 0 \leq k < 24 \\ 0 \leq n < 64 \end{cases}$$

In the equation, $\exp()$ denotes the complex exponential function and i is the imaginary unit.

Every loop in the flowchart produces 24 complex-valued subband samples, each representing the output from one filterbank subband. For every SBR frame the filterbank will produce $numTimeSlots \cdot RATE$ subband samples for every subband, corresponding to a time domain signal of length $numTimeSlots \cdot RATE \cdot 24$ samples. In the flowchart $\mathbf{W}[k][l]$ corresponds to subband sample l in QMF subband k .

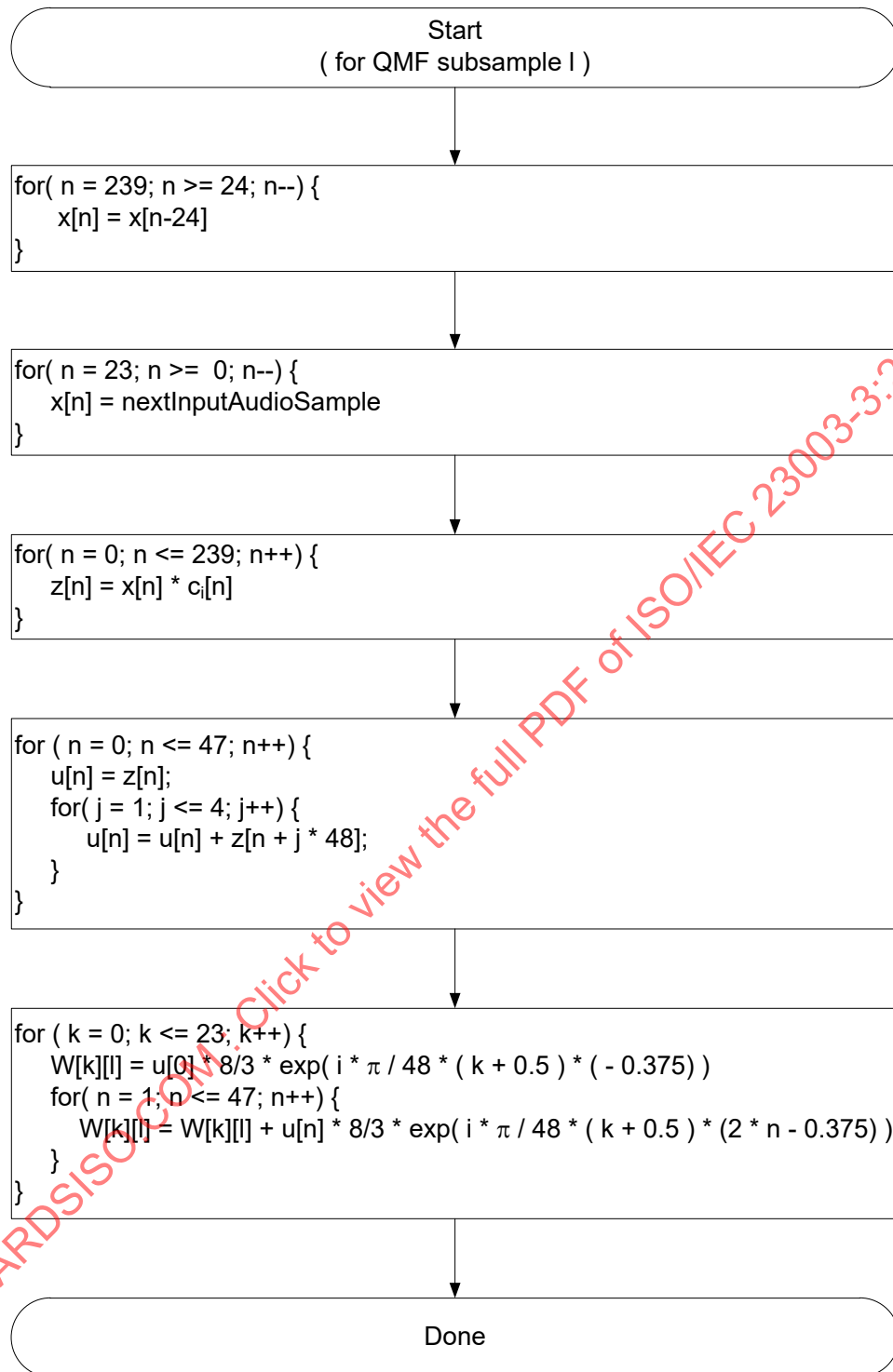


Figure 5 — Flowchart of the 24 band system decoder analysis QMF bank

7.5.2 Additional pre-processing in the MPEG-4 SBR within USAC

7.5.2.1 General

When the SBR QMF-patching algorithm as described in ISO/IEC 14496-3:2019, 4.6.18.6.3 is used, an additional step is introduced aimed at avoiding discontinuities in the shape of the spectral envelope of the high frequency signal being input to the subsequent envelope adjuster. This improves the operation of the subsequent envelope adjustment stage, resulting in a highband signal that is perceived to be more stable.

The additional pre-processing shall be done when the bitstream element `bs_sbr_preprocessing` is set to one. The additional pre-processing is described in 7.5.2.2.

7.5.2.2 Modifications and additions to the MPEG-4 SBR tool

The SBR tool used in USAC, is defined in MPEG-4 SBR but modified according to the following. In MPEG-4 SBR, the HF generated signal is derived by the following formula (ISO/IEC 14496-3:2019, 4.6.18.6.3):

$$\mathbf{X}_{High}(k, l + t_{HFAdj}) = \mathbf{X}_{Low}(p, l + t_{HFAdj}) + \mathbf{bwArray}(g(k)) \cdot \alpha_0(p) \cdot \mathbf{X}_{Low}(p, l - 1 + t_{HFAdj}) + \left[\mathbf{bwArray}(g(k)) \right]^2 \cdot \alpha_1(p) \cdot \mathbf{X}_{Low}(p, l - 2 + t_{HFAdj}),$$

The above shall be replaced by the following, for the instances where `bs_sbr_preprocessing` = 1:

$$\mathbf{X}_{High}(k, l + t_{HFAdj}) = preGain(p) \cdot \left(\mathbf{X}_{Low}(p, l + t_{HFAdj}) + \mathbf{bwArray}(g(k)) \cdot \alpha_0(p) \cdot \mathbf{X}_{Low}(p, l - 1 + t_{HFAdj}) + \left[\mathbf{bwArray}(g(k)) \right]^2 \cdot \alpha_1(p) \cdot \mathbf{X}_{Low}(p, l - 2 + t_{HFAdj}) \right),$$

where the $preGain()$ curve is calculated according to the following.

$$preGain(k) = 10^{\left(\frac{meanNrg - lowEnvSlope(k)}{20} \right)}, 0 \leq k < k_0$$

where $lowEnvSlope$ is calculated by the pseudo code in Table 117, according to:

`polyfit(3, k0, x_lowband, lowEnv, polyCoeffs);`

$$lowEnvSlope(k) = \sum_{i=0}^3 polyCoeffs(3-i) \cdot x_lowband(k)^i$$

and where

$$lowEnv(k) = 10 \log_{10} \left(\frac{\phi_k(0,0)}{numTimeSlots + 3} \cdot RATE \right), 0 \leq k < k_0$$

and where $x_lowband(k) = [0 \quad \dots \quad k_0 - 1]$, and

$$meanNrg = \frac{\sum_{k=0}^{k_0-1} lowEnv(k)}{k_0}.$$

Table 117 — Pseudo code for curve calculation, “polyfit()”

```

#define MAXDEG 3
void polyfit(int deg, int n, float x[], float y[], float p[]) {
    int i, j, k;
    float A[MAXDEG+1][MAXDEG+1];
    float b[MAXDEG+1];
    float v[2*MAXDEG+1];

    for (i = 0; i <= deg; i++) {
        b[i] = 0.0f;
        for (j = 0; j <= deg; j++) {
            A[i][j] = 0.0f;
        }
    }

    for (k = 0; k < n; k++) {
        v[0] = 1.0;
        for (i = 1; i <= 2*deg; i++) {
            v[i] = x[k]*v[i-1];
        }

        for (i = 0; i <= deg; i++) {
            b[i] += v[deg-i]*y[k];
            for (j = 0; j <= deg; j++) {
                A[i][j] += v[2*deg-i-j];
            }
        }
    }
    gaussSolve(deg + 1, A, b, p);
}

static void gaussSolve(int n, float A[][MAXDEG+1], float b[], float y[]) {
    int i, j, k, imax;
    float v;

    for (i = 0; i < n; i++) {
        imax = i;
        for (k = i + 1; k < n; k++) { // find pivot
            if (fabs(A[k][i]) > fabs(A[imax][i])) {
                imax = k;
            }
        }

        if (imax != i) { // swap rows
            v = b[imax];
            b[imax] = b[i];
            b[i] = v;
            for (j = i; j < n; j++) {
                v = A[imax][j];
                A[imax][j] = A[i][j];
                A[i][j] = v;
            }
        }

        v = A[i][i]; // normailize row
        b[i] /= v;
        for (j = i; j < n; j++) {
            A[i][j] /= v;
        }

        for (k = i + 1; k < n; k++) { // subtract row i for row > i
            v = A[k][i];
            b[k] -= v*b[i];
            for (j = i + 1; j < n; j++) {
                A[k][j] -= v*A[i][j];
            }
        }
    }
}

```

```

    }
}

for (i = n - 1; i >= 0; i--) {    // back substitution
    y[i] = b[i];
    for (j = i + 1; j < n; j++) {
        y[i] -= A[i][j]*y[j];
    }
}
}
}

```

7.5.3 DFT based harmonic transposer

7.5.3.1 Tool description

In case bitstream parameters **sbrPatchingMode[*ch*]** equals 1 or **harmonicSBR** equals 0, SBR patching as described in ISO/IEC 14496-3:2019, 4.6.18.6.3 is performed. When the **harmonicSBR** flag equals 1 and **sbrPatchingMode[*ch*]** equals 0, the above mentioned SBR standard QMF-patching algorithm is replaced by a phase-vocoder frequency spreading as shown in Figure 6.

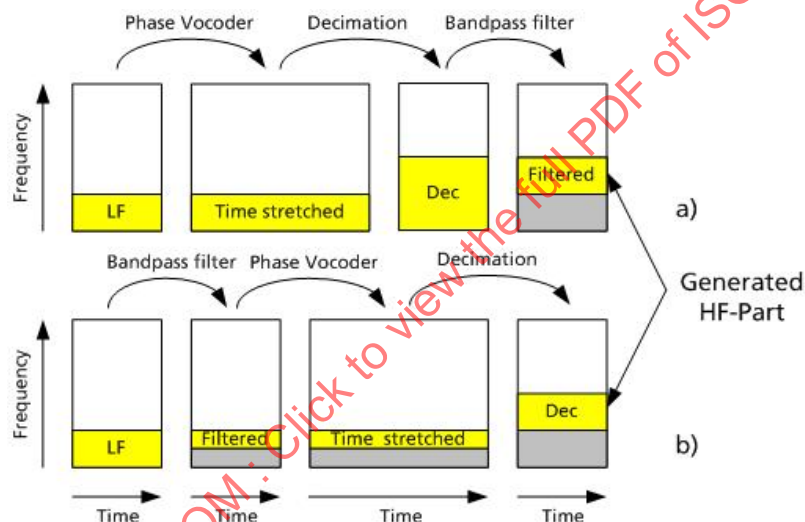


Figure 6 — Steps of harmonic bandwidth extension

The core coder time-domain-signal is bandwidth extended using a modified phase vocoder structure. The bandwidth extension is performed by time stretching followed by decimation, i.e., transposition, using several transposition factors ($T = 2, 3, 4$) in a common analysis/synthesis transform stage. For example, in the case of **sbrRatio**="2:1" the output signal of the transposer will have a sampling rate twice that of the input signal, which means that for a transposition factor of $T=2$, the signal will be time stretched but not decimated, efficiently producing a signal of equal time duration as the input signal but having twice the sampling frequency (for **sbrRatio**="8:3": $8/3$ the sampling frequency). The combined system may be interpreted as three parallel transposers using transposition factors of 2, 3 and 4 respectively. To reduce complexity, the factor 3 and 4 transposers (3rd and 4th order transposers) are integrated into the factor 2 transposer (2nd order transposer) by means of interpolation. Hence, the only analysis and synthesis transform stages are the stages required for a 2nd order transposer. Furthermore, to improve the transient response, a signal adaptive frequency domain oversampling is applied controlled by a flag in the bitstream.

The frequency domain oversampling factor F which is necessary and sufficient for adequate transient response is determined by $F = (Q + 1) / 2$ where Q is the quotient (synthesis/analysis) of the physical frequency bin spacing of the DFT filter banks. Due to the sampling rate changes described above it holds here that $Q = 2$ so $F = 1.5$.

For each frame (corresponding to `coreCoderFrameLength` core coder samples), the nominal “full size” transform size of the transposer is first determined by:

$$\begin{aligned} \text{fftSize} &= \begin{cases} \text{coreCoderFrameLength}, & \text{for } \mathbf{sbrOversamplingFlag}[\text{ch}] = 0 \\ 1.5 \cdot \text{coreCoderFrameLength}, & \text{for } \mathbf{sbrOversamplingFlag}[\text{ch}] = 1 \end{cases} \\ \text{fftSizeSyn} &= \begin{cases} 1024, & \text{for } \mathbf{sbrOversamplingFlag}[\text{ch}] = 0 \\ 1536, & \text{for } \mathbf{sbrOversamplingFlag}[\text{ch}] = 1 \end{cases} \end{aligned}$$

where **sbrOversamplingFlag[ch]** is signalled in the bitstream. This would be the transform size actually used in the transposer if critical sampling is deactivated, i.e., when $M_S = 32$ and $M_A = 64$ (for a `coreCoderFrameLength` of 768: $M_S=24$). The variables M_S and M_A are defined in 7.5.3.3.2 and 7.5.3.3.3 respectively.

As critical sampling is active, blocks of $32 \cdot M_S$ windowed input samples (corresponding to `coreCoderFrameLength` core coder samples), using a hop size (or stride) of $4 \cdot M_S$ samples (corresponding to `coreCoderFrameLength`/8 core coder samples) are transformed to the frequency domain by means of a DFT of size $32 \cdot M_S$ or $48 \cdot M_S = 1.5 \cdot 32 \cdot M_S$ depending on the signal adaptive frequency domain oversampling control signal. The phases of the complex-valued DFT coefficients are modified according to the three transposition factors used. For 2nd order transposition the phases are doubled. For 3rd and 4th order transposition the phases are either tripled or quadrupled or interpolated from two consecutive DFT coefficients. The modified coefficients are subsequently transformed back to the time domain by means of a DFT of size $16 \cdot M_A$ or $24 \cdot M_A = 1.5 \cdot 16 \cdot M_A$, windowed and combined by means of overlap-add using an output time stride of $4 \cdot M_A$ samples (corresponding to 256 decoder output samples).

Let $s(n)$ be the input time domain data provided by the sub-sampled synthesis QMF bank and $o(n)$ the output time domain signal subsequently provided to the sub-sampled analysis QMF bank at sample positions n ($n \in \mathbb{N}_0$). For each frame ($32 \cdot M_S$ time domain input samples), the analysis transform size S_a and the synthesis transform size S_s used by the transposer is determined by:

$$S_a = \text{fftSize} \cdot M_S \cdot 32 / \text{coreCoderFrameLength}$$

$$S_s = \text{fftSizeSyn} \cdot M_A / 64$$

The variable *transSamp* specifying the number of frequency domain transition samples is obtained from:

$$\text{transSamp} = 3 \cdot \text{fftSizeSyn} / 256$$

The variable *numPatches* and the array **xOverBin** of maximum 4 elements are calculated according to the pseudo code of Figure 7, where $\mathbf{f}_{TableHigh}$, $\mathbf{f}_{TableLow}$, N_{High} and N_{Low} are defined in ISO/IEC 14496-3:2019, 4.6.18.3.2. For each transposition factor ($T = 2, 3, 4$), a frequency domain window of *fftSize* elements is created as:

$$\Omega^{(T)}(k) = \begin{cases} 0 & 0 \leq k < \mathbf{xOverBin}(T-2) - \text{transSamp} / 2 \\ 0.5 + 0.5 \cdot \sin\left(\frac{\pi}{\text{transSamp}} \cdot (k - \mathbf{xOverBin}(T-2))\right) & \mathbf{xOverBin}(T-2) - \text{transSamp} / 2 \leq k \leq \mathbf{xOverBin}(T-2) + \text{transSamp} / 2 \\ 1 & \mathbf{xOverBin}(T-2) + \text{transSamp} / 2 < k < \mathbf{xOverBin}(T-1) - \text{transSamp} / 2 \\ 0.5 - 0.5 \cdot \sin\left(\frac{\pi}{\text{transSamp}} \cdot (k - \mathbf{xOverBin}(T-1))\right) & \mathbf{xOverBin}(T-1) - \text{transSamp} / 2 \leq k \leq \mathbf{xOverBin}(T-1) + \text{transSamp} / 2 \\ 0 & \mathbf{xOverBin}(T-1) + \text{transSamp} / 2 < k < \text{fftSize} \end{cases}$$

The time domain transform windows are given by:

$$\omega_a(n) = \sin\left(\frac{\pi}{32 \cdot M_S} \cdot (n + 0.5)\right), 0 \leq n < 32 \cdot M_S$$

for the analysis transform and:

$$\omega_s(n) = \sin\left(\frac{\pi}{16 \cdot M_A} \cdot (n + 0.5)\right), 0 \leq n < 16 \cdot M_A$$

for the synthesis transform. The following variables are set:

$$p_a = (S_a - 32 \cdot M_S) / 2$$

$$p_s = (S_s - 16 \cdot M_A) / 2$$

$$\delta_a = 4 \cdot M_S$$

$$\delta_s = 4 \cdot M_A$$

$$\Delta_a = k_L \cdot \text{fftSize} \cdot 32 / \text{coreCoderFrameLength}$$

$$\Delta_s = k_A \cdot \text{fftSizeSyn} / 64$$

where p_a and p_s are the analysis and synthesis zero pad sizes, δ_a and δ_s are the input and output hop lengths in samples, and Δ_a and Δ_s are analysis and synthesis transform offset variables respectively. The variables k_L and k_A are defined in 7.5.3.3.2 and 7.5.3.3.3 respectively. An input frame consists of 8 granules $(32 \cdot M_S) / \delta_a$. The index u depicts the current granule ($u \in \mathbf{N}_0$). One granule γ_u is calculated from the input signal as:

$$\gamma_u(n) = \begin{cases} 0 & , 0 \leq n < p_a \\ s(n + \delta_a \cdot u) \cdot \omega_a(n - p_a) & , p_a \leq n < p_a + 32 \cdot M_S \\ 0 & , p_a + 32 \cdot M_S \leq n < S_a \end{cases}$$

The granule is time-domain shifted $S_a/2$ samples as:

$$\hat{\gamma}_u(n) = \begin{cases} \gamma_u(n + S_a / 2) & , 0 \leq n < S_a / 2 \\ \gamma_u(n - S_a / 2) & , S_a / 2 \leq n < S_a \end{cases}$$

The shifted granule is then transformed to the frequency domain by an S_a -size DFT:

$$\Gamma_u = \mathbf{F}\{\hat{\gamma}_u\}$$

and the DFT coefficients are converted to polar coordinates as:

$$\begin{cases} \phi_u(k) = r_u(k) = 0 & , 0 \leq k < \Delta_a \\ \begin{cases} \phi_u(k) = \angle\{\Gamma_u(k - \Delta_a)\} \\ r_u(k) = |\Gamma_u(k - \Delta_a)| \end{cases} & , \Delta_a \leq k < \Delta_a + S_a \\ \phi_u(k) = r_u(k) = 0 & , \Delta_a + S_a \leq k < \text{fftSize} \end{cases}$$

For each transposition factor $T = 2, 3, 4$ for which $T \leq \text{numPatches} + 1$, a new granule of spectral coefficients $\bar{\Gamma}_u^{(T)}$ is computed according to:

$$\begin{aligned} \bar{\Gamma}_u^{(T)}(k) = & \Omega^{(T)}(k) \cdot r_u(\mu^{(T)}(k))^{1-\rho^{(T)}(k)} \cdot r_u(\mu^{(T)}(k)+1)^{\rho^{(T)}(k)} \cdot \\ & \exp\left[j \cdot T \cdot \left((1-\rho^{(T)}(k)) \cdot \phi_u(\mu^{(T)}(k)) + \rho^{(T)}(k) \cdot \phi_u(\mu^{(T)}(k)+1)\right)\right] \\ & + \Omega_C^{(T)}(k) \cdot r_u(\mu_1^{(T)}(k))^{1-m^{(T)}(k)/T} \cdot r_u(\mu_2^{(T)}(k))^{m^{(T)}(k)/T} \cdot \\ & \exp\left[j \cdot \left((T-m^{(T)}(k)) \cdot \phi_u(\mu_1^{(T)}(k)) + m^{(T)}(k) \cdot \phi_u(\mu_2^{(T)}(k))\right)\right] \\ & \text{for } 0 \leq k \leq \text{fftSizeSyn} / 2 \end{aligned}$$

and

$$\bar{\Gamma}_u^{(T)}(k) = \text{conj}\left\{\bar{\Gamma}_u^{(T)}(\text{fftSizeSyn} - k)\right\}, \quad \text{fftSizeSyn}/2 < k < \text{fftSizeSyn}$$

where $\mu^{(T)}(k)$ and $\rho^{(T)}(k)$ are defined as the integer and fractional parts of $2k/T$, respectively, and $\text{conj}\{x\}$ denotes complex conjugation of the argument x . The cross product gain $\Omega_C^{(T)}(k)$ is set to zero if the cross product pitch parameter $p < 1$. p is determined from the bitstream parameter **sbrPitchInBins[ch]** as:

$$p = \text{sbrPitchInBins[ch]} \cdot \text{fftSizeSyn} / 1536$$

If $p \geq 1$, then $\Omega_C^{(T)}(k)$ and the integer parameters $\mu_1^{(T)}(k)$, $\mu_2^{(T)}(k)$, and $m^{(T)}(k)$ are defined as follows.

Let M be the maximum of the at most $T-1$ values $\min\{r_u(n_1), r_u(n_2)\}$, for which

- n_1 is the integer part of $\frac{2k - mp}{T} + \frac{1}{2}$, and $n_1 \geq 0$;
- n_2 is the integer part of $n_1 + p$, and $0 \leq n_2 \leq S_A / 2$;
- $m = 1, \dots, T-1$.

Then

$$\Omega_C^{(T)}(k) = \begin{cases} \Omega^{(T)}(k), & \text{if } M > 4r_u(\mu^{(T)}(k)); \\ 0, & \text{otherwise.} \end{cases}$$

In the first case, $m^{(T)}(k)$ is defined to be the smallest $m = 1, \dots, T-1$ for which $\min\{r_u(n_1), r_u(n_2)\} = M$ and the integer pair $(\mu_1^{(T)}(k), \mu_2^{(T)}(k))$ is defined as the corresponding maximizing pair (n_1, n_2) .

The granules are mapped and added to form the combined spectral granule:

$$\bar{\Gamma}_u(k) = \sum_{T=2}^{\text{numPatches}+1} \bar{\Gamma}_u^{(T)}(k + \Delta_s), \quad 0 \leq k < S_s.$$

The combined spectral granule is transformed by an S_s -size inverse DFT to:

$$\bar{\hat{\gamma}}_u = \mathbf{F}^{-1} \{ \bar{\Gamma}_u \}$$

and the time domain shift is reversed to form an output time granule as:

$$\bar{\gamma}_u(n) = \begin{cases} \bar{\hat{\gamma}}_u(n + S_s / 2) & , 0 \leq n < S_s / 2 \\ \bar{\hat{\gamma}}_u(n - S_s / 2) & , S_s / 2 \leq n < S_s \end{cases}$$

The output granules are finally windowed and superimposed using overlap-add:

$$o(\delta_s \cdot u + m) = \sum_{v=0}^{\eta_s} \bar{\gamma}_{u-v+\eta_s}(\delta_s \cdot v + m + p_s) \cdot \omega_s(\delta_s \cdot v + m), 0 \leq m < \delta_s, \forall u, u \in \mathbf{N}_0$$

where $\eta_s = 16 \cdot M_A / \delta_s - 1 = 3$. The output time domain signal $o(n)$ is subsequently fed to the sub-sampled analysis QMF bank.

```

sfbL=0, sfbH=0
for patch = 1 to 4
    while (sfbL <= NLow) && (fTableLow(sfbL) <= patch * fTableLow(0))
        sfbL = sfbL+1
    end
    if (sfbL <= NLow)
        if ((patch * fTableLow(0) - fTableLow(sfbL-1)) <= 3)
            xOverBin(patch-1) = NINT(fftSizeSyn * fTableLow(sfbL-1)/128)
        else
            while (sfbH <= NHigh) && (fTableHigh(sfbH) <= patch * fTableHigh(0))
                sfbH = sfbH + 1
            end
            xOverBin(patch-1) = NINT(fftSizeSyn * fTableHigh(sfbH-1)/128)
        end
    else
        xOverBin(patch-1) = NINT(fftSizeSyn * fTableLow(NLow)/128)
        numPatches = patch-1
        break
    end
end
end

```

Figure 7 — Calculation of xOverBin and numPatches

7.5.3.2 Limiter frequency band table

The limiter frequency band table in the SBR tool (ISO/IEC 14496-3:2019, 4.6.18.3.2.3) contains indices of the synthesis filterbank subbands which describe the borders of the limiter bands. The number of elements equals the number of limiter bands plus one. The table is constructed to have either one limiter band over the entire SBR range or approximately 1.2, 2 or 3 bands per octave, as signalled by *bs_limiter_bands*. In the latter case additional band borders are installed which correspond to the HF generator patch borders. If *sbrPatchingMode*==1 these HF generator patch borders are calculated according to the flowchart of ISO/IEC 14496-3:2019, 4.6.18.6.3, Figure 4.48.

When harmonic SBR is active, i.e., when *sbrPatchingMode*==0, the above-mentioned additional band borders are instead determined by the bands created from the different transposition factors T of the harmonic SBR tool as specified in Figure 7.

The exact process of constructing the limiter frequency band table is described below.

The first element is always k_x . $\mathbf{f}_{TableLim}$ is a subset of the union of $\mathbf{f}_{TableLow}$ and the patch borders derived by the variables *numPatches* and **patchNumSubbands** given below.

If *bs_limiter_bands* is zero only one limiter band is used and $\mathbf{f}_{TableLim}$ is created as:

$$\mathbf{f}_{TableLim} = [\mathbf{f}_{TableLow}(0), \mathbf{f}_{TableLow}(N_{Low})]$$

$$N_L = 1$$

If *bs_limiter_bands* > 0 the limiter frequency resolution table is created according to the flowchart of ISO/IEC 14496-3:2019, Figure 4.41, for which the variables *numPatches* and **patchNumSubbands** are calculated as follows:

$$\mathbf{numPatches} = \begin{cases} \text{numPatches calculated from pseudo code of Figure 7} & , \text{ for sbrPatchingMode}=0 \\ \text{numPatches calculated from ISO/IEC 14496-3:2019, 4.6.18.6.3, Figure 4.48} & , \text{ for sbrPatchingMode}=1 \end{cases}$$

$$\mathbf{patchNumSubbands} = \begin{cases} \frac{128}{fftSizeSyn} \cdot \mathbf{xOverBin} & , \text{ for sbrPatchingMode}=0 \\ \text{patchNumSubbands calculated from Figure 4.48 in ISO/IEC 14496-3:2009, 4.6.18.6} & , \text{ for sbrPatchingMode}=1 \end{cases}$$

where the array **xOverBin** is calculated from the pseudo code of Figure 7 and *fftSizeSyn* is determined from *sbrOversamplingFlag* as outlined in 7.5.3.1.

7.5.3.3 Sub-sampled filter banks for HQ critical sampling processing

7.5.3.3.1 General

The strategy behind critical sampling processing is to use the subband signals from the 32-band (coreCoderFrameLength of 768: 24-band) analysis QMF bank already present in the SBR tool. A subset of the subbands, which cover the source range for the transposer, is synthesized in the time domain by a small sub-sampled real-valued QMF bank. The time domain output from this filter bank is then fed to the transposer. The transposer time domain input is now a bandwidth limited segment of the original core decoded lowband, which is frequency modulated to the baseband. Consequently, the transform sizes of the transposer need to be adjusted. After transposition, the likewise modulated time domain output is processed by a sub-sampled complex-valued analysis QMF bank, and the resulting QMF subbands are mapped back to the appropriate subbands in the 64-band QMF buffer.

This approach enables a substantial saving in computational complexity as only the relevant source range is processed by the transposer. The small QMF banks are obtained by sub-sampling of the original 64-band QMF bank, where the prototype filter coefficients are obtained by linear interpolation of the original prototype filter.

7.5.3.3.2 Real-valued sub-sampled M_S -channel synthesis filter bank

The processing of the sub-sampled real-valued synthesis QMF bank is described in Figure 8 and the processing steps below. First, the following variables are determined:

$$M_S = 4 \cdot \text{floor}\{(\mathbf{f}_{TableLow}(0) + 4)/8 + 1\}$$

$$k_L = \text{startSubband2kL}(\mathbf{f}_{TableLow}(0))$$

where M_S is the size of the sub-sampled synthesis filter bank and k_L represents the subband index of the first channel from the 32-band (coreCoderFrameLength of 768: 24-band) QMF bank to enter the sub-sampled

synthesis filter bank. The array **startSubband2kL** is listed in Table 118. The function $\text{floor}\{x\}$ rounds the argument x to the largest integer not greater than x , i.e., rounding towards $-\infty$.

When $\text{coreCoderFrameLength} = 768$ samples and $k_L + M_S > 24$, k_L is calculated as $k_L = 24 - M_S$.

Table 118 — $y = \text{startSubband2kL}(x)$

x	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
y	0	0	0	0	0	0	0	2	2	2	4	4	4	4	4	6	6	6	8	8	8	8	8	10	10	10	12	12	12	12	12	12	12

- A set of M_S real-valued subband samples are calculated from the M_S new complex-valued subband samples according to the first step of Figure 8 as:

$$V(k - k_L) = \text{Re} \left\{ X_{\text{Low}}(k) \cdot \exp \left(i \frac{\pi}{2} \left(k_L - \frac{(k + 0.5) \cdot 191}{64} \right) \right) \right\}, k_L \leq k < k_L + M_S$$

In the equation, $\exp()$ denotes the complex exponential function, i is the imaginary unit and k_L is defined as above.

- Shift the samples in the array **v** by $2M_S$ positions. The oldest $2M_S$ samples are discarded.
- The M_S real-valued subband samples are multiplied by the matrix **N**, i.e., the matrix-vector product **N**·**V** is computed, where:

$$N(k, n) = \frac{1}{M_S} \cdot \cos \left(\frac{\pi \cdot (k + 0.5) \cdot (2 \cdot n - M_S)}{2M_S} \right), \begin{cases} 0 \leq k < M_S \\ 0 \leq n < 2M_S \end{cases}$$

The output from this operation is stored in the positions 0 to $2M_S - 1$ of array **v**.

- Extract samples from **v** according to the flowchart in Figure 8 to create the $10M_S$ -element array **g**.
- Multiply the samples of array **g** by window **c_i** to produce array **w**. The window coefficients **c_i** are obtained by linear interpolation of the coefficients **c**, i.e., through:

$$c_i(n) = \rho(n) c(\mu(n) + 1) + (1 - \rho(n)) c(\mu(n)), \quad 0 \leq n < 10M_S$$

where $\mu(n)$ and $\rho(n)$ are defined as the integer and fractional parts of $64 \cdot n / M_S$, respectively. The window coefficients of **c** can be found in ISO/IEC 14496-3:2019, 4.A.62, Table 4.A.89.

- Calculate M_S new output samples by summation of samples from array **w** according to the last step in the flowchart of in Figure 8.

7.5.3.3.3 Complex-valued Sub-sampled **M_A**-channel analysis filter bank

The processing of the sub-sampled complex-valued analysis QMF bank is described in Figure 9 and the processing steps below. First, the following variables are determined:

$$M_A = 4 \cdot \text{floor} \left\{ \left(\min \{ 64, \mathbf{f}_{\text{TableLow}}(N_{\text{Low}}) + 1 \} - 2 \cdot \text{floor} \{ (\mathbf{f}_{\text{TableLow}}(0) - 1) / 2 \} - 1 \right) / 4 + 1 \right\}$$

$$k_A = 2 \cdot \text{floor} \left\{ (\mathbf{f}_{\text{TableLow}}(0) - 1) / 2 \right\} - \max \{ 0, 2 \cdot \text{floor} \{ (\mathbf{f}_{\text{TableLow}}(0) - 1) / 2 \} + M_A - 64 \}$$

where M_A is the size of the sub-sampled analysis filter bank and k_A represents the index of the first band of the 64-band QMF buffer that the subbands from the sub-sampled analysis filter bank are fed to. The function $\min\{x,y\}$ returns the argument x or y closest to minus infinity, and the function $\max\{x,y\}$ returns the argument x or y closest to infinity.

- Shift the samples in the array $\mathbf{x}$ by M_A positions according to the first step of Figure 9. The oldest M_A samples are discarded and M_A new samples are stored in positions 0 to M_A-1 .
- Multiply the samples of array $\mathbf{x}$ by the coefficients of window $\mathbf{c}_i$. The window coefficients $\mathbf{c}_i$ are obtained by linear interpolation of the coefficients $\mathbf{c}$, i.e., through:

$$c_i(n) = \rho(n)c(\mu(n)+1) + (1-\rho(n))c(\mu(n)), \quad 0 \leq n < 10M_A$$

where $\mu(n)$ and $\rho(n)$ are defined as the integer and fractional parts of $64 \cdot n / M_A$, respectively. The window coefficients of $\mathbf{c}$ can be found in ISO/IEC 14496-3:2019, 4.A.62, Table 4.A.89.

- Sum the samples according to the formula in the flowchart in Figure 9 to create the $2M_A$ -element array $\mathbf{u}$.
- Calculate M_A new complex-valued subband samples by the matrix-vector multiplication $\mathbf{M} \cdot \mathbf{u}$, where:

$$M(k,n) = \exp\left(\frac{i \cdot \pi \cdot (k+0.5) \cdot (2 \cdot n - M_A/64)}{2M_A} - \frac{i \cdot \pi \cdot k_A}{32}\right) \cdot \begin{cases} 0 \leq k < M_A \\ 0 \leq n < 2M_A \end{cases}$$

In the equation, $\exp()$ denotes the complex exponential function, i is the imaginary unit and M_A and k_A is defined as above.

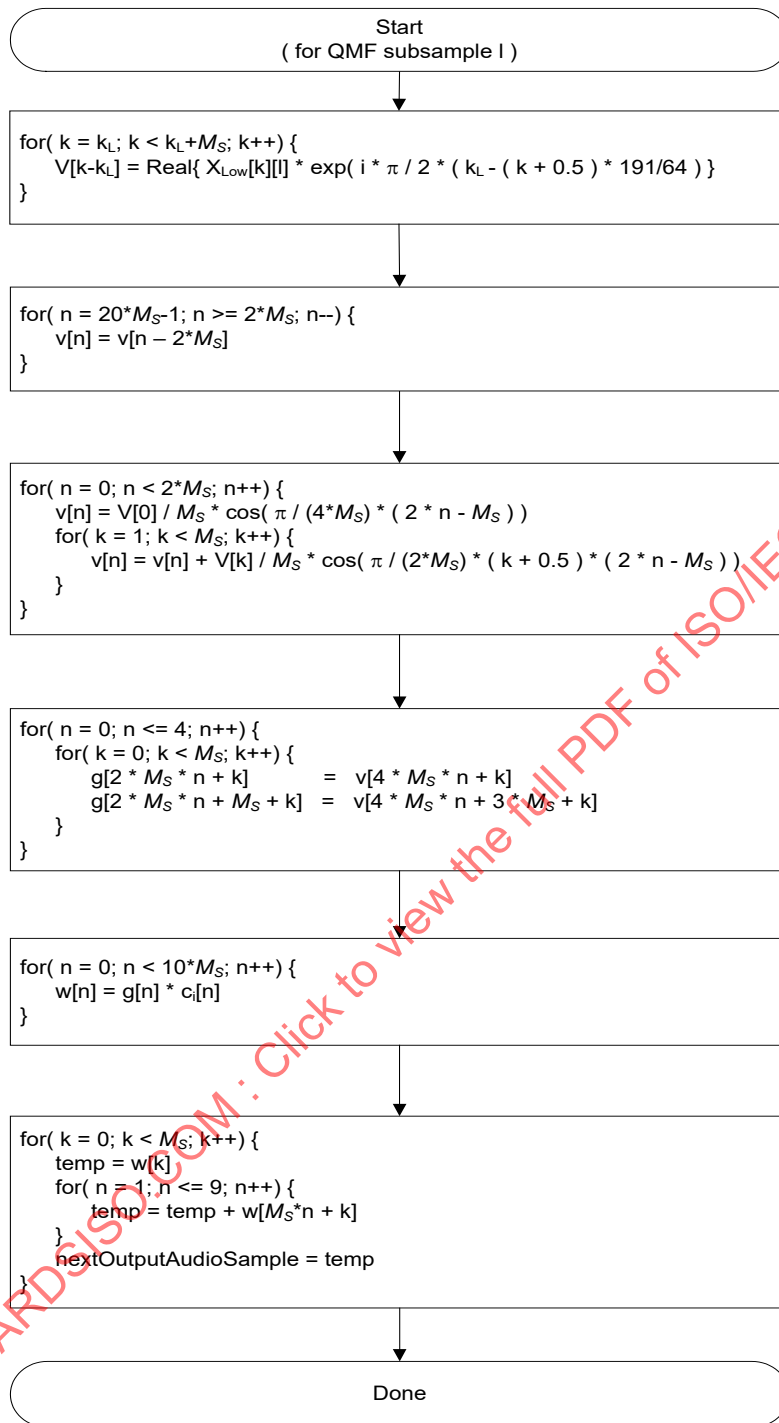
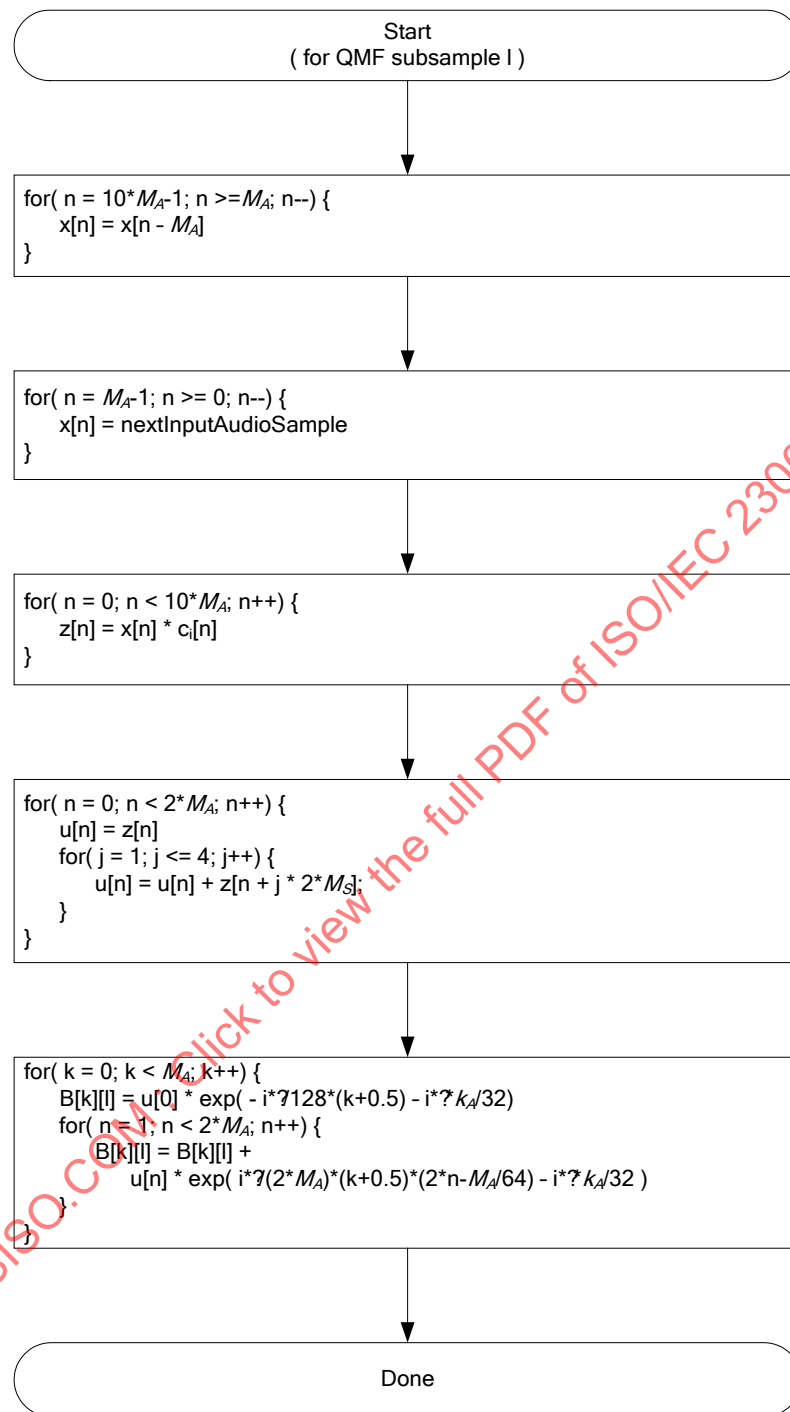


Figure 8 — Flowchart of real-valued sub-sampled M_S -ch synthesis QMF bank

Figure 9 — Flowchart of complex-valued sub-sampled M_A -ch analysis QMF bank

7.5.4 QMF based harmonic transposer

7.5.4.1 Tool description

The harmonic transposition scheme which is described in 7.5.3 may be replaced by a QMF based harmonic transposer. The bandwidth extension of the core coder time-domain-signal is carried out entirely in the QMF domain, using a modified phase vocoder structure, performing decimation followed by time stretching for every QMF subband. Transposition using several transposition factors ($T = 2, 3, 4$) is carried out in a common QMF analysis/synthesis transform stage. For example, in the case of `sbrRatio="2:1"` the output signal of the transposer will have a sampling rate twice that of the input signal (for `sbrRatio="8:3"`: $8/3$ the sampling frequency), which means that, for a transposition factor of $T=2$, the complex QMF subband signals resulting from the complex transposer QMF analysis bank will be time stretched but not decimated and fed into a QMF synthesis bank of twice the physical subband spacing as in the transposer QMF analysis bank. The combined system may be interpreted as three parallel transposers using transposition factors of 2, 3 and 4 respectively. To reduce complexity, the factor 3 and 4 transposers (3rd and 4th order transposers) are integrated into the factor 2 transposer (2nd order transposer) by means of interpolation. Hence, the only QMF analysis and synthesis transform stages are the stages required for a 2nd order transposer. Since the QMF based harmonic transposer does not feature signal adaptive frequency domain oversampling, the corresponding flag in the bitstream is ignored.

In case of `sbrPatchingMode[ch] == 1` or `harmonicSBR == 0` SBR patching as described in ISO/IEC 14496-3:2019, 4.6.18.6.3 is performed.

The variable `numPatches` and the array `xOverQmf` of maximum 4 elements are calculated according to the pseudo code of Figure 7, where $f_{TableHigh}$, $f_{TableLow}$, N_{High} and N_{Low} are defined in ISO/IEC 14496-3 and according to:

$$\mathbf{xOverQmf} = \frac{128}{fftSizeSyn} \cdot \mathbf{xOverBin}.$$

A complex output gain value is defined for all synthesis subbands by :

$$\Omega(k) = \begin{cases} \exp\left[-j\pi \frac{385}{128} \left(k + \frac{1}{2}\right)\right], & \mathbf{xOverQmf}(0) \leq k < \mathbf{xOverQmf}(1) \\ 0.7071 \cdot \exp\left[-j\pi \frac{385}{128} \left(k + \frac{1}{2}\right)\right], & \mathbf{xOverQmf}(1) \leq k < \mathbf{xOverQmf}(2) \\ 2 \cdot \exp\left[-j\pi \frac{385}{128} \left(k + \frac{1}{2}\right)\right], & \mathbf{xOverQmf}(2) \leq k < \mathbf{xOverQmf}(3) \end{cases}$$

The core coder time-input-signal is transformed to the QMF domain, using blocks of `coreCoderFrameLength` input samples. To save computational complexity, the transform is implemented by applying a critical sampling processing (described in 7.5.4.2) on the subband signals from the 32-band (`coreCoderFrameLength` of 768: 24-band) analysis QMF bank that is already present in the SBR tool.

Let the 32-band (`coreCoderFrameLength` of 768: 24-band) QMF domain signal for the current frame be given by the matrix $X_{Low}(m, k)$ with time subband samples $m = 0, 1, \dots, 31$ and subbands $k = 0, 1, \dots, 31$ (`coreCoderFrameLength` of 768: $k = 0, 1, \dots, 23$). The critical sampling processing transforms the matrix $X_{Low}(m, k)$ into new QMF submatrices $\Gamma(\mu, n)$ with doubled frequency resolution with the subband samples $\mu = 0, 1, \dots, 15$ and subbands $n = 2 * k_L, \dots, 2 * k_L + 2 * M_s - 1$ (see 7.5.4.2).

The given QMF submatrices $\Gamma(\mu, n)$ are operated by the subband block processing with time extent of twelve subband samples at a subband sample stride equal to one. It performs linear extractions and nonlinear operations on those submatrices and overlap-adds the modified submatrices at a subband sample stride equal to two. The result is that the QMF output undergoes a subband domain stretch of a factor two and subband domain transpositions of factors $T/2 = 1, 3/2, 2$. Upon synthesis with a QMF bank of twice the physical subband spacing as the transposer analysis bank, the required transposition with factors $T = 2, 3, 4$ will result.

In the following, the nonlinear processing of a single submatrix of samples will be described. The variable $u = 0, 1, 2, \dots$ denotes the position of the submatrix. For notational purposes, this index will be omitted from the variables as it is fixed and it is practical to use the following indexing of the submatrix.

$$B(m, n) = \Gamma(m + 6 + u, n), \quad m = -6, \dots, 5 \quad n = 0, \dots, 2M_S - 1.$$

The output of the nonlinear modification is denoted by $Y(m, k)$ where $m = -6, \dots, 5$ and $\mathbf{xOverQmf}(0) \leq k < \mathbf{xOverQmf}(\text{numPatches})$. Each synthesis subband with index k is the result of one transposition order and as the processing is slightly different depending on this order, the three cases will be considered separately below. A common feature is that analysis subbands with indices approximating $2k / T$ are chosen.

For $\mathbf{xOverQmf}(0) \leq k < \mathbf{xOverQmf}(1)$, where $T = 2$

A block with time extent of ten subband samples is extracted from the analysis band $n = 2k / T = k$,

$$X(m, k) = B(m, k), \quad m = -5, \dots, 4$$

The QMF samples are converted to polar coordinates as:

$$\begin{cases} \phi(m, k) = \angle\{X(m, k)\} \\ r(m, k) = |X(m, k)| \end{cases}$$

The output is then defined for $m = -5, \dots, 4$ by:

$$Y^{(2)}(m, k) = \Omega(k) \cdot r(0, k)^{1-1/T} \cdot r(m, k)^{1/T} \cdot \exp[j \cdot (T-1) \cdot \phi(0, k) + \phi(m, k)],$$

and $Y^{(2)}(m, k)$ is extended by zeros for $m \in \{-6, 5\}$. This latter operation is equivalent to a synthesis windowing with a rectangular window of length ten.

For $\mathbf{xOverQmf}(1) \leq k < \mathbf{xOverQmf}(2)$, where $T = 3$

Define the analysis subband index $\tilde{n}$ as the integer part of $2k / T = 2k / 3$ and define another analysis subband index $n = \tilde{n} + \kappa$ where:

$$\kappa = \begin{cases} 1 & k \in 3Z_+ + 1 \\ 0 & \text{else} \end{cases} \quad \text{where } Z_+ \text{ denotes the positive integer set.}$$

A block with time extent of eight subband samples is extracted for $v = n, \tilde{n}$,

$$X(m, v) = B(3m/2, v), \quad m = -4, \dots, 3.$$

Here the non-integer subband sample entries are obtained by a two tap interpolation of the form:

$$B(\mu + 0.5, v) = h_0(v)B(\mu, v) + h_1(v)B(\mu + 1, v)$$

with the filter coefficients defined for $v = n, \tilde{n}$ and $\varepsilon = 0, 1$ by:

$$h_\varepsilon(v) = 0.56342741195967 \cdot \exp\left[j(-1)^\varepsilon \frac{\pi}{2} \left(v + \frac{1}{2}\right)\right].$$

The QMF samples are converted to polar coordinates for $v = n, \tilde{n}$ as:

$$\begin{cases} \phi(m, v) = \angle \{X(m, v)\} \\ r(m, v) = |X(m, v)| \end{cases}$$

The output is then defined for $m = -4, \dots, 3$ by:

$$Y^{(3)}(m, k) = \Omega(k) \cdot \begin{cases} (2 - \kappa) \cdot r(0, \tilde{n})^{1-1/T} \cdot r(m, n)^{1/T} \cdot \exp[j \cdot ((T-1) \cdot \phi(0, \tilde{n}) + \phi(m, n))] + \\ \kappa \cdot r(0, n)^{1-1/T} \cdot r(m, \tilde{n})^{1/T} \cdot \exp[j \cdot ((T-1) \cdot \phi(0, n) + \phi(m, \tilde{n}))] \end{cases}$$

and $Y^{(3)}(m, k)$ is extended by zeros for $m \in \{-6, -5, 4, 5\}$. This latter operation is equivalent to a synthesis windowing with a rectangular window of length eight.

For $\text{xOverQmf}(2) \leq k < \text{xOverQmf}(3)$, where $T = 4$

Define the analysis subband index $\tilde{n}$ as the integer part of $2k / T = k / 2$ and define another analysis subband index n according to:

$$n = \begin{cases} \tilde{n} - 1, & k \text{ even;} \\ \tilde{n} + 1, & k \text{ odd.} \end{cases}$$

A block with time extent of six subband samples is extracted for $v = n, \tilde{n}$,

$$X(m, v) = B(2m, v), \quad m = -3, \dots, 2$$

The QMF samples are converted to polar coordinates as:

$$\begin{cases} \phi(m, v) = \angle \{X(m, v)\} \\ r(m, v) = |X(m, v)| \end{cases}$$

The output is then defined for $m = -3, \dots, 2$ by:

$$Y^{(4)}(m, k) = \Omega(k) \cdot r(0, \tilde{n})^{1-1/T} \cdot r(m, n)^{1/T} \cdot \exp[j \cdot ((T-1) \cdot \phi(0, \tilde{n}) + \phi(m, n))],$$

and $Y^{(4)}(m, k)$ is extended by zeros for $m \in \{-6, -5, -4, 3, 4, 5\}$. This latter operation is equivalent to a synthesis windowing with a rectangular window of length six.

Next, the addition of cross products is considered. For each k with $\text{xOverQmf}(0) \leq k < \text{xOverQmf}(\text{numPatches})$, a unique transposition factor $T = 2, 3, 4$, is defined by the rule $\text{xOverQmf}(T-2) \leq k < \text{xOverQmf}(T-1)$. A cross product gain $\Omega_C(m, k)$ is set to zero if the cross product pitch parameter satisfies $p < 1$. p is determined from the bitstream parameter **sbrPitchInBins[ch]** as:

$$p = \text{sbrPitchInBins[ch]} / 12$$

If $p \geq 1$, then $\Omega_C(m, k)$ and the intermediate integer parameters $\mu_1(k)$, $\mu_2(k)$, and $t(k)$ are defined by the following procedure. Let M be the maximum of the at most $T-1$ values $\min\{|B(0, n_1)|, |B(0, n_2)|\}$, where:

- n_1 is the integer part of $\frac{2k+1-tp}{T}$ and $n_1 \geq 0$;
- n_2 is the integer part of $n_1 + p$ and $n_2 < 2M_S$;

— $t = 1, \dots, T - 1$.

If $M \leq |B(0, \mu(k))|$, where $\mu(k)$ is defined as the integer part of $2k/T$, then the cross product addition is canceled and $\Omega_C(m, k) = 0$. Otherwise, $t(k)$ is defined to be the smallest $t = 1, \dots, T - 1$ for which $\min\{|B(0, n_1)|, |B(0, n_2)|\} = M$ and the integer pair $(\mu_1(k), \mu_2(k))$ is defined as the corresponding maximizing pair (n_1, n_2) . Two downsampling factors $D_1(k)$ and $D_2(k)$ are determined from the values of T and $t(k)$ as the particular solutions to the equation $(T - t(k))D_1 + t(k)D_2 = T/2$ that are given in Table 119.

Table 119 — Downsampling factors

T	$t(k)$	$D_1(k)$	$D_2(k)$
2	1	0	1
3	1	0	1.5
3	2	1.5	0
4	1	0	2
4	2	0	1
4	3	2	0

In the cases where $p \geq 1$ and $M > |B(0, \mu(k))|$ the cross product gain is then defined by:

$$\Omega_C(m, k) = (7 - T) \cdot \Omega(k) \exp \left[-i\pi p \frac{t(k)(T - t(k))}{T} (D_2(k) - D_1(k))m \right], \quad m = -1, 0.$$

Two blocks with time extent of two subband samples are extracted according to:

$$\begin{cases} X_1(m) = B(D_1(k)m, \mu_1(k)) \\ X_2(m) = B(D_2(k)m, \mu_2(k)) \end{cases} \quad m = -1, 0$$

where the use of a downsampling factor equal to zero corresponds to repetition of a single subband sample value and the use of a non-integer downsampling factor will require the computation of non-integer subband sample entries. These are obtained as previously by a two tap interpolation of the form

$$B(\mu + 0.5, \nu) = h_0(\nu)B(\mu, \nu) + h_1(\nu)B(\mu + 1, \nu)$$

with the filter coefficients defined for $\nu = \mu_1(k), \mu_2(k)$ and $\varepsilon = 0, 1$ by

$$h_\varepsilon(\nu) = 0.56342741195967 \cdot \exp \left[j(-1)^\varepsilon \frac{\pi}{2} (\nu + \frac{1}{2}) \right].$$

The extracted QMF samples are converted to polar coordinates:

$$\begin{cases} \phi_i(m) = \angle \{X_i(m)\} \\ r_i(m) = |X_i(m)| \end{cases}, \quad i = 1, 2, \quad m = -1, 0$$

The cross product term is then computed as:

$$Y_C^{(T)}(m, k) = \Omega_C(m, k) \cdot r_1(m)^{1-t(k)/T} \cdot r_2(m)^{t(k)/T} \cdot \exp \left[j \cdot ((T - t(k))\phi_1(m) + t(k)\phi_2(m)) \right], \quad m = -1, 0,$$

and $Y_C^{(T)}(m, k)$ is extended by zeros for $m \in \{-6, -5, -4, -3, -2, 1, 2, 3, 4, 5\}$.

The transposition outputs are added to form the combined QMF output

$$\bar{Y}_u(m, k) = \sum_{T=2}^{numPatches+1} \left(Y^{(T)}(m, k) + Y_C^{(T)}(m, k) \right) \text{ for } m = -6, -5, \dots, 5,$$

and for $xOverQmf(0) \leq k < xOverQmf(numPatches)$, and $\forall u, u \in N_0$.

The combined QMF outputs are finally superimposed using overlap-add:

$$O(2 \cdot u + m + 6, k) = \frac{1}{3} \sum_{v=0}^{\eta_s} \bar{Y}_{u-v+\eta_s}(m + 2 \cdot v, k), \text{ for } -6 \leq m \leq -5,$$

and for $xOverQmf(0) \leq k < xOverQmf(numPatches)$, and $\eta_s = 12/2 - 1 = 5$.

7.5.4.2 Sub-sampled filter banks for QMF critical sampling processing

7.5.4.2.1 General

The strategy behind critical sampling processing is to use the subband signals from the 32-band (coreCoderFrameLength of 768: 24-band) analysis QMF bank already present in the SBR tool. A subset of the subbands covering the source range for the transposer is synthesized to the time domain by a small sub-sampled real-valued QMF bank. The time domain output from this filter bank is then fed to a complex-valued analysis QMF bank of twice the filter bank size. This approach enables a substantial saving in computational complexity as only the relevant source range is transformed to the QMF subband domain having doubled frequency resolution. The small QMF banks are obtained by sub-sampling of the original 64-band QMF bank, where the prototype filter coefficients are obtained by linear interpolation of the original prototype filter.

The processing of the real-valued synthesis QMF bank is identical to the processing in the FFT based transposer outlined in 7.5.3.3, but is repeated here for completeness.

The processing of the sub-sampled filter banks are described in the flowcharts of Figure 10 and Figure 11. First, the following variables are determined

$$M_S = 4 \cdot \text{floor}\{(\mathbf{f}_{TableLow}(0) + 4)/8 + 1\}$$

$$k_L = \text{startSubband2kL}(\mathbf{f}_{TableLow}(0))$$

where M_S is the size of the sub-sampled synthesis filter bank and k_L represents the subband index of the first channel from the 32-band (coreCoderFrameLength of 768: 24-band) QMF bank to enter the sub-sampled synthesis filter bank. The array **startSubband2kL** is listed in Table 120. The function $\text{floor}\{x\}$ rounds the argument x to the largest integer not greater than x , i.e., rounding towards $-\infty$. When $\text{coreCoderFrameLength} = 768$ samples and $k_L + M_S > 24$, k_L is calculated as $k_L = 24 - M_S$.

Table 120 — $y = \text{startSubband2kL}(x)$

x	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
y	0	0	0	0	0	0	0	2	2	2	4	4	4	4	4	6	6	6	8	8	8	8	8	10	10	10	12	12	12	12	12	12	12

7.5.4.2.2 Real-valued sub-sampled MS-channel synthesis filter bank

- A set of M_S real-valued subband samples are calculated from the M_S new complex-valued subband samples according to the first step of Figure 10 as:

$$V(k - k_L) = \text{Re} \left\{ X_{Low}(k) \cdot \exp \left(i \frac{\pi}{2} \left(k_L - \frac{(k + 0.5) \cdot 191}{64} \right) \right) \right\}, k_L \leq k < k_L + M_S$$

In the equation, $\exp()$ denotes the complex exponential function, i is the imaginary unit and k_L is defined in 7.5.4.2.1.

- Shift the samples in the array $\mathbf{v}$ by $2M_S$ positions. The oldest $2M_S$ samples are discarded.
- The M_S real-valued subband samples are multiplied by the matrix $\mathbf{N}$, i.e., the matrix-vector product $\mathbf{N} \cdot \mathbf{V}$ is computed, where:

$$N(k, n) = \frac{1}{M_S} \cdot \cos \left(\frac{\pi \cdot (k + 0.5) \cdot (2 \cdot n - M_S)}{2M_S} \right), \begin{cases} 0 \leq k < M_S \\ 0 \leq n < 2M_S \end{cases}$$

The output from this operation is stored in the positions 0 to $2M_S - 1$ of array $\mathbf{v}$.

- Extract samples from $\mathbf{v}$ according to the flowchart in Figure 10 to create the $10M_S$ -element array $\mathbf{g}$.
- Multiply the samples of array $\mathbf{g}$ by window $\mathbf{c}_i$ to produce array $\mathbf{w}$. The window coefficients $\mathbf{c}_i$ are obtained by linear interpolation of the coefficients $\mathbf{c}$, i.e., through:

$$c_i(n) = \rho(n) c(\mu(n) + 1) + (1 - \rho(n)) c(\mu(n)), \quad 0 \leq n < 10M_S$$

where $\mu(n)$ and $\rho(n)$ are defined as the integer and fractional parts of $64 \cdot n / M_S$, respectively. The window coefficients of $\mathbf{c}$ can be found in ISO/IEC 14496-3:2009, 4.A.62, Table 4.A.89.

- Calculate M_S new output samples by summation of samples from array $\mathbf{w}$ according to the last step in the flowchart in Figure 10.

7.5.4.2.3 Complex-valued sub-sampled 2M-channel analysis filter bank

- Shift the samples in the array $\mathbf{x}$ by $2M_S$ positions according to the first step of Figure 11. The oldest $2M_S$ samples are discarded and $2M_S$ new samples are stored in positions 0 to $2M_S - 1$.
- Multiply the samples of array $\mathbf{x}$ by the coefficients of window $\mathbf{c}_{2i}$. The window coefficients $\mathbf{c}_{2i}$ are obtained by linear interpolation of the coefficients $\mathbf{c}$, i.e., through:

$$c_{2i}(n) = \rho(n) c(\mu(n) + 1) + (1 - \rho(n)) c(\mu(n)), \quad 0 \leq n < 20M_S$$

where $\mu(n)$ and $\rho(n)$ are defined as the integer and fractional parts of $32 \cdot n / M_S$, respectively. The window coefficients of $\mathbf{c}$ can be found in ISO/IEC 14496-3:2009, 4.A.62, Table 4.A.89.

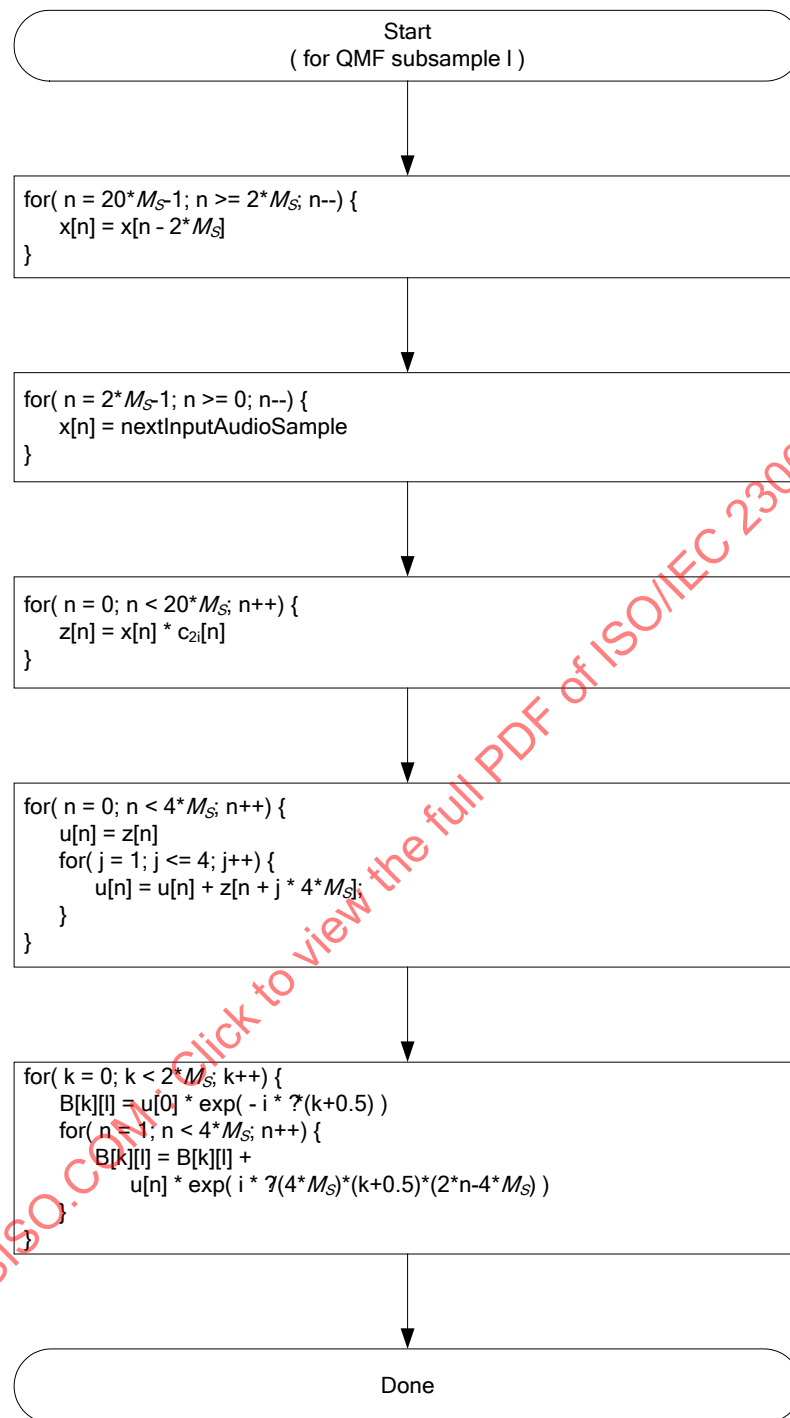
- Sum the samples according to the formula in the flowchart in Figure 11 to create the $4M_S$ -element array $\mathbf{u}$.
- Calculate $2M_S$ new complex-valued subband samples by the matrix-vector multiplication $\mathbf{M} \cdot \mathbf{u}$, where:

$$M(k, n) = \exp\left(\frac{i \cdot \pi \cdot (k + 0.5) \cdot (2 \cdot n - 4 \cdot M_S)}{4M_S}\right), \begin{cases} 0 \leq k < 2M_S \\ 0 \leq n < 4M_S \end{cases}$$

In the equation, $\exp()$ denotes the complex exponential function, and i is the imaginary unit.



Figure 10 — Flowchart of real-valued sub-sampled M_S -ch synthesis QMF bank

Figure 11 — Flowchart of complex-valued sub-sampled $2M_S$ -ch analysis QMF bank

7.5.5 4:1 Structure for SBR in USAC

7.5.5.1 General

When the core-decoder operates at low sampling rates, the SBR module as described in ISO/IEC 14496-3:2019, 4.6.18, which is designed as 2:1 system, i.e., SBR runs at twice the core-coder sampling rate, can be operated as 4:1 system, i.e., SBR runs at fourfold the core-coder sampling rate. This overcomes the inherent limitation of the 2:1 system concerning the flexibility of the output sampling rates so that a high output audio bandwidth can be achieved even at low sampling rates.

7.5.5.2 Modifications and additions to the MPEG-4 SBR tool

When the SBR tool operates in 4:1 mode, the definition of the constant rate found in ISO/IEC 14496-3:2019, 4.6.18.2.5 is modified to the following:

$RATE = 4$ A constant indicating the number of QMF subband samples per timeslot.

The definition of the variable $F_{S_{SBR}}$ found in ISO/IEC 14496-3:2019, 4.6.18.2.6 is modified to the following:

$F_{S_{SBR}}$ Internal sampling frequency of the SBR tool. If the SBR tool is operated in 4:1 mode, $F_{S_{SBR}}$ is four times the sampling frequency of the core coder (after sampling frequency mapping, Table 84). The sampling frequency of the SBR processed output signal is equal to the internal sampling frequency of the SBR tool.

The master frequency band table for the 4:1 SBR system is calculated according to the instructions given in 7.5.1.2 and ISO/IEC 14496-3:2019, 4.6.18.3.2. However, the boundaries of the table are derived using half the SBR sampling frequency and half the number of QMF subbands. Therefore, the subband representing the lower frequency boundary of the master frequency band table k_0 is determined by:

$$k_0 = startMin + offset(bs_start_freq)$$

with

$$offset = \begin{cases} [-8, -7, -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7], & \frac{F_{S_{SBR}}}{2} = 16000 \\ [-5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 9, 11, 13] & , \frac{F_{S_{SBR}}}{2} = 22050 \\ [-5, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 9, 11, 13, 16] & , \frac{F_{S_{SBR}}}{2} = 24000 \\ [-6, -4, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 9, 11, 13, 16] & , \frac{F_{S_{SBR}}}{2} = 32000 \\ [-1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 13, 15, 17, 19] & , \frac{F_{S_{SBR}}}{2} = 40000 \\ [-4, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 9, 11, 13, 16, 20] & , 44100 \leq \frac{F_{S_{SBR}}}{2} \leq 64000 \\ [-2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 9, 11, 13, 16, 20, 24] & , \frac{F_{S_{SBR}}}{2} > 64000 \end{cases}$$

$$startMin = \begin{cases} NINT \left(3000 \cdot \frac{64}{\left(\frac{Fs_{SBR}}{2} \right)} \right), & \frac{Fs_{SBR}}{2} < 32000 \\ NINT \left(4000 \cdot \frac{64}{\left(\frac{Fs_{SBR}}{2} \right)} \right), & 32000 \leq \frac{Fs_{SBR}}{2} < 64000 \\ NINT \left(5000 \cdot \frac{64}{\left(\frac{Fs_{SBR}}{2} \right)} \right), & 64000 \leq \frac{Fs_{SBR}}{2} \end{cases}$$

The upper frequency boundary of the master frequency band table k_2 is determined according to ISO/IEC 14496-3:2019, 4.6.18.3.2 as:

$$k_2 = \begin{cases} \min \left(64, stopMin + \sum_{i=0}^{bs_stop_freq-1} stopDkSort(i) \right), & 0 \leq bs_stop_freq < 14 \\ \min(64, 2 \cdot k_0), & bs_stop_freq = 14 \\ \min(64, 3 \cdot k_0), & bs_stop_freq = 15 \end{cases}$$

but with the following modification to $stopMin$:

$$stopMin = \begin{cases} NINT \left(6000 \cdot \frac{64}{\left(\frac{Fs_{SBR}}{2} \right)} \right), & \frac{Fs_{SBR}}{2} < 32000 \\ NINT \left(8000 \cdot \frac{64}{\left(\frac{Fs_{SBR}}{2} \right)} \right), & 32000 \leq \frac{Fs_{SBR}}{2} < 64000 \\ NINT \left(10000 \cdot \frac{64}{\left(\frac{Fs_{SBR}}{2} \right)} \right), & 64000 \leq \frac{Fs_{SBR}}{2} \end{cases}$$

stopDkSort = *sort*(**stopDk**)

$$\mathbf{stopDk}(p) = NINT \left(stopMin \cdot \left(\frac{64}{stopMin} \right)^{\frac{p+1}{13}} \right) - NINT \left(stopMin \cdot \left(\frac{64}{stopMin} \right)^{\frac{p}{13}} \right), 0 \leq p \leq 12$$

For all other sampling rates $\frac{F_{S_{SBR}}}{2}$, the mapping as defined in 7.5.1.2 shall be applied to build the master frequency table.

In case $bs_freq_scale > 0$ the master frequency band table, $\mathbf{f}_{Master}$, is calculated according to the flowchart in Figure 12.

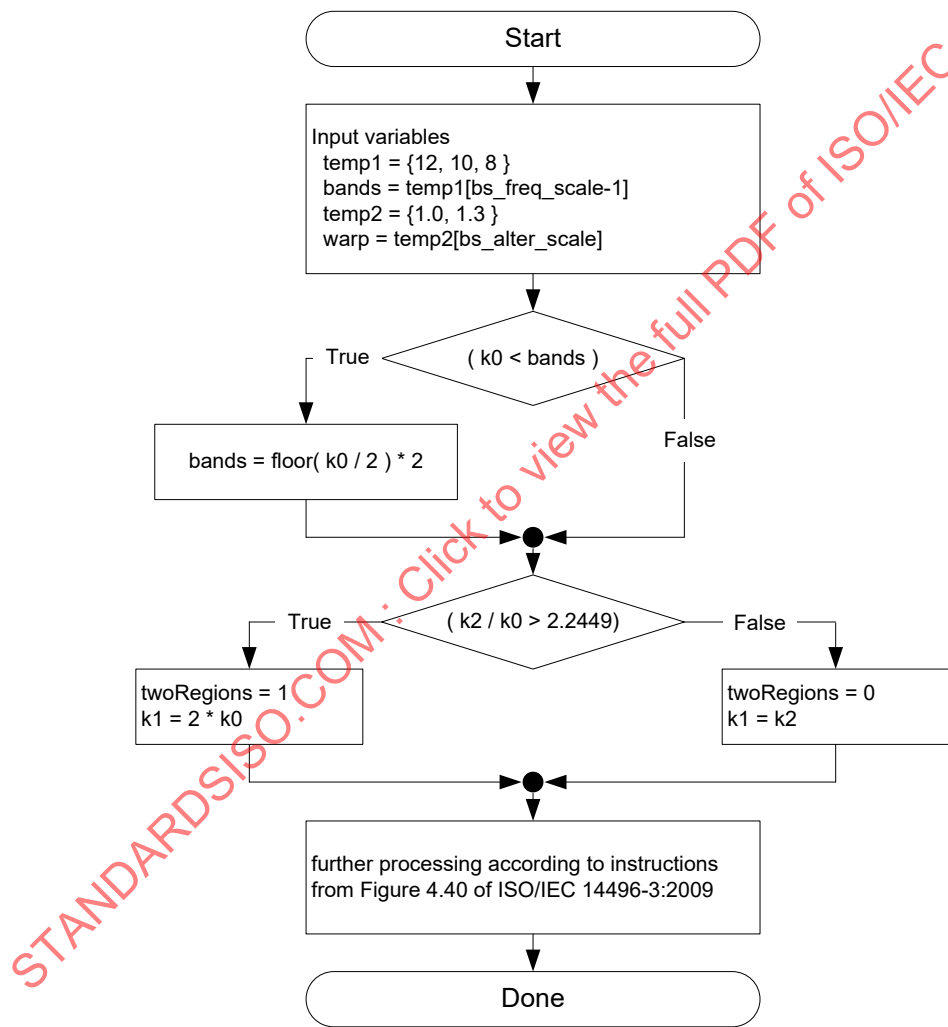


Figure 12 — Flowchart calculation of $\mathbf{f}_{Master}$ for 4:1 system when $bs_freq_scale > 0$

The following requirements found in ISO/IEC 14496-3:2019, 4.6.18.3.6 are adapted to the 4:1 system as shown here:

- The number of QMF subbands covered by SBR, i.e., $k_2 - k_0$ shall satisfy:

$$k_2 - k_0 \leq 56, F_{S_{SBR}} \leq 64 \text{kHz}.$$

- The start frequency border of the SBR range shall be within $\frac{F_{S_{SBR}}}{8}$, i.e., $k_x \leq 16$.
- The largest interval from the f_{Master} , i.e., $f_{\text{Master}}(N_{\text{Master}}) - f_{\text{Master}}(N_{\text{Master}} - 1)$ shall satisfy

$$f_{\text{Master}}(N_{\text{Master}}) - f_{\text{Master}}(N_{\text{Master}} - 1) \leq k_0 - 2.$$

When the SBR module is operated in 4:1 mode, the 32 band QMF analysis filterbank from ISO/IEC 14496-3:2019, 4.6.18.4.1 is replaced by a 16 band QMF analysis filterbank. This QMF bank is used to split the time domain signal output from the core decoder into 16 subband signals. The resulting subband samples are complex-valued and thus oversampled by a factor of two compared to a regular QMF bank. The flowchart of this operation is given in Figure 14. The filtering involves the following steps, where an array $\mathbf{x}$ consisting of 160 time domain input samples is assumed. A higher index into the array corresponds to older samples.

- Shift the samples in the array $\mathbf{x}$ by 16 positions. The oldest 16 samples are discarded and 16 new samples are stored in positions 0 to 15.
- Multiply the samples of array $\mathbf{x}$ by every fourth coefficient of window $\mathbf{c}$. The window coefficients can be found in ISO/IEC 14496-3:2009, 4.A.62, Table 4.A.89.
- Sum the samples according to the formula in the flowchart to create the 32-element array $\mathbf{u}$.
- Calculate 16 new subband samples by the matrix operation $\mathbf{Mu}$, where:

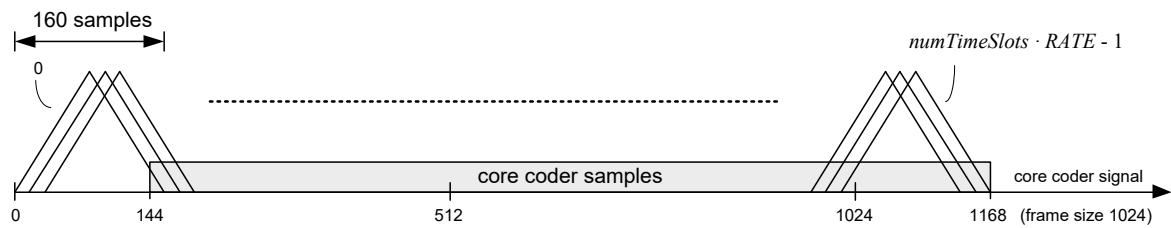
$$\mathbf{M}(k, n) = 4 \cdot \exp\left(\frac{i \cdot \pi \cdot (k + 0.5) \cdot (2 \cdot n - 0.25)}{32}\right), \begin{cases} 0 \leq k < 16 \\ 0 \leq n < 32 \end{cases}$$

In the equation, $\exp()$ denotes the complex exponential function and i is the imaginary unit.

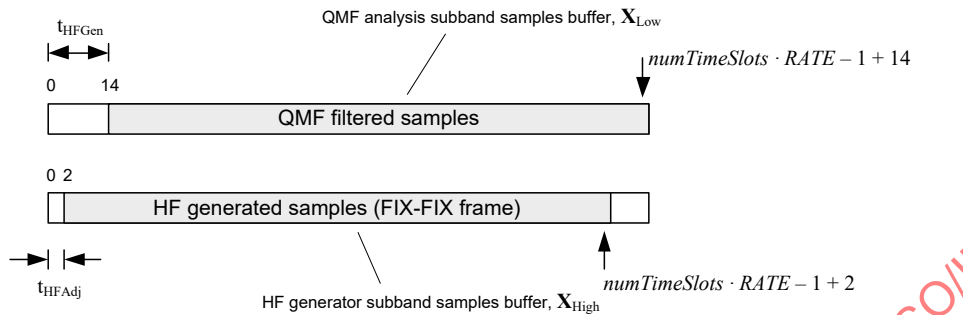
Every execution in the flowchart from “Start” to “Done” produces 16 complex-valued subband samples, each representing the output from one filterbank subband. For every SBR frame, the filterbank will produce $\text{numTimeSlots} \cdot \text{RATE}$ subband samples for every subband, corresponding to a time domain signal of length $\text{numTimeSlots} \cdot \text{RATE} \cdot 16$ samples. In the flowchart $\mathbf{W}[k][l]$ corresponds to subband sample l in QMF subband k .

Figure 13 (a) shows the timing of the analysis windowing. The output from the analysis QMF bank is delayed t_{HFGen} subband samples, before being fed to the synthesis QMF bank. To achieve synchronization $t_{\text{HFGen}} = 14$. The resulting subband samples are shown in Figure 13 (b) as the upper dashed block. The HF generator calculates $\mathbf{X}_{\text{High}}$ given the matrix $\mathbf{X}_{\text{Low}}$ according to the scheme outlined in ISO/IEC 14496-3:2019, 4.6.18.6. The process is guided by the SBR data contained in the current SBR frame. The result is illustrated by the dashed block in Figure 13 (b).

Due to the modified buffer management in the SBR 4:1 system, the calculation of the covariance matrix, $\phi_k(i, j)$, from ISO/IEC 14496-3:2019, 4.6.18.6.2 shall be modified such that in the equation the index n of the sum runs to an upper limit of $\text{numTimeSlots} \cdot \text{RATE} + 12 - 1$ (as opposed to $\text{numTimeSlots} \cdot \text{RATE} + 6 - 1$).



(a) 4:1 system core coder signal QMF analysis windowing



(b) 4:1 system subband samples buffers, X_{Low} and X_{High}

Figure 13 — Synchronization and timing in the 4:1 system

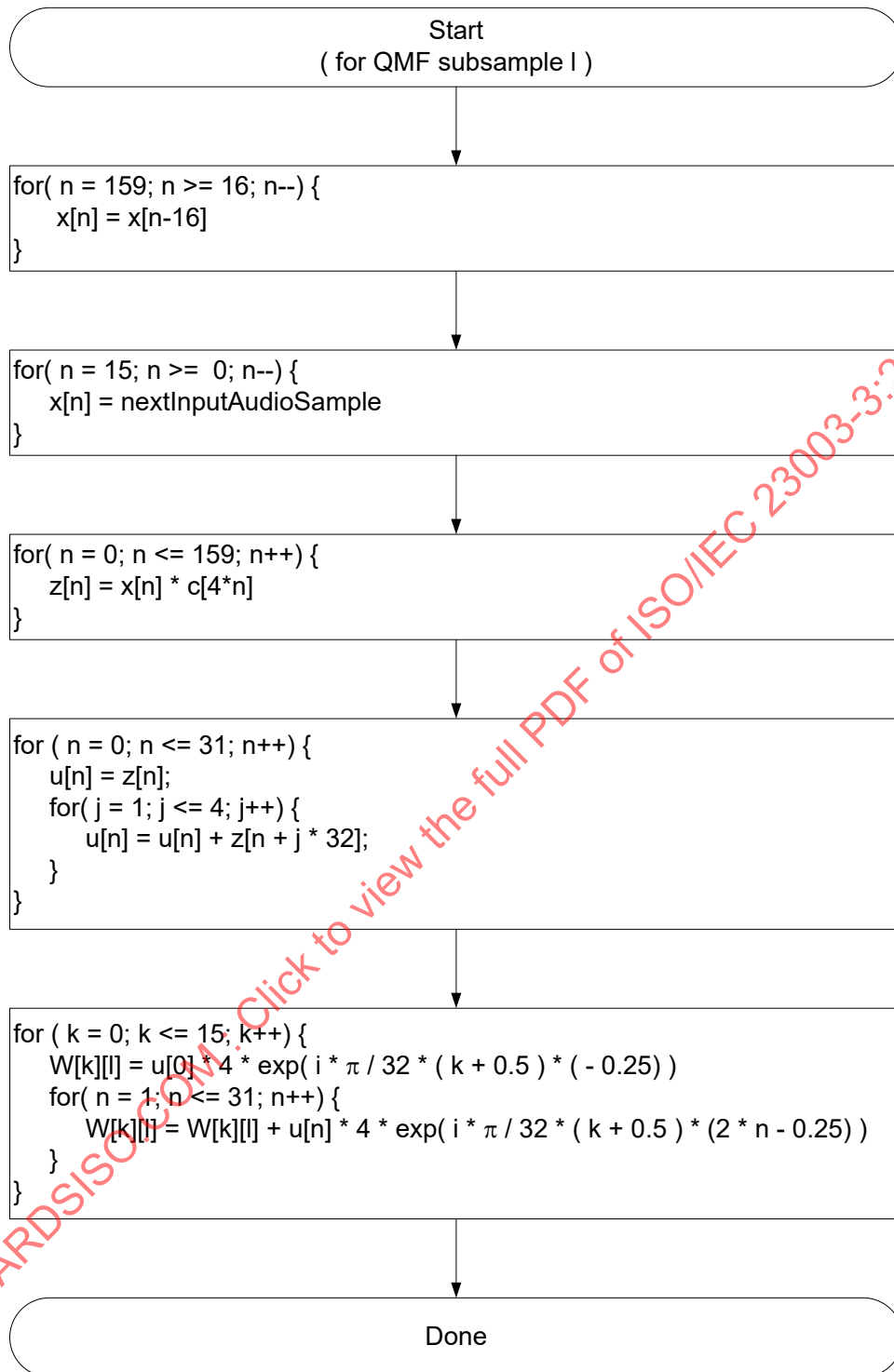


Figure 14 — Flowchart of 4:1 system decoder analysis QMF bank

7.5.5.3 Modifications and additions to DFT based harmonic SBR

When the SBR 4:1 system is combined with harmonic transposition, the synthesis DFT size of the modified phase vocoder structure as described in 7.5.3.1 is increased by a factor of 2 without altering the frequency bin spacing of the DFT synthesis filterbank. This way the output signal of the transposer has a sampling rate which is four times that of the input signal, enabling harmonic transposition beyond the Nyquist frequency of the 2:1 system.

Therefore, for each frame (corresponding to `coreCoderFrameLength` core coder samples), the synthesis transform size of the transposer is first determined by:

$$fftSizeSyn = 2 \cdot fftSize = \begin{cases} 2048, & \text{for } \mathbf{sbrOversamplingFlag[ch]} = 0 \\ 3072, & \text{for } \mathbf{sbrOverSamplingFlag[ch]} = 1 \end{cases}$$

where **sbrOversamplingFlag[ch]** is signalled in the bitstream and `fftSize` is defined in 7.5.3.1. This would be the transform size actually used in the transposer synthesis if critical sampling is deactivated, i.e., when $M_S = 16$ and $M_A = 64$. The variables M_S and M_A are defined in 7.5.3.3.2 and 7.5.3.3.3 respectively.

As critical sampling is active, blocks of $64 \cdot M_S$ windowed input samples (corresponding to 1024 core coder samples), using a hop size (or stride) of $8 \cdot M_S$ samples (corresponding to 128 core coder samples) are transformed to the frequency domain by means of a DFT of size $64 \cdot M_S$ or $96 \cdot M_S$ depending on the signal adaptive frequency domain oversampling control signal. The phases of the complex-valued DFT coefficients are modified as described in 7.5.3.1. The modified coefficients are subsequently transformed back to the time domain by means of a DFT of size $32 \cdot M_A$ or $48 \cdot M_A = 1,5 \cdot 32 \cdot M_A$, windowed and combined by means of overlap-add using an output timestride of $8 \cdot M_A$ samples (corresponding to 512 decoder output samples).

For each frame ($64 \cdot M_S$ time domain input samples), the analysis transform size S_a and the synthesis transform size S_s used by the transposer is determined by:

$$S_a = fftSize \cdot M_S / 16$$

and

$$S_s = fftSizeSyn \cdot M_A / 64$$

where `fftSize` is defined in 7.5.3.1.

The variable `numPatches` and the array **xOverBin** are calculated according to the pseudo code of Figure 15, for the maximum number of patches, where $f_{TableHigh}$, $f_{TableLow}$, N_{High} and N_{Low} are defined in ISO/IEC 14496-3:2019, 4.6.18.3.2. For each transposition factor ($T = 2, 3, 4$), a frequency domain window of `fftSize` elements is created according to the instructions given in 7.5.3.1.

```

sfbL=0, sfbH=0, numPatches=3
for patch=1 to 6
  while (sfbL <= NLow) && (fTableLow(sfbL) <= patch*fTableLow(0))
    sfbL = sfbL+1
  end
  if (sfbL <= NLow)
    if (patch*fTableLow(0)-fTableLow(sfbL-1)) <= 3
      xOverBin(patch-1) = NINT( fftSizeSyn*fTableLow(sfbL-1)/128 )
    else
      while (sfbH <= NHigh) && (fTableHigh(sfbH) <= patch*fTableHigh(0))
        sfbH = sfbH+1
      end
      xOverBin(patch-1) = NINT( fftSizeSyn*fTableHigh(sfbH-1)/128 )
    end
  else
    xOverBin(patch-1) = NINT( fftSizeSyn*fTableLow(NLow)/128 )
    numPatches = min(patch-1,3)
    break
  end
end
end

```

Figure 15 — Calculation of xOverBin and numPatches for 4:1 system

The time domain transform windows are given by:

$$\omega_a(n) = \sin\left(\frac{\pi}{64 \cdot M_s} \cdot (n + 0.5)\right), 0 \leq n < 64 \cdot M_s$$

for the analysis transform and

$$\omega_s(n) = \sin\left(\frac{\pi}{32 \cdot M_A} \cdot (n + 0.5)\right), 0 \leq n < 32 \cdot M_A$$

for the synthesis transform.

The following variables from 7.5.3.1 are set:

$$p_A = (S_A - 64 \cdot M_s) / 2$$

$$p_S = (S_S - 32 \cdot M_A) / 2$$

$$\delta_A = 8 \cdot M_s$$

$$\delta_S = 8 \cdot M_A$$

$$\Delta_A = k_L \cdot \text{fftSize} / 16$$

$$\Delta_S = k_A \cdot \text{fftSize} / 32$$

where p_a and p_s are the analysis and synthesis zero pad sizes, δ_a and δ_s are the input and output hop lengths in samples, and Δ_a and Δ_s are analysis and synthesis transform offset variables respectively. An input frame consists of 8 granules $(64 \cdot M_s) / \delta_a$. The index u depicts the current granule ($u \in \mathbb{N}_0$). One granule γ_u is calculated from the input signal as:

$$\gamma_u(n) = \begin{cases} 0 & , 0 \leq n < p_a \\ s(n + \delta_a \cdot u) \cdot \omega_a(n - p_a) & , p_a \leq n < p_a + 64 \cdot M_s \\ 0 & , p_a + 64 \cdot M_s \leq n < S_a \end{cases}$$

The granule is processed according to 7.5.3.1, i.e., time-domain shifted $S_a/2$ samples, transformed to the frequency domain and conversion of the DFT coefficients to polar coordinates.

Subsequently, for each transposition factor $T = 2, 3, 4$ for which $T \leq \text{numPatches} + 1$, a new granule of spectral coefficients $\bar{\Gamma}_u^{(T)}$ is calculated according to the formula in 7.5.3.1 for $0 \leq k \leq \text{fftSizeSyn} / 2$ and $\bar{\Gamma}_u^{(T)}(k) = \text{conj}\{\bar{\Gamma}_u^{(T)}(\text{fftSizeSyn} - k)\}$, $\text{fftSizeSyn} / 2 < k < \text{fftSizeSyn}$.

The remaining processing steps are carried out according to the instructions given in 7.5.3.1.

If the SBR stop frequency exceeds the maximum output bandwidth of the harmonic transposer the remaining bandwidth up to the SBR stop frequency is filled with copies of consecutive QMF subbands from the highest order harmonic patch starting with the highest QMF band. If necessary this operation is repeated to fill the desired frequency range. These patches also need to be considered in the calculation of the limiter frequency band table.

7.5.5.4 Modifications and additions to sub-sampled filter banks for HQ critical sampling processing

The critical sampling processing as outlined in 7.5.3.3 in the SBR 4:1 system is adapted to synthesize a subset of the subband signals from the 16-band analysis QMF bank to the time domain by a small sub-sampled real-valued QMF bank.

The variables M_s and k_l for the real-valued sub-sampled M_s -channel synthesis filter bank are determined as described in 7.5.3.3.2, where M_s is the size of the sub-sampled synthesis filter bank and k_l represents the subband index of the first channel from the 16-band QMF bank to enter the sub-sampled synthesis filter bank.

If $k_l + M_s > 16$, when M_s and k_l are calculated to these formulas, k_l is calculated as $k_l = 16 - M_s$.

Apart from that, the processing of the real-valued sub-sampled synthesis filter bank is carried out as described in 7.5.3.3.2.

The processing of the complex-valued sub-sampled M_A -channel analysis filter bank is performed according to the instructions given in 7.5.3.3.3.

7.5.5.5 Modifications and additions to QMF based harmonic transposer

When the SBR 4:1 system is combined with the QMF based harmonic transposer as described in 7.5.4, harmonic bandwidth extension of the core-coder time-domain-signal is carried out entirely in the QMF domain, using a modified phase vocoder structure.

The variable *numPatches* and the array **xOverQmf** are calculated according to the pseudo code of Figure 16 for the maximum number of patches, where $\mathbf{f}_{TableHigh}$, $\mathbf{f}_{TableLow}$, N_{High} and N_{Low} are defined in ISO/IEC 14496-3.

```

sfbL=0, sfbH=0, numPatches=3
for patch=1 to 6
  while (sfbL <= NLow) && (fTableLow(sfbL) <= patch*fTableLow(0))
    sfbL = sfbL+1
  end
  if (sfbL <= NLow)
    if (patch*fTableLow(0) - fTableLow(sfbL-1)) <= 3
      xOverQmf(patch-1) = fTableLow(sfbL-1)
    else
      while (sfbH <= NHigh) && (fTableHigh(sfbH) <= patch*fTableHigh(0))
        sfbH = sfbH+1
      end
      xOverQmf(patch-1) = fTableHigh(sfbH-1)
    end
  else
    xOverQmf(patch-1) = fTableLow(NLow)
    numPatches = min(patch-1,3)
    break
  end
end
end

```

Figure 16 — Calculation of xOverQmf and numPatches for 4:1 system

A complex output gain value is defined for all synthesis subbands according to 7.5.4.1.

The core coder time-input-signal is transformed to the QMF domain, using blocks of coreCoderFrameLength input samples. To reduce computational complexity, the transform is implemented by applying a critical sampling processing (described in 7.5.4.2) on the subband signals from the 16-band analysis QMF bank that is already present when the SBR tool is operated as 4:1 system.

Let the 16-band QMF domain signal for the current frame be given by the matrix $X_{Low}(m, k)$ with time subband samples $m = 0, 1, \dots, 63$ and subbands $k = 0, 1, \dots, 15$. The critical sampling processing transforms the matrix $X_{Low}(m, k)$ into new QMF submatrices $\Gamma(\mu, n)$ with doubled frequency resolution, where the subband samples $\mu = 0, 1, \dots, 31$ and subbands $n = 2 * k_L, \dots, 2 * k_L + 2 * M_s - 1$ (see 7.5.4.2).

The given QMF submatrices $\Gamma(\mu, n)$ are operated by the subband block processing according to the instructions given in 7.5.4.1, whereupon the cross product pitch parameter is determined from the bitstream parameter **sbrPitchInBins[ch]** as:

$$p = \text{sbrPitchInBins}[\text{ch}] / 24$$

If the SBR stop frequency exceeds the maximum output bandwidth of the harmonic transposer the remaining bandwidth up to the SBR stop frequency is filled with copies of consecutive QMF subbands from the highest order harmonic patch starting with the highest QMF band. If necessary this operation is repeated to fill the desired frequency range. These patches also need to be considered in the calculation of the limiter frequency band table.

7.5.5.6 Modifications and additions to sub-sampled filter banks for QMF critical sampling processing

The critical sampling processing as outlined in 7.5.4.2 in the SBR 4:1 system is adapted to synthesize a subset of the subband signals from the 16-band analysis QMF bank to the time domain by a small sub-sampled real-valued QMF bank.

The variables M_S and k_L are determined as described in 7.5.4.2.1, where M_S is the size of the sub-sampled synthesis filter bank and k_L represents the subband index of the first channel from the 16-band QMF bank to enter the sub-sampled synthesis filter bank.

Furthermore, if $k_L + M_S > 16$, then k_L is calculated according to $k_L = 16 - M_S$.

The processing of the real-valued sub-sampled M_S -channel synthesis filter bank and the processing of the complex-valued sub-sampled $2M_S$ -channel analysis filter bank are performed according to the instructions given in 7.5.4.2.2 and 7.5.4.2.3 respectively.

7.5.6 Predictive vector coding (PVC) decoding process

7.5.6.1 Overview

In order to improve the subjective quality of the eSBR tool, in particular for speech content at low bitrates, predictive vector coding (PVC) is added to the eSBR tool. Generally, for speech signals, there is a relatively high correlation between the spectral envelopes of low frequency bands and high frequency bands. In the PVC scheme, this is exploited by the prediction of the spectral envelope in high frequency bands from the spectral envelope in low frequency bands, where the coefficient matrices for the prediction are coded by means of vector quantization.

The block diagram of the eSBR decoder including the PVC decoder is shown in Figure 17. The analysis and synthesis QMF banks and HF generator remain unchanged, but the HF envelope adjuster is modified to process the envelopes generated by the PVC decoder. The indices of the coefficient matrices for the prediction, $pvcID(t)$, $t=0,1,2,\dots,15$ are transmitted in the bitstream.

The required tables for decoding PVC shall be defined as given in Annex D.

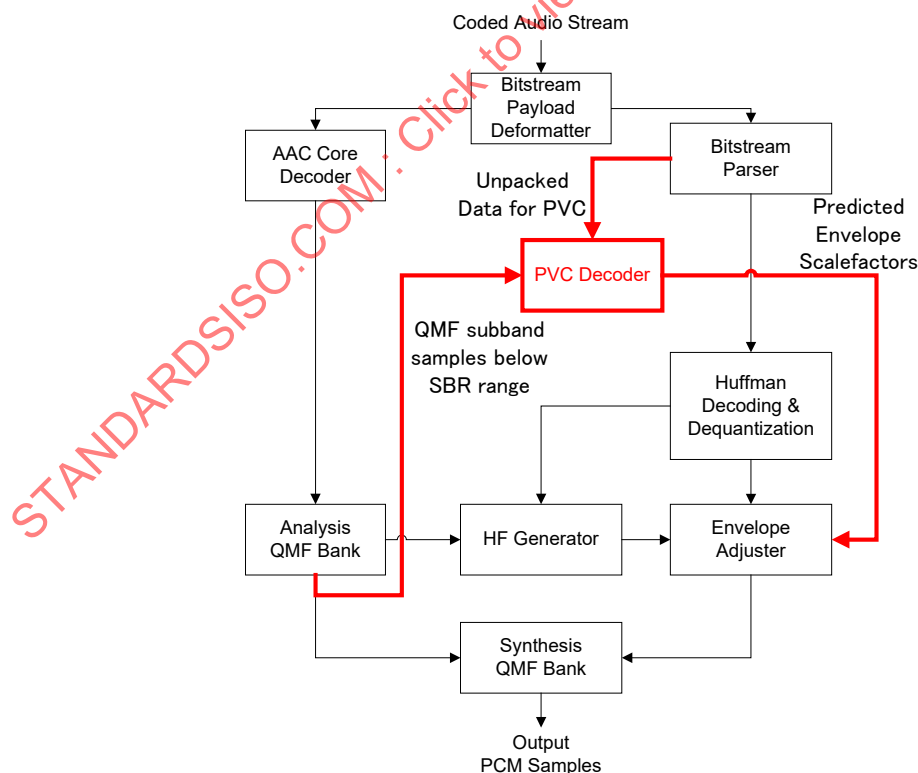


Figure 17 — Block diagram of the decoder including PVC decoder

7.5.6.2 Symbols and abbreviations

t	index of time slot
k	index of QMF subband
$RATE$	number of QMF subband samples per time slot
k_x	index of the first QMF subband in the SBR range
t_{HFAdj}	offset for the envelope adjuster module
t_{HFGen}	offset for the HF-generation module
X_{low}	complex input QMF bank subband matrix to the HF generator
ksg	index of grouped QMF subband
$pvcID(t)$	prediction coefficient matrix index corresponding to t
$H(ksg, kb, pvcID(t))$	prediction coefficient matrix corresponding to $pvcID(t)$
$E(k, t)$	energy of QMF subband samples below the SBR range
$Esg(ksg, t)$	subband-grouped energy below the SBR range
$lsb(ksg)$	index of the start QMF subband in the grouped QMF subband below the SBR range
$leb(ksg)$	index of the stop QMF subband in the grouped QMF subband below the SBR range
$hsb(ksg)$	index of the start QMF subband in the grouped QMF subband in the SBR range
$heb(ksg)$	index of the stop QMF subband in the grouped QMF subband in the SBR range
lbw	number of QMF subbands for a grouped QMF subband below the SBR range
hbw	number of QMF subbands for a grouped QMF subband in the SBR range
SC	coefficients for time-smoothing of $Esg(ksg, t)$
ns	number of time slots for time-smoothing of $Esg(ksg, t)$
$SEsg(ksg, t)$	time-smoothed subband-grouped energy below the SBR range
$\hat{E}sg(ksg, t)$	predicted subband-grouped energy in the SBR range
$\hat{E}(k, t)$	predicted SBR envelope scalefactors in the SBR range
$nbLow$	number of grouped QMF subbands below the SBR range
$nbHigh$	number of grouped QMF subbands in the SBR range

7.5.6.3 Subband grouping in QMF subbands below SBR range

The energy of QMF subband samples below the SBR range, $E(ib, t)$ is subband-grouped along the frequency axis as follows:

$$E_{sg}(ksg, t) = \begin{cases} \frac{\sum_{ib=lsb(ksg)}^{leb(ksg)} E(ib, t)}{lbw} & , \text{if } lsb(ksg) \geq 0 \\ 0.1 & , \text{otherwise} \end{cases}$$

for

$$0 \leq ksg \leq nbLow - 1$$

where:

$$E(ib, t) = \frac{\sum_{i=t_{HFAdj}}^{RATE-1+t_{HFAdj}} X_{low}(ib, RATE \cdot t + i) \cdot X_{low}^*(ib, RATE \cdot t + i)}{RATE}$$

$$lsb(ksg) = k_x - lbw \cdot nbLow + lbw \cdot ksg,$$

$$leb(ksg) = lsb(ksg) + lbw - 1,$$

$$lbw = 8 / RATE, \text{ and}$$

$$nbLow = 3$$

Then, the subband-grouped energy below the SBR range, $E_{sg}(ksg, t)$ is limited to a value not less than 0.1 as follows:

$$E_{sg}(ksg, t) = \begin{cases} 0.1 & , \text{if } E_{sg}(ksg, t) < 0.1 \\ E_{sg}(ksg, t) & , \text{otherwise} \end{cases}$$

for

$$0 \leq ksg \leq nbLow - 1.$$

7.5.6.4 Time domain smoothing of subband-grouped energy

The subband-grouped energy below the SBR range, $E_{sg}(ksg, t)$ is converted to log domain and then smoothed along the time axis as follows:

$$SEsg(ksg, t) = \sum_{n=0}^{ns-1} (10 \cdot \log_{10}(E_{sg}(ksg, t_c)) \cdot SC(ti)), \text{ for } 0 \leq ksg \leq nbLow - 1$$

with

$$t_c = \begin{cases} t_{EPVC}(0), & \text{if } t - ti < t_{EPVC}(0) \text{ and } ((bs_pvc_mode' = 0 \text{ and } bs_pvc_mode \neq 0) \text{ or } (k'_x \neq k_x)) \\ t - ti & , \text{otherwise} \end{cases}$$

where $t_{EPVC}(0)$ is the first PVC time slot of the current PVC SBR frame, bs_pvc_mode' is the PVC mode of the previous frame and k'_x is the index of the first subband in the SBR range of the previous frame respectively and where SC is the smoothing window as defined in D.1.

7.5.6.5 SBR envelope scalefactor prediction

The prediction coefficient matrix, $H(ksg, kb, pvcID(t))$ that corresponds to the prediction coefficient matrix index, $pvcID(t)$ is applied to the time-smoothed subband-grouped energy below the SBR range, $SEsg(kb, t)$ to get the predicted subband-grouped energy in the SBR range, $\hat{E}sg(ksg, t)$ as follows:

$$\hat{E}sg(ksg, t) = \left(\sum_{kb=0}^{nbLow-1} H(ksg, kb, pvcID(t)) \cdot SEsg(kb, t) \right) + H(ksg, nbLow, pvcID(t))$$

for

$$0 \leq ksg \leq nbHigh - 1$$

where

$H(ksg, kb, pvcID(t))$ is the prediction coefficient matrix as shown in D.2.

Then, the predicted subband-grouped energy in the SBR range is converted to the linear domain as follows:

$$\hat{E}(k, t) = 10^{\frac{\hat{E}sg(ksg, t)}{10}}$$

for

$$hsb(ksg) \leq k \leq heb(ksg), \quad 0 \leq ksg \leq nbHigh - 1$$

where

$$hsb(ksg) = k_x + ksg \cdot hbw,$$

$$heb(ksg) = \begin{cases} 63 & , \text{if } ksg \geq nbHigh - 1 \\ hsb(ksg) + hbw - 1 & , \text{otherwise} \end{cases},$$

$$hbw = \begin{cases} 8 / RATE & , bs_pvc_mode = 1 \\ 12 / RATE & , bs_pvc_mode = 2 \end{cases}, \text{ and}$$

$$nbHigh = \begin{cases} 8 & , bs_pvc_mode = 1 \\ 6 & , bs_pvc_mode = 2 \end{cases}$$

7.6 Inter-subband-sample temporal envelope shaping (inter-TES)

7.6.1 Tool Description

The inter-subband-sample temporal envelope shaping (inter-TES) tool processes the QMF subband samples subsequent to the envelope adjuster. This module shapes the temporal envelope of the higher frequency band with a finer temporal granularity than that of the envelope adjuster. By applying a gain factor to each QMF

subband sample in an SBR envelope, inter-TES shapes the temporal envelope among the QMF subband samples. Figure 18 shows the inter-TES block diagram contained in eSBR.

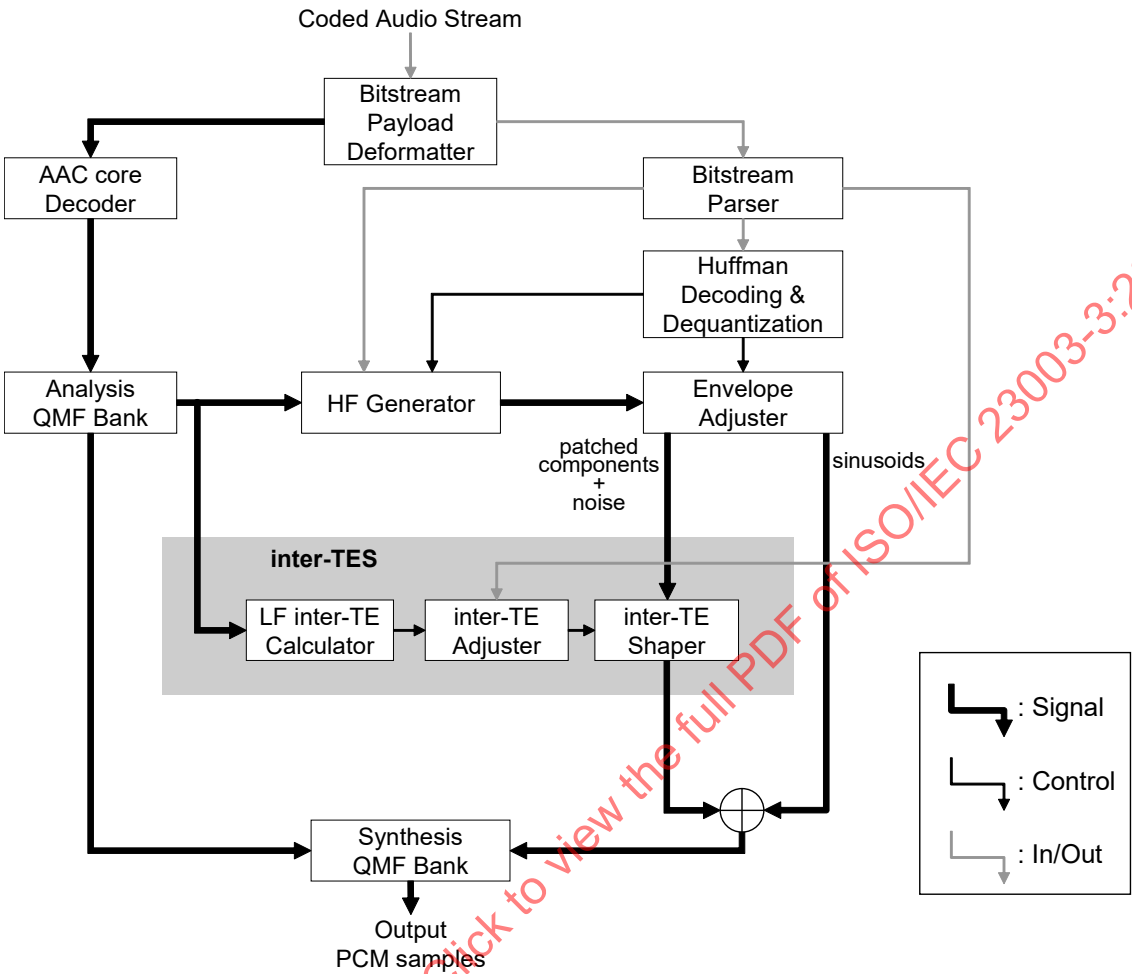


Figure 18 — inter-TES block diagram

7.6.2 Definition of elements

bs_temp_shape[ch][env] This flag signals the usage of inter-TES.

bs_inter_temp_shape_mode[ch][env] Indicates the values of the parameter γ in inter-TES according to Table 121.

Table 121 — bs_inter_temp_shape_mode

bs_inter_temp_shape_mode	γ
0	0
1	1.0
2	2.0
3	4.0

7.6.3 Inter-TES

Inter-TES consists of three modules: lower frequency inter-subband-sample temporal envelope calculator (LF inter-TE calculator), inter-subband-sample temporal envelope adjuster (inter-TE Adjuster), and inter-subband-sample temporal envelope shaper (inter-TE Shaper).

The LF inter-TE calculator computes the inter-subband-sample temporal envelope of the lower frequency band $e_{LOW}(i)$:

$$e_{LOW}(i) = \sqrt{\frac{\sum_{k=0}^{k_x-1} |\mathbf{X}_{LOW}(k, i + t_{HFAdj})|^2}{E_{LOW}(l) + \varepsilon_{INV}}}, \quad RATE \cdot t_E(l) \leq i < RATE \cdot t_E(l+1), \quad 0 \leq l < L_E,$$

where

$$E_{LOW}(l) = \frac{\sum_{i=RATE \cdot t_E(l) + t_{HFAdj}}^{RATE \cdot t_E(l+1) - 1 + t_{HFAdj}} \sum_{k=0}^{k_x-1} |\mathbf{X}_{LOW}(k, i)|^2}{(RATE \cdot t_E(l+1) - RATE \cdot t_E(l))}, \quad 0 \leq l < L_E.$$

$\mathbf{X}_{LOW}$ is the complex QMF bank subband matrix that is input to the HF generator, k_x is the first QMF subband in the SBR range, t_{HFAdj} is the offset for the envelope adjuster module, ε_{INV} is the relaxation parameter ($\varepsilon_{INV} = 1E-6$), $t_E(l)$ is the start time border for l -th SBR envelope, and L_E is the number of SBR envelopes.

From the temporal envelope of the lower frequency band $e_{LOW}(i)$ and the factor $\gamma(l)$, which is obtained from Table 121, the inter-TE Adjuster calculates the gains $g_{inter}(i)$ to shape the temporal envelope of the higher frequency band:

$$g_{inter}(i) = 1 + \gamma(l) (e_{LOW}(i) - 1),$$

$$\text{with } RATE \cdot t_E(l) \leq i < RATE \cdot t_E(l+1),$$

$$0 \leq l < L_E,$$

and subject to the further constraint that $g_{inter}(i) \geq 0.2$.

In order to maintain the total energy within each SBR envelope, the gains $g_{inter}(i)$ are scaled as following:

$$g'_{inter}(i) = g_{inter}(i) \cdot \sqrt{\frac{\sum_{\xi=RATE \cdot t_E(l)}^{RATE \cdot t_E(l+1)-1} \sum_{m=0}^{M-1} |\mathbf{W}_2(m, \xi)|^2}{\sum_{\xi=RATE \cdot t_E(l)}^{RATE \cdot t_E(l+1)-1} \sum_{m=0}^{M-1} |g_{inter}(\xi) \cdot \mathbf{W}_2(m, \xi)|^2 + \varepsilon_{INV}}},$$

$$RATE \cdot t_E(l) \leq i < RATE \cdot t_E(l+1), \quad 0 \leq l < L_E.$$

The inter-TE Shaper applies the scaled gains $g'_{inter}(i)$ to the QMF subband samples of the intermediate output from the HF adjuster $\mathbf{W}_2$ which contains patched components and the additional noise:

$$\mathbf{W}_{2,inter}(m, i) = g'_{inter}(i) \cdot \mathbf{W}_2(m, i), \quad 0 \leq m < M, \quad RATE \cdot t_E(0) \leq i < RATE \cdot t_E(L_E),$$

where M is the number of QMF subbands in the SBR range.

The higher frequency band of the input to the synthesis QMF bank $\mathbf{Y}(m+k_x, i+t_{HFAdj})$ is obtained by adding the sinusoid $\Psi(m, l, i)$ to the output from inter-TES $\mathbf{W}_{2,inter}(m, i)$:

$$\mathbf{Y}(m+k_x, i+t_{HFAdj}) = \mathbf{W}_{2,inter}(m, i) + \Psi(m, l, i), \begin{cases} RATE \cdot \mathbf{t}_E(l) \leq i < RATE \cdot \mathbf{t}_E(l+1) \\ 0 \leq l < L_E \\ 0 \leq m < M \end{cases}.$$

7.7 Joint stereo coding

7.7.1 M/S stereo

The M/S stereo tool is defined in ISO/IEC 14496-3:2019, 4.6.8.1, but with the following modifications.

The interpretation of the **ms_mask_present** syntax element (originally defined in ISO/IEC 14496-3:2019, 4.6.8.1.2) is modified as follows:

ms_mask_present Indicates stereo mode according to Table 122.

Table 122 — ms_mask_present

ms_mask_present	Meaning
0	all zeros
1	a mask of max_sfb_ste bands of ms_used follows this field
2	all ones
3	M/S coding is disabled, complex stereo prediction is enabled

7.7.2 Complex stereo prediction

7.7.2.1 Tool description

Complex stereo prediction is a tool for efficient coding of channel pairs with level and/or phase differences between the channels. Using a complex-valued parameter α , the left and right channels are reconstructed via the following matrix. dmx_{Im} denotes the MDST corresponding to the MDCT of the downmix channel dmx_{Re} .

$$\begin{bmatrix} l \\ r \end{bmatrix} = \begin{bmatrix} 1 - \alpha_{Re} & -\alpha_{Im} & 1 \\ 1 + \alpha_{Re} & \alpha_{Im} & -1 \end{bmatrix} \begin{bmatrix} dmx_{Re} \\ dmx_{Im} \\ res \end{bmatrix}$$

This equation can be implemented via a sum/difference transform as shown in Figure 19 where first the side signal s is being reconstructed from the complex-valued coefficient α and the downmix signals dmx_{Re} and dmx_{Im} .

$$s = res - (\alpha_{Re} dmx_{Re} + \alpha_{Im} dmx_{Im})$$

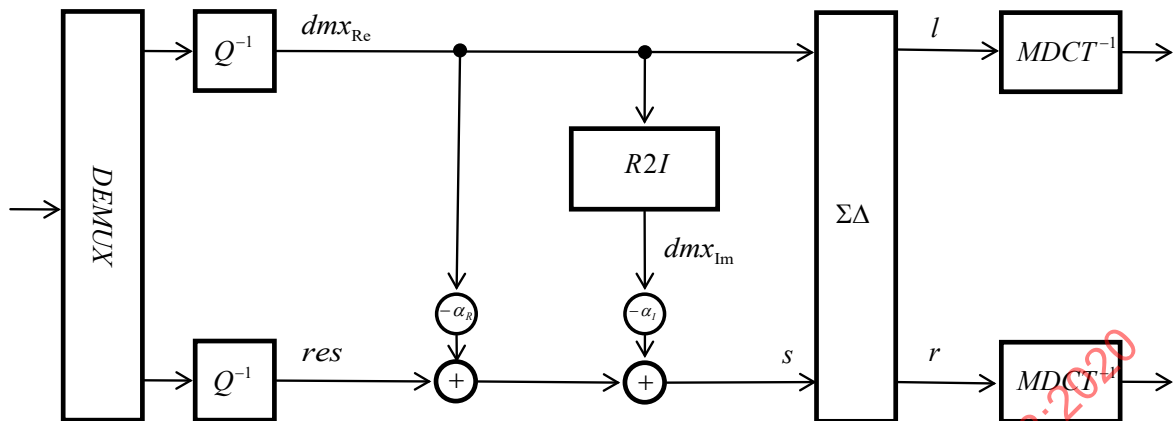


Figure 19 — Block diagram of the decoder with complex stereo prediction

7.7.2.2 Definition of elements

7.7.2.2.1 Data elements

cplx_pred_all Indicates if all bands use complex stereo prediction according to Table 123.

Table 123 — cplx_pred_all

cplx_pred_all	Meaning
0	some bands use left/right coding, as signalled by cplx_pred_used[]
1	all bands use complex stereo prediction

cplx_pred_used[g][sfb] One-bit flag per window group *g* and scalefactor band *sfb* (after mapping from prediction bands). Table 124 gives the corresponding meaning for each flag value of cplx_pred_used.

Table 124 — cplx_pred_used

cplx_pred_used	Meaning
0	left/right coding is being used
1	complex stereo prediction is being used

pred_dir Indicates the direction of prediction according to Table 125.

Table 125 — pred_dir

pred_dir	Meaning
0	prediction from mid to side channel
1	prediction from side to mid channel

complex_coef Indicates whether real or complex coefficients are transmitted according to Table 126.

Table 126 — complex_coef

complex_coef	Meaning
0	$\alpha_{lm} = 0$ for all prediction bands
1	α_{lm} is transmitted for all prediction bands

use_prev_frame

Indicates the mode for MDST estimation according to Table 127.

Table 127 — use_prev_frame

use_prev_frame	Meaning
0	use only the current frame for MDST estimation
1	use the current and previous frame for MDST estimation

delta_code_time

Indicates the coding scheme used for the prediction coefficients according to Table 128.

Table 128 — delta_code_time

delta_code_time	Meaning
0	frequency differential coding of prediction coefficients
1	time differential coding of prediction coefficients

hcod_alpha_q_reHuffman code of α_{Re} **hcod_alpha_q_im**Huffman code of α_{Im} **7.7.2.2.2 Help elements**

<code>l_spec[]</code>	Array containing the left channel spectrum of the respective channel pair.
<code>r_spec[]</code>	Array containing the right channel spectrum of the respective channel pair.
<code>dmx_re[]</code>	Array containing the current MDCT spectrum of the downmix channel.
<code>dmx_re_prev[]</code>	Array containing the previous MDCT spectrum of the downmix channel.
<code>dmx_im[]</code>	Array containing the MDST spectrum estimate of the downmix channel.
<code>SFB_PER_PRED_BAND</code>	Number of scalefactor bands per complex prediction band, equal to 2.
<code>dpcm_alpha_q_re[g][sfb]</code>	Differentially coded real part of prediction coefficient of group <i>g</i> , scalefactor band <i>sfb</i> .
<code>dpcm_alpha_q_im[g][sfb]</code>	Differentially coded imaginary part of prediction coefficient of group <i>g</i> , scalefactor band <i>sfb</i> .

`alpha_q[g][sfb]` Real or imaginary parts of prediction coefficients.

`alpha_q_prev_frame[g][sfb]` Real or imaginary prediction coefficients of previous frame.

7.7.2.3 Decoding process

7.7.2.3.1 Generate MDST spectrum of downmix

Complex stereo prediction requires the downmix MDCT spectrum of the current channel pair and, in case of `complex_coef == 1`, an estimate of the downmix MDST spectrum of the current channel pair, i.e., the imaginary counterpart of the MDCT spectrum. The downmix MDST estimate is computed from the current frame's MDCT downmix and, in case of `use_prev_frame == 1`, the previous frame's MDCT downmix. The previous frame's MDCT downmix `dmx_re_prev[g][b]` of window group `g` and group window `b` is obtained from that frame's reconstructed left and right spectra and the current frame's `pred_dir` indicator as follows:

```
for (g = 0; g < num_window_groups; g++) {
    for (b = 0; b < window_group_length[g]; b++) {
        for (sfb = 0; sfb < max_sfb_ste; sfb++) {
            if (pred_dir == 0) {
                for (i = 0; i < swb_offset[sfb+1]-swb_offset[sfb]; i++) {
                    dmx_re_prev[g][b][sfb][i] =
                        0.5*(l_spec[g][b][sfb][i]+r_spec[g][b][sfb][i]);
                }
            }
            else {
                for (i = 0; i < swb_offset[sfb+1]-swb_offset[sfb]; i++) {
                    dmx_re_prev[g][b][sfb][i] =
                        0.5*(l_spec[g][b][sfb][i]-r_spec[g][b][sfb][i]);
                }
            }
        }
    }
}
```

The current frame's MDCT downmix `dmx_re[g][b]` is derived from the left/downmix and right spectra (prior to inverse L/R TNS filtering if `tns_on_lr == 1`), the `pred_dir` indicator, and the `cplx_pred_used[][]` mask:

```
for (g = 0; g < num_window_groups; g++) {
    for (b = 0; b < window_group_length[g]; b++) {
        for (sfb = 0; sfb < max_sfb_ste; sfb++) {
            if (cplx_pred_used[g][sfb] == 1) {
                for (i = 0; i < swb_offset[sfb+1]-swb_offset[sfb]; i++) {
                    dmx_re[g][b][sfb][i] = l_spec[g][b][sfb][i];
                    /* l_spec contains downmix */
                }
            }
            else {
                if (pred_dir == 0) {
                    for (i = 0; i < swb_offset[sfb+1]-swb_offset[sfb]; i++) {
                        dmx_re[g][b][sfb][i] =
                            0.5*(l_spec[g][b][sfb][i]+r_spec[g][b][sfb][i]);
                    }
                }
                else {
                    for (i = 0; i < swb_offset[sfb+1]-swb_offset[sfb]; i++) {
                        dmx_re[g][b][sfb][i] =
                            0.5*(l_spec[g][b][sfb][i]-r_spec[g][b][sfb][i]);
                    }
                }
            }
        }
    }
}
```

The computation of the downmix MDST spectrum $dmx_im[g][b]$ from the MDCT data depends on:

- **use_prev_frame:** If both the current and previous frame are to be used for the MDST estimation ($use_prev_frame == 1$), the downmix spectra of the current and preceding frame are required. Otherwise ($use_prev_frame == 0$), only the current frame's downmix spectrum is needed, i.e., every MDCT coefficient of the previous frame's downmix spectrum is assumed to equal zero.
- **window_sequence:** Downmix MDST estimates are computed for each group window pair. In case of $window_sequence == EIGHT_SHORT_SEQUENCE$, use_prev_frame is evaluated only for the first of the eight short-window pairs. For each of the remaining seven window pairs, the preceding window pair is always used in the MDST estimate, which implies $use_prev_frame = 1$. In case of transform length switching (i.e. $window_sequence == EIGHT_SHORT_SEQUENCE$ preceded by $window_sequence != EIGHT_SHORT_SEQUENCE$, or vice versa), use_prev_frame shall be 0.
- **Window shapes:** The MDST estimation parameters for the current window, which are filter coefficients as described below, depend on the shapes of the left and right window halves. For single-long window sequences and the first window of an $EIGHT_SHORT_SEQUENCE$, this means that the filter parameters are a function of the current and previous frames' $window_shape$ flags. The remaining seven windows in a short sequence are only affected by the current $window_shape$.

A $dmx_im[g][b]$ estimate is obtained by initializing every coefficient of dmx_im to zero and adding to each coefficient a filtered version of the corresponding MDCT coefficient(s) depending on use_prev_frame :

```
filterAndAdd(dmx_re[g][b], dmx_length, filter_coefs, dmx_im[g][b], 1, 1);
if (use_prev_frame == 1) {
    filterAndAdd(dmx_re_prev[g][b], dmx_length, filter_coefs_prev,
                dmx_im[g][b], -1, 1);
}
```

dmx_length is the even-valued MDCT transform length, which depends on $window_sequence$. $filter_coefs$ and $filter_coefs_prev$ are arrays containing the filter kernels and are derived according to Table 129 and Table 130. Helper function `filterAndAdd()` performs the actual filtering and addition and is defined as follows:

```
filterAndAdd(in, length, filter, out, factorEven, factorOdd)
{
    i = 0;
    s = filter[6]*in[2] + filter[5]*in[1] + filter[4]*in[0] + filter[3]*in[0] +
        filter[2]*in[1] + filter[1]*in[2] + filter[0]*in[3];
    out[i] += s*factorEven;
    i = 1;
    s = filter[6]*in[1] + filter[5]*in[0] + filter[4]*in[0] + filter[3]*in[1] +
        filter[2]*in[2] + filter[1]*in[3] + filter[0]*in[4];
    out[i] += s*factorOdd;
    i = 2;
    s = filter[6]*in[0] + filter[5]*in[0] + filter[4]*in[1] + filter[3]*in[2] +
        filter[2]*in[3] + filter[1]*in[4] + filter[0]*in[5];
    out[i] += s*factorEven;
    for (i = 3; i < length-4; i += 2) {
        s = filter[6]*in[i-3] + filter[5]*in[i-2] + filter[4]*in[i-1] + filter[3]*in[i] +
            filter[2]*in[i+1] + filter[1]*in[i+2] + filter[0]*in[i+3];
        out[i] += s*factorOdd;
        s = filter[6]*in[i-2] + filter[5]*in[i-1] + filter[4]*in[i] + filter[3]*in[i+1] +
            filter[2]*in[i+2] + filter[1]*in[i+3] + filter[0]*in[i+4];
        out[i+1] += s*factorEven;
    }
    i = length-3;
    s = filter[6]*in[i-3] + filter[5]*in[i-2] + filter[4]*in[i-1] + filter[3]*in[i] +
        filter[2]*in[i+1] + filter[1]*in[i+2] + filter[0]*in[i+2];
    out[i] += s*factorOdd;
    i = length-2;
    s = filter[6]*in[i-3] + filter[5]*in[i-2] + filter[4]*in[i-1] + filter[3]*in[i] +
        filter[2]*in[i+1] + filter[1]*in[i+1] + filter[0]*in[i];
    out[i] += s*factorEven;
}
```

```

i = length-1;
s = filter[6]*in[i-3] + filter[5]*in[i-2] + filter[4]*in[i-1] + filter[3]*in[i] +
  filter[2]*in[i] + filter[1]*in[i-1] + filter[0]*in[i-2];
out[i] += s*factorOdd;
}

```

Table 129 — MDST filter parameters for current window (filter_coefs)

Current window sequence	Left half: sine shape right half: sine shape	Left half: KBD shape right half: KBD shape
ONLY_LONG_SEQUENCE, EIGHT_SHORT_SEQUENCE	[0.000000, 0.000000, 0.500000, 0.000000, -0.500000, 0.000000, 0.000000]	[0.091497, 0.000000, 0.581427, 0.000000, -0.581427, 0.000000, -0.091497]
LONG_START_SEQUENCE	[0.102658, 0.103791, 0.567149, 0.000000, -0.567149, -0.103791, -0.102658]	[0.150512, 0.047969, 0.608574, 0.000000, -0.608574, -0.047969, -0.150512]
LONG_STOP_SEQUENCE	[0.102658, -0.103791, 0.567149, 0.000000, -0.567149, 0.103791, -0.102658]	[0.150512, -0.047969, 0.608574, 0.000000, -0.608574, 0.047969, -0.150512]
STOP_START_SEQUENCE	[0.205316, 0.000000, 0.634298, 0.000000, -0.634298, 0.000000, -0.205316]	[0.209526, 0.000000, 0.635722, 0.000000, -0.635722, 0.000000, -0.209526]
Current window sequence	Left half: Sine shape right half: KBD shape	Left half: KBD shape right half: sine shape
ONLY_LONG_SEQUENCE, EIGHT_SHORT_SEQUENCE	[0.045748, 0.057238, 0.540714, 0.000000, -0.540714, -0.057238, -0.045748]	[0.045748, -0.057238, 0.540714, 0.000000, -0.540714, 0.057238, -0.045748]
LONG_START_SEQUENCE	[0.104763, 0.105207, 0.567861, 0.000000, -0.567861, -0.105207, -0.104763]	[0.148406, 0.046553, 0.607863, 0.000000, -0.607863, -0.046553, -0.148406]
LONG_STOP_SEQUENCE	[0.148406, -0.046553, 0.607863, 0.000000, -0.607863, 0.046553, -0.148406]	[0.104763, -0.105207, 0.567861, 0.000000, -0.567861, 0.105207, -0.104763]
STOP_START_SEQUENCE	[0.207421, 0.001416, 0.635010, 0.000000, -0.635010, -0.001416, -0.207421]	[0.207421, -0.001416, 0.635010, 0.000000, -0.635010, 0.001416, -0.207421]

Table 130 — MDST filter parameters for previous window (filter_coefs_prev)

Current window sequence	Left half of current window: sine shape	Left half of current window: KBD shape
ONLY_LONG_SEQUENCE, LONG_START_SEQUENCE, EIGHT_SHORT_SEQUENCE	[0.000000, 0.106103, 0.250000, 0.318310, 0.250000, 0.106103, 0.000000]	[0.059509, 0.123714, 0.186579, 0.213077, 0.186579, 0.123714, 0.059509]
LONG_STOP_SEQUENCE, STOP_START_SEQUENCE	[0.038498, 0.039212, 0.039645, 0.039790, 0.039645, 0.039212, 0.038498]	[0.026142, 0.026413, 0.026577, 0.026631, 0.026577, 0.026413, 0.026142]

7.7.2.3.2 Decoding of prediction coefficients

For all prediction coefficients the difference to a preceding (in time or frequency) value is coded using the Huffman code book specified in ISO/IEC 14496-3:2019, Table 4.A.1. See ISO/IEC 14496-3:2019, 4.6.3, for a detailed description of the Huffman decoding process. Prediction coefficients are not transmitted for prediction bands for which $\text{cplx_pred_used}[g][\text{sfb}] = 0$. The following pseudo code describes how to decode the prediction coefficient $\alpha_q[g][\text{sfb}]$, α_q being either $\alpha_q\text{-re}$ or $\alpha_q\text{-im}$.

```

for (g = 0; g < num_window_groups; g++) {
    for (sfb = 0; sfb < max_sfb_ste; sfb += SFB_PER_PRED_BAND) {
        if (delta_code_time == 1) {
            if (g > 0) {
                last_alpha_q = alpha_q[g-1][sfb];
            }
            else {
                last_alpha_q = alpha_q_prev_frame[sfb];
            }
        }
        else {
            if (sfb > 0) {
                last_alpha_q = alpha_q[g][sfb-1];
            }
            else {
                last_alpha_q = 0;
            }
        }

        if (cplx_pred_used[g][sfb] == 1) {
            dpcm_alpha = -decode_huffman() + 60; /* function returns dpcm_alpha_q[g][sfb] */
            alpha_q[g][sfb] = dpcm_alpha + last_alpha_q;
        }
        else {
            alpha_q[g][sfb] = 0;
        }
        /* Assign a prediction coefficient to each scalefactor band */
        /* If max_sfb is odd, last prediction band covers only one scalefactor
           band */
        if ((sfb+1) < max_sfb_ste) {
            alpha_q[g][sfb+1] = alpha_q[g][sfb];
        }
    }
}

```

alpha_q_prev_frame[sfb] contains the decoded prediction coefficients of the last window group of the previous frame. If no prediction was used for the previous frame or for the respective scalefactor band in the previous frame, alpha_q_prev_frame[sfb] is set to zero.

Both the real and imaginary coefficient histories are reset to zero upon a transform length change, and in case of complex_coef == 0, all imaginary coefficients up to num_swb are set to zero.

7.7.2.3.3 Inverse quantization of prediction coefficients

The inverse quantized prediction coefficients alpha_re and alpha_im are given by:

alpha_re = alpha_q_re * 0.1

alpha_im = alpha_q_im * 0.1

7.7.2.3.4 Upmix process

Reconstruct the spectral coefficients of the first ("left") and second ("right") channel as specified by the **ms_mask_present**, **pred_dir**, and **cplx_pred_used[][]** flags as follows:

```

if ((ms_mask_present == 3) && (stereoConfigIndex == 0)) {
    for (g = 0; g < num_window_groups; g++) {
        for (b = 0; b < window_group_length[g]; b++) {
            for (sfb = 0; sfb < max_sfb; sfb++) {
                if (cplx_pred_used[g][sfb]) {
                    if (pred_dir == 0) {
                        for (i = 0; i < swb_offset[sfb+1]-swb_offset[sfb]; i++) {
                            side = r_spec[g][b][sfb][i]
                                - alpha_re[g][b][sfb] * l_spec[g][b][sfb][i]
                                - alpha_im[g][b][sfb] * dmx_im[g][b][sfb][i];
                        }
                    }
                }
            }
        }
    }
}

```

7.8.1 General

7.8.2 Definition of elements

tns_active	TNS is active on at least one channel.
common_tns	Use the same TNS filter for both channels.
tns_on_lr	Indicates the mode of operation for TNS filtering according to Table 131.

tns_on_lr	Meaning
0	TNS is applied after inverse quantization of MDCT spectrum, prior to upmix
1	TNS is applied on left/right MDCT spectrum after upmix, prior to inverse MDCT

Table 132 — tns_data_present[0]

tns_data_present[0]	Meaning
0	no TNS data transmitted for channel 0
1	separate TNS data transmitted for channel 0

151

Table 133 — **tns_data_present[1]**

tns_data_present[1]	Meaning
0	no TNS data transmitted for channel 1
1	separate TNS data transmitted for channel 1

tns_present_both

Indicates if both channels have separate TNS data transmitted according to Table 134.

Table 134 — **tns_present_both**

tns_present_both	Meaning
0	at least one channel has no individual TNS data
1	separate TNS data transmitted for both channel 0 and channel 1

7.8.3 Decoding process

The decoding process in ISO/IEC 14496-3:2019, 4.6.9.3 is extended as follows.

The spectral domain on which TNS is applied depends on the value of **tns_on_lr**. If **tns_on_lr** == 0, TNS is applied after inverse quantization and prior to any mid/side or complex prediction processing. If **tns_on_lr** == 1, TNS is applied to the spectral coefficients of left and right channel after mid/side or complex prediction processing.

Depending on the FD window sequence the size of the following data elements and the definition of TNS_MAX_ORDER is adapted for each transform window according to its window size according to Table 135.

Table 135 — Definition of TNS_MAX_ORDER and size of data elements

	Long window sequences	Short window sequence
TNS_MAX_ORDER	15	7
size of 'n_filt'	2	1
size of 'order'	4	3
size of 'length'	6	4

7.8.4 Maximum TNS bandwidth

Based on the sampling rate in use the value for the constant TNS_MAX_BANDS is set according to Table 136. For sampling frequencies not explicitly listed in the table, use the entry following the sampling frequency mapping according to Table 84.

Table 136 — Definition of TNS_MAX_BANDS depending on windowing and sampling rate

Sampling rate [Hz]	Long window sequences	Short window sequence
96000	31	9
88200	31	9
64000	34	10
48000	40	14
44100	42	14
32000	51	14
24000	47	15
22050	47	15
16000	43	15
12000	43	15
11025	43	15
8000	40	15

7.9 Filterbank and block switching

7.9.1 Tool description

The time/frequency representation of the signal is mapped onto the time domain by feeding it into the filterbank module. This module consists of an inverse modified discrete cosine transform (IMDCT), and a window and an overlap-add function. In order to adapt the time/frequency resolution of the filterbank to the characteristics of the input signal, a block switching tool is also adopted. N represents the window length, where N is a function of the **window_sequence** (see 6.2.9.3). For each channel, the $N/2$ time-frequency values $X_{i,k}$ are transformed into the N time domain values $x_{i,n}$ via the IMDCT. After applying the window function, for each channel, the first half of the $z_{i,n}$ sequence is added to the second half of the previous block windowed sequence $z_{(i-1),n}$ to reconstruct the output samples for each channel $out_{i,n}$.

7.9.2 Definition of elements

window_sequence 2 bit indicating which window sequence (i.e., block size) is used.

window_shape 1 bit indicating which window function is selected.

Table 93 shows the **window_sequences** based on the seven transform windows. (ONLY_LONG_SEQUENCE, LONG_START_SEQUENCE, EIGHT_SHORT_SEQUENCE, LONG_STOP_SEQUENCE, STOP_START_SEQUENCE).

In the following LPD_SEQUENCE refers to all allowed window/coding mode combinations inside the so called linear prediction domain codec (see 6.2.10). In decoding a frequency domain coded frame it is only important to know if a following frame is encoded with the LP domain coding modes, which is represented by an LPD_SEQUENCE. This is true regardless of the exact structure within the LPD_SEQUENCE.

7.9.3 Decoding process

7.9.3.1 IMDCT

The analytical expression of the IMDCT is:

$$x_{i,n} = \frac{2}{N} \sum_{k=0}^{N/2-1} spec[i][k] \cos\left(\frac{2\pi}{N}(n+n_0)\left(k + \frac{1}{2}\right)\right), \text{ for } 0 \leq n < N$$

where:

n = sample index;

i = window index;

k = spectral coefficient index;

N = window length based on the window_sequence value:

$$n_0 = (N/2 + 1) / 2.$$

The synthesis window length N for the inverse transform is a function of the syntax element **window_sequence** and the algorithmic context. It is defined in Table 137.

Table 137 — Value of synthesis window length N depending on window_sequence and coreCoderFrameLength

window_sequence	coreCoderFrameLength == 768	coreCoderFrameLength == 1024
ONLY_LONG_SEQUENCE LONG_START_SEQUENCE LONG_STOP_SEQUENCE STOP_START_SEQUENCE	1536	2048
EIGHT_SHORT_SEQUENCE	192	256

The meaningful block transitions are listed in the following Table 138. A tick mark (☑) in a given table cell indicates that a window sequence listed in that particular row may be followed by a window sequence listed in that particular column.

Table 138 — Allowed window sequences

Window sequence From ↓ To →	ONLY_LONG_SEQUENCE	LONG_START_SEQUENCE	EIGHT_SHORT_SEQUENCE	LONG_STOP_SEQUENCE	STOP_START_SEQUENCE	LPD_SEQUENCE
ONLY_LONG_SEQUENCE	☑	☑				
LONG_START_SEQUENCE			☑	☑	☑	☑
EIGHT_SHORT_SEQUENCE			☑	☑	☑	☑
LONG_STOP_SEQUENCE	☑	☑				
STOP_START_SEQUENCE			☑	☑	☑	☑
LPD_SEQUENCE			☑	☑	☑	☑

7.9.3.2 Windowing and block switching

Depending on the **window_sequence** and **window_shape** element different transform windows are used. A combination of the window halves described as follows offers all possible window_sequences. Window lengths specified below are dependent on the core-coder frame length. Numbers are listed for coreCoderFrameLength of 1024 (768).

For **window_shape** == 1, the window coefficients are given by the Kaiser-Bessel derived (KBD) window as follows:

$$W_{KBD_LEFT,N}(n) = \frac{\sum_{p=0}^n [W'(p, \alpha)]}{\sum_{p=0}^{N/2} [W'(p, \alpha)]}, \text{ for } 0 \leq n < \frac{N}{2}$$

$$W_{KBD_RIGHT,N}(n) = \frac{\sum_{p=0}^{N-n-1} [W'(p, \alpha)]}{\sum_{p=0}^{N/2} [W'(p, \alpha)]}, \text{ for } \frac{N}{2} \leq n < N$$

where:

W' , Kaiser-Bessel kernel window function is defined as follows:

$$W'(n, \alpha) = \frac{I_0 \left[\pi \alpha \sqrt{1.0 - \left(\frac{n - N/4}{N/4} \right)^2} \right]}{I_0[\pi \alpha]}$$

$$I_0[x] = \sum_{k=0}^{\infty} \left[\frac{\left(\frac{x}{2} \right)^k}{k!} \right]^2$$

$$\alpha = \text{kernel window alpha factor, } \alpha = \begin{cases} 4 & \text{, for } N = 2048 \text{ (1536)} \\ 6 & \text{, for } N = 256 \text{ (192)} \end{cases}$$

Otherwise, for **window_shape** == 0, a sine window is employed as follows:

$$W_{SIN_LEFT,N}(n) = \sin\left(\frac{\pi}{N}\left(n + \frac{1}{2}\right)\right), \text{ for } 0 \leq n < \frac{N}{2}$$

$$W_{SIN_RIGHT,N}(n) = \sin\left(\frac{\pi}{N}\left(n + \frac{1}{2}\right)\right), \text{ for } \frac{N}{2} \leq n < N$$

The window length N can be 2048 (1536) or 256 (192) for the KBD and the sine window.

How to obtain the possible window sequences is explained in the parts a)-e) of this subclause.

For all kinds of window_sequences the window_shape of the left half of the first transform window is determined by the window shape of the previous block. The following formula expresses this fact:

$$W_{LEFT,N}(n) = \begin{cases} W_{KBD_LEFT,N}(n) & , \text{if } window_shape_previous_block == 1 \\ W_{SIN_LEFT,N}(n) & , \text{if } window_shape_previous_block == 0 \end{cases}$$

where:

window_shape_previous_block is equal to the **window_shape** of the previous block ($i - 1$).

For the first raw_data_block() to be decoded the **window_shape** of the left and right half of the window are identical.

In the case that the previous block was coded using LPD mode, *window_shape_previous_block* is set to 0.

a) ONLY_LONG_SEQUENCE:

The **window_sequence** == ONLY_LONG_SEQUENCE is equal to one LONG_WINDOW with a total window length N_l of 2048 (1536).

For **window_shape** == 1 the window for ONLY_LONG_SEQUENCE is given as follows:

$$W(n) = \begin{cases} W_{LEFT,N_l}(n) & , \text{for } 0 \leq n < \frac{N_l}{2} \\ W_{KBD_RIGHT,N_l}(n) & , \text{for } \frac{N_l}{2} \leq n < N_l \end{cases}$$

If **window_shape** == 0 the window for ONLY_LONG_SEQUENCE can be described as follows:

$$W(n) = \begin{cases} W_{LEFT,N_l}(n) & , \text{for } 0 \leq n < \frac{N_l}{2} \\ W_{SIN_RIGHT,N_l}(n) & , \text{for } \frac{N_l}{2} \leq n < N_l \end{cases}$$

After windowing, the time domain values ($z_{i,n}$) can be expressed as:

$$z_{i,n} = W(n) \cdot x_{i,n}$$

b) LONG_START_SEQUENCE:

The LONG_START_SEQUENCE can be used to obtain a correct overlap and add for a block transition from a ONLY_LONG_SEQUENCE to any block with a low-overlap (short window slope) window half on the left (EIGHT_SHORT_SEQUENCE, LONG_STOP_SEQUENCE, STOP_START_SEQUENCE or LPD_SEQUENCE).

In case the following window sequence is not an LPD_SEQUENCE:

Window lengths N_l and N_s are set to 2048 (1536) and 256 (192) respectively.

In case the following window sequence is an LPD_SEQUENCE:

Window lengths N_l and N_s are set to 2048 (1536) and 512 (384) respectively.

If **window_shape** == 1 the window for LONG_START_SEQUENCE is given as follows:

$$W(n) = \begin{cases} W_{LEFT, N_l}(n) & , \text{for } 0 \leq n < \frac{N_l}{2} \\ 1.0 & , \text{for } \frac{N_l}{2} \leq n < \frac{3N_l - N_s}{4} \\ W_{KBD_RIGHT, N_s}(n + \frac{N_s}{2} - \frac{3N_l - N_s}{4}) & , \text{for } \frac{3N_l - N_s}{4} \leq n < \frac{3N_l + N_s}{4} \\ 0.0 & , \text{for } \frac{3N_l + N_s}{4} \leq n < N_l \end{cases}$$

If **window_shape** == 0 the window for LONG_START_SEQUENCE looks like:

$$W(n) = \begin{cases} W_{LEFT, N_l}(n) & , \text{for } 0 \leq n < \frac{N_l}{2} \\ 1.0 & , \text{for } \frac{N_l}{2} \leq n < \frac{3N_l - N_s}{4} \\ W_{SIN_RIGHT, N_s}(n + \frac{N_s}{2} - \frac{3N_l - N_s}{4}) & , \text{for } \frac{3N_l - N_s}{4} \leq n < \frac{3N_l + N_s}{4} \\ 0.0 & , \text{for } \frac{3N_l + N_s}{4} \leq n < N_l \end{cases}$$

The windowed time-domain values can be calculated with the formula explained in a).

c) EIGHT_SHORT

The **window_sequence** == EIGHT_SHORT comprises eight overlapped and added SHORT_WINDOWs with a length N_s of 256 (192) each. The total length of the window_sequence together with leading and following zeros is 2048 (1536). Each of the eight short blocks are windowed separately first. The short block number is indexed with the variable $j = 0, \dots, M - 1$ ($M = N_l / N_s$).

The **window_shape** of the previous block influences the first of the eight short blocks ($W_0(n)$) only. If **window_shape** == 1 the window functions can be given as follows:

$$W_0(n) = \begin{cases} W_{LEFT, N_s}(n) & , \text{for } 0 \leq n < \frac{N_s}{2} \\ W_{KBD_RIGHT, N_s}(n) & , \text{for } \frac{N_s}{2} \leq n < N_s \end{cases}$$

$$W_j(n) = \begin{cases} W_{KBD_LEFT, N_s}(n) & , \text{for } 0 \leq n < \frac{N_s}{2} \\ W_{KBD_RIGHT, N_s}(n) & , \text{for } \frac{N_s}{2} \leq n < N_s \end{cases} , 0 < j \leq M - 1$$

Otherwise, if **window_shape** == 0, the window functions can be described as:

$$W_0(n) = \begin{cases} W_{LEFT, N_s}(n), & \text{for } 0 \leq n < \frac{N_s}{2} \\ W_{SIN_RIGHT, N_s}(n), & \text{for } \frac{N_s}{2} \leq n < N_s \end{cases}$$

$$W_j(n) = \begin{cases} W_{SIN_LEFT, N_s}(n) & \text{for } 0 \leq n < \frac{N_s}{2} \\ W_{SIN_RIGHT, N_s}(n) & \text{for } \frac{N_s}{2} \leq n < N_s \end{cases}, 0 < j \leq M-1$$

The overlap and add between the EIGHT_SHORT **window_sequence** resulting in the windowed time domain values $Z_{i,n}$ is described as follows:

$$Z_{i,n} = \begin{cases} 0 & \text{for } 0 \leq n < \frac{N_l - N_s}{4} \\ x_{0,n - \frac{N_l - N_s}{4}} \cdot W_0(n - \frac{N_l - N_s}{4}) & \text{for } \frac{N_l - N_s}{4} \leq n < \frac{N_l + N_s}{4} \\ x_{j-1, n - \frac{N_l + (2j-3)N_s}{4}} \cdot W_{j-1}(n - \frac{N_l + (2j-3)N_s}{4}) + x_{j, n - \frac{N_l + (2j-1)N_s}{4}} \cdot W_j(n - \frac{N_l + (2j-1)N_s}{4}) & \text{for } 1 \leq j < M, \frac{N_l + (2j-1)N_s}{4} \leq n < \frac{N_l + (2j+1)N_s}{4} \\ x_{M-1, n - \frac{N_l + (2M-3)N_s}{4}} \cdot W_{M-1}(n - \frac{N_l + (2M-3)N_s}{4}) & \text{for } \frac{N_l + (2M-1)N_s}{4} \leq n < \frac{N_l + (2M+1)N_s}{4} \\ 0 & \text{for } \frac{N_l + (2M+1)N_s}{4} \leq n < N_l \end{cases}$$

d) LONG_STOP_SEQUENCE

This window_sequence is needed to switch from an EIGHT_SHORT_SEQUENCE or LPD_SEQUENCE back to an ONLY_LONG_SEQUENCE.

In case the previous window sequence is not an LPD_SEQUENCE:

Window lengths N_l and N_s are set to 2048 (1536) and 256 (192) respectively.

In case the previous window sequence is an LPD_SEQUENCE:

Window lengths N_l and N_s are set to 2048 (1536) and 512 (384) respectively.

If **window_shape** == 1 the window for LONG_STOP_SEQUENCE is given as follows:

$$W(n) = \begin{cases} 0.0 & \text{for } 0 \leq n < \frac{N_l - N_s}{4} \\ W_{LEFT, N_s}(n - \frac{N_l - N_s}{4}) & \text{for } \frac{N_l - N_s}{4} \leq n < \frac{N_l + N_s}{4} \\ 1.0 & \text{for } \frac{N_l + N_s}{4} \leq n < \frac{N_l}{2} \\ W_{KBD_RIGHT, N_l}(n) & \text{for } \frac{N_l}{2} \leq n < N_s \end{cases}$$

If **window_shape** == 0 the window for LONG_START_SEQUENCE is determined by:

$$W(n) = \begin{cases} 0.0 & ,\text{for } 0 \leq n < \frac{N_l - N_s}{4} \\ W_{LEFT, N_s} \left(n - \frac{N_l - N_s}{4} \right) & ,\text{for } \frac{N_l - N_s}{4} \leq n < \frac{N_l + N_s}{4} \\ 1.0 & ,\text{for } \frac{N_l + N_s}{4} \leq n < \frac{N_l}{2} \\ W_{SIN_RIGHT, N_l}(n) & ,\text{for } \frac{N_l}{2} \leq n < N_l \end{cases}$$

The windowed time domain values can be calculated with the formula explained in a).

e) STOP_START_SEQUENCE:

The STOP_START_SEQUENCE can be used to obtain a correct overlap and add for a block transition from any block with a low-overlap (short window slope) window half on the right to any block with a low-overlap (short window slope) window half on the left and if a single long transform is desired for the current frame.

In case the following window sequence is not an LPD_SEQUENCE:

Window lengths N_l and N_{sr} are set to 2048 (1536) and 256 (192) respectively.

In case the following window sequence is an LPD_SEQUENCE:

Window lengths N_l and N_{sr} are set to 2048 (1536) and 512 (384) respectively.

In case the previous window sequence is not an LPD_SEQUENCE:

Window lengths N_l and N_{sl} are set to 2048 (1536) and 256 (192) respectively.

In case the previous window sequence is an LPD_SEQUENCE:

Window lengths N_l and N_{sl} are set to 2048 (1536) and 512 (384) respectively.

If **window_shape** == 1 the window for STOP_START_SEQUENCE is given as follows:

$$W(n) = \begin{cases} 0.0 & ,\text{for } 0 \leq n < \frac{N_l - N_{sl}}{4} \\ W_{LEFT, N_{sl}} \left(n - \frac{N_l - N_{sl}}{4} \right) & ,\text{for } \frac{N_l - N_{sl}}{4} \leq n < \frac{N_l + N_{sl}}{4} \\ 1.0 & ,\text{for } \frac{N_l + N_{sl}}{4} \leq n < \frac{3N_l - N_{sr}}{4} \\ W_{KBD_RIGHT, N_{sr}} \left(n + \frac{N_{sr}}{2} - \frac{3N_l - N_{sr}}{4} \right) & ,\text{for } \frac{3N_l - N_{sr}}{4} \leq n < \frac{3N_l + N_{sr}}{4} \\ 0.0 & ,\text{for } \frac{3N_l + N_{sr}}{4} \leq n < N_l \end{cases}$$

If **window_shape** == 0 the window for STOP_START_SEQUENCE looks like:

$$W(n) = \begin{cases} 0.0 & , \text{for } 0 \leq n < \frac{N_l - N_{sl}}{4} \\ W_{LEFT, N_{sl}}(n - \frac{N_l - N_{sl}}{4}), & , \text{for } \frac{N_l - N_{sl}}{4} \leq n < \frac{N_l + N_{sl}}{4} \\ 1.0, & , \text{for } \frac{N_l + N_{sl}}{4} \leq n < \frac{3N_l - N_{sr}}{4} \\ W_{SIN_RIGHT, N_{sr}}(n + \frac{N_{sr}}{2} - \frac{3N_l - N_{sr}}{4}), & , \text{for } \frac{3N_l - N_{sr}}{4} \leq n < \frac{3N_l + N_{sr}}{4} \\ 0.0 & , \text{for } \frac{3N_l + N_{sr}}{4} \leq n < N_l \end{cases}$$

The windowed time-domain values can be calculated with the formula explained in a).

7.9.3.3 Overlapping and adding with previous window sequence

Besides the overlap and add within the EIGHT_SHORT **window_sequence**, the first (left) part of every **window_sequence** is overlapped and added with the second (right) part of the previous **window_sequence** resulting in the final time domain values $out_{i,n}$. The mathematic expression for this operation can be described as follows.

In case of ONLY_LONG_SEQUENCE, LONG_START_SEQUENCE, EIGHT_SHORT_SEQUENCE, LONG_STOP_SEQUENCE, STOP_START_SEQUENCE:

$$out[i_{out} + n] = z_{i,n} + z_{i-1, n + \frac{N_l}{2}}; \forall 0 \leq n < \frac{N_l}{2}$$

N_l is the size of the window sequence. i_{out} indexes the output buffer out and is incremented by the number $\frac{N_l}{2}$ of written samples.

In case of LPD_SEQUENCE:

If the previous decoded windowed signal was coded with ACELP, the tool FAC is applied as described in 7.16. Otherwise, when the previous decoded windowed signal $z_{i-1,n}$ was coded with the MDCT based TCX, a conventional overlap and add is performed for obtaining the final time signal out . The overlap and add operation can be expressed by the following formula when FD mode window sequence is a LONG_START_SEQUENCE or an EIGHT_SHORT_SEQUENCE:

$$out[i_{out} + n] = \begin{cases} z_{i, \frac{N_l - N_s}{4} + n} + z_{i-1, \frac{3N_l - N_s}{4} + n} & \forall 0 \leq n < \frac{N_s}{2} \\ z_{i, \frac{N_l - N_s}{4}} & \forall \frac{N_s}{2} \leq n < \frac{N_l + N_s}{4} \end{cases}$$

N_{i-1} corresponds to the size $2lg$ of the previous window applied in MDCT based TCX. i_{out} indexes the output buffer out and is incremented by the number $(N_l + N_s)/4$ of written samples. $N_s/2$ should be equal to the value L of the previous MDCT based TCX defined in Table 155.

For a STOP_START_SEQUENCE the overlap and add operation between FD mode and MDCT based TCX is performed according to the following expression:

$$out[i_{out} + n] = \begin{cases} z_{i, \frac{N_l - N_{sl}}{4} + n} + z_{i-1, \frac{3 \cdot N_{l-1} - 2 \cdot N_{sl}}{4} + n} & \forall 0 \leq n < \frac{N_{sl}}{2} \\ z_{i, \frac{N_l - N_{sl}}{4} + n} & \forall \frac{N_{sl}}{2} \leq n < \frac{N_l + N_{sl}}{4} \end{cases}$$

N_{l-1} corresponds to the size $2lg$ of the previous window applied in MDCT based TCX. i_{out} indexes the output buffer out and is incremented by the number $(N_l + N_{sl})/4$ of written samples. $N_{sl}/2$ should be equal to the value L of the previous MDCT based TCX defined in Table 155.

7.10 Time-warped filterbank and blockswitching

7.10.1 Tools description

When the time-warped MDCT is enabled for the stream (the **twMdct** flag is set in the `UsacConfig()`), this tool replaces the standard filterbank and blockswitching (see 7.9). In addition to the IMDCT the tool contains a time-domain to time-domain mapping from an arbitrarily spaced time grid to the normal linearly spaced time grid and a corresponding adaptation of the window shapes.

7.10.2 Definition of elements

7.10.2.1 Data elements

<code>tw_data()</code>	Contains the side information necessary to decode and apply the time-warped MDCT on an <code>fd_channel_stream()</code> for SCE and CPE elements. The <code>fd_channel_streams</code> of a <code>UsacChannelPairElement()</code> may share one common <code>tw_data()</code> .
<code>tw_data_present</code>	1 bit indicating that a non-flat warp contour is transmitted in this frame.
<code>tw_ratio[]</code>	Codebook index of the warp ratio for node i .
<code>window_sequence</code>	2 bit indicating which window sequence (i.e., block size) is used.
<code>window shape</code>	1 bit indicating which window function is selected.

7.10.2.2 Help elements

<code>warp_node_values[]</code>	Decoded warp contour node values.
<code>warp_value_tbl[]</code>	Quantization table for the warp node ratio values, shown in Table 139.

Table 139 — warp_value_tbl

Index	value
0	0.982857168
1	0.988571405
2	0.994285703
3	1
4	1.0057143
5	1.01142859
6	1.01714289
7	1.02285719

<code>new_warp_contour[]</code>	Decoded and interpolated warp contour for this frame (n_{long} samples).
---------------------------------	---

<code>past_warp_contour[]</code>	past warp contour ($2 \times n_{\text{long}}$ samples).
<code>norm_fac</code>	Normalization factor for the past <i>warp_contour</i> .
<code>warp_contour[]</code>	Complete warp contour ($3 \times n_{\text{long}}$ samples).
<code>last_warp_sum</code>	Sum of first part of the warp contour.
<code>cur_warp_sum</code>	Sum of the middle part of the warp contour.
<code>next_warp_sum</code>	Sum of the last part of the warp contour.
<code>time_contour[]</code>	Complete time contour ($3 \times n_{\text{long}} + 1$ samples).
<code>sample_pos[]</code>	Positions of the warped samples on a linear time scale ($2 \times n_{\text{long}}$ samples + $2 \times \text{IP_LEN_2S}$).
<code>X[w][]</code>	Output of the IMDCT for window <i>w</i> .
<code>z[]</code>	Windowed and (optionally) internally overlapped time vector for one frame in the time warped domain.
<code>zp[]</code>	<code>z[]</code> with zero padding.
<code>y[]</code>	Time vector for one frame in the linear time domain after resampling.
$y'_{i,n}$	Time vector for frame <i>i</i> after postprocessing.
<code>out[]</code>	Output vector for one frame.
<code>b[]</code>	Impulse response of the resampling filter.
<i>N</i>	Synthesis window length, see 7.9.3.1.
<i>N_f</i>	Frame length, $N_f = 2 \times \text{coreCoderFrameLength}$.
<code>next_window_sequence</code>	Following window sequence.
<code>prev_window_sequence</code>	Previous window sequence.

7.10.2.3 Constants

<code>NUM_TW_NODES</code>	16
<code>OS_FACTOR_WIN</code>	16
<code>OS_FACTOR_RESAMP</code>	128
<code>IP_LEN_2S</code>	12
<code>IP_LEN_2</code>	$\text{OS_FACTOR_RESAMP} \times \text{IP_LEN_2S} + 1$
<code>IP_SIZE</code>	$\text{IP_LEN_2} + \text{OS_FACTOR_RESAMP}$
<code>n_long</code>	<i>coreCoderFrameLength</i>
<code>n_short</code>	$\text{coreCoderFrameLength} / 8$
<code>interp_dist</code>	$n_{\text{long}} / \text{NUM_TW_NODES}$

NOTIME

-100000

7.10.3 Decoding process

7.10.3.1 Warp contour

The codebook indices of the warp contour nodes are decoded as follows to warp values for the individual nodes:

$$warp_node_values[i] = \begin{cases} 1 & , \text{for } tw_data_present = 0, 0 \leq i \leq NUM_TW_NODES \\ 1 & , \text{for } tw_data_present = 1, i = 0 \\ \prod_{k=0}^{i-1} warp_value_tbl[tw_ratio[k]] & , \text{for } tw_data_present = 1, 0 < i \leq NUM_TW_NODES \end{cases}$$

To obtain the samplewise (n_long samples) `new_warp_contour[]`, the `warp_node_values[]` are now interpolated linearly between the equally spaced (`interp_dist` apart) nodes:

```
for ( i = 0 ; i < NUM_TW_NODES ; i++ ) {
    d = (warp_node_values[i+1] - warp_node_values[i] ) / interp_dist;
    for ( j = 0 ; j < interp_dist; j++ ) {
        new_warp_contour[i*interp_dist + j] = warp_node_values[i-1] + (j+1)*d;
    }
}
```

Before obtaining the full warp contour for this frame, the buffered values from the past have to be rescaled, so that the last warp value of the `past_warp_contour[]` equals 1:

$$norm_fac = \frac{1}{past_warp_contour[2 \cdot n_long - 1]}$$

$$past_warp_contour[i] = past_warp_contour[i] \cdot norm_fac \text{ for } 0 \leq i < 2 \cdot n_long$$

$$last_warp_sum = last_warp_sum \cdot norm_fac$$

$$cur_warp_sum = cur_warp_sum \cdot norm_fac$$

Now the full `warp_contour[]` is obtained by concatenating the `past_warp_contour` and the `new_warp_contour`, and `new_warp_sum` is calculated as sum over all `new_warp_contour[]` values:

$$new_warp_sum = \sum_{i=0}^{n_long-1} new_warp_contour[i]$$

7.10.3.2 Sample position and window length adjustment

From the `warp_contour[]` a vector of the sample position of the warped samples on a linear time scale is computed. For this, first the time contour is generated:

$$time_contour[i] = \begin{cases} -w_{res} \cdot last_warp_sum & , \text{for } i = 0 \\ w_{res} \left(-last_warp_sum + \sum_{k=0}^{i-1} warp_contour[k] \right) & , \text{for } 0 < i \leq 3 \cdot n_long \end{cases}$$

$$\text{where } w_{res} = \frac{n_long}{cur_warp_sum}$$

With the helper functions `warp_inv_vec()` and `warp_time_inv()`:

```
warp_time_inv(time_contour[],t_warp) {
    i = 0;
    if ( t_warp < time_contour[0] ) {
        return NOTIME;
    }
    while ( t_warp > time_contour[i+1] ) {
        i++;
    }
    return (i + (t_warp - time_contour[i])/(time_contour[i+1]-time_contour[i]));
}

warp_inv_vec(time_contour[],t_start,n_samples,sample_pos[]) {
    t_warp = t_start;
    j = 0;
    while (( i = floor(warp_time_inv(time_contour,t_warp-0.5))) == NOTIME) {
        t_warp += 1;
        j++;
    }
    while ( j < n_samples && (t_warp + 0.5) < time_contour[3*n_long] ) {
        while ( t_warp > time_contour[i+1]) {
            i++;
        }
        sample_pos[j] =
            i + (t_warp - time_contour[i])/(time_contour[i+1]-
            time_contour[i]);
        j++;
        t_warp += 1;
    }
}
```

the sample position vector and the transition lengths are computed:

```
t_start = n_long-3*N_f/4 - IP_LEN_2S + 0.5

warp_inv_vec(time_contour,
             t_start,
             N_f + 2*IP_LEN_2S,
             sample_pos[]);

if ( last_warp_sum > cur_warp_sum ) {
    warped_trans_len_left = n_long/2;
}
else {
    warped_trans_len_left = n_long/2*last_warp_sum/cur_warp_sum;
}

if (new_warpSum > cur_warp_sum ) {
    warped_trans_len_right = n_long/2;
}
else {
    warped_trans_len_right = n_long/2*new_warp_sum/cur_warp_sum;
}

switch ( window_sequence ) {
    case LONG_START_SEQUENCE:
        if ( next_window_sequence == LPD_SEQUENCE ) {
            warped_trans_len_right /= 4;
        }
        else {
            warped_trans_len_right /= 8;
        }
        break;
    case LONG_STOP_SEQUENCE:
        if ( prev_window_sequence == LPD_SEQUENCE ) {
            warped_trans_len_left /= 4;
        }
}
```

```

    else {
        warped_trans_len_left /= 8;
    }
    break;
case EIGHT_SHORT_SEQUENCE:
    warped_trans_len_right /= 8;
    warped_trans_len_left /= 8;
    break;
case STOP_START_SEQUENCE:
    if ( prev_window_sequence == LPD_SEQUENCE ) {
        warped_trans_len_left /= 4;
    }
    else {
        warped_trans_len_left /= 8;
    }
    if ( next_window_sequence == LPD_SEQUENCE ) {
        warped_trans_len_right /= 4;
    }
    else {
        warped_trans_len_right /= 8;
    }
    break;
}
first_pos = ceil(N_f/4-0.5-warped_trans_len_left);
last_pos = floor(3*N_f/4-0.5+warped_trans_len_right);

```

7.10.3.3 IMDCT

See 7.9.3.1.

7.10.3.4 Windowing and block switching

Depending on the **window_shape** element different oversampled transform window prototypes are used, the length of the oversampled windows is:

$$N_{OS} = 2 \cdot n_long \cdot OS_FACTOR_WIN$$

For **window_shape** == 1, the window coefficients are given by the Kaiser-Bessel derived (KBD) window as follows:

$$W_{KBD} \left(n - \frac{N_{OS}}{2} \right) = \sqrt{\frac{\sum_{p=0}^{N_{OS}-n-1} [W(p, \alpha)]}{\sum_{p=0}^{N_{OS}/2} [W(p, \alpha)]}} \quad , \text{for } \frac{N_{OS}}{2} \leq n < N_{OS}$$

where:

W' , Kaiser-Bessel kernel function is defined as follows:

$$W'(n, \alpha) = \frac{I_0 \left[\pi \alpha \sqrt{1.0 - \left(\frac{n - N_{OS}/4}{N_{OS}/4} \right)^2} \right]}{I_0[\pi \alpha]} \quad , \text{for } 0 \leq n \leq \frac{N_{OS}}{2}$$

$$I_0[x] = \sum_{k=0}^{\infty} \left[\frac{\left(\frac{x}{2}\right)^k}{k!} \right]^2$$

α = kernel window alpha factor, $\alpha = 4$

Otherwise, for **window_shape** == 0, a sine window is employed as follows:

$$W_{SIN}\left(n - \frac{N_{OS}}{2}\right) = \sin\left(\frac{\pi}{N_{OS}}\left(n + \frac{1}{2}\right)\right) \text{ , for } \frac{N_{OS}}{2} \leq n < N_{OS}$$

For all kinds of window_sequences the used prototype for the left window part is the determined by the window shape of the previous block. The following formula expresses this fact:

$$left_window_shape[n] = \begin{cases} W_{KBD}[n] & , \text{ if } window_shape_previous_block == 1 \\ W_{SIN}[n] & , \text{ if } window_shape_previous_block == 0 \end{cases}$$

Likewise the prototype for the right window shape is determined by the following formula:

$$right_window_shape[n] = \begin{cases} W_{KBD}[n] & , \text{ if } window_shape == 1 \\ W_{SIN}[n] & , \text{ if } window_shape == 0 \end{cases}$$

Since the transition lengths are already determined, it only has to be differentiated between EIGHT_SHORT_SEQUENCES and all other:

a) EIGHT SHORT SEQUENCE:

The following c-code like portion describes the windowing and internal overlap-add of a EIGHT_SHORT_SEQUENCE:

```
tw_windowing_short(X[], z[], first_pos, last_pos, warped_trans_len_left, warped_trans_len_right, left_window_shape[], right_window_shape[]) {
    offset = n_long - 4*n_short - n_short/2;

    tr_scale_l = 0.5*n_long/warped_trans_len_left*OS_FACTOR_WIN;
    tr_pos_l = warped_trans_len_left + (first_pos - n_long/2) + 0.5*tr_scale_l;
    tr_scale_r = 8*OS_FACTOR_WIN;
    tr_pos_r = tr_scale_r/2;

    for ( i = 0 ; i < n_short ; i++ ) {
        z[i] = X[0][i];
    }

    for (i=0; i<first_pos; i++)
        z[i] = 0.;

    for (i=n_long-1-first_pos; i>=first_pos; i--) {
        z[i] *= left_window_shape[floor(tr_pos_l)];
        tr_pos_l += tr_scale_l;
    }

    for (i=0; i<n_short; i++) {
        z[offset+i+n_short] =
            X[0][i+n_short]*right_window_shape[floor(tr_pos_r)];
    }
}
```

```

    tr_pos_r += tr_scale_r;
}

offset += n_short;

for ( k = 1 ; k < 7 ; k++ ) {
    tr_scale_l = n_short*OS_FACTOR_WIN;
    tr_pos_l = tr_scale_l/2;
    tr_pos_r = OS_FACTOR_WIN*n_long-tr_pos_l;
    for ( i = 0 ; i < n_short ; i++ ) {
        z[i + offset] += X[k][i]*right_window_shape[floor(tr_pos_r)];
        z[offset + n_short + i] =
            X[k][n_short + i]*right_window_shape[floor(tr_pos_l)];
        tr_pos_l += tr_scale_l;
        tr_pos_r -= tr_scale_l;
    }
    offset += n_short;
}

tr_scale_l = n_short*OS_FACTOR_WIN;
tr_pos_l = tr_scale_l/2;

for ( i = n_short - 1 ; i >= 0 ; i-- ) {
    z[i + offset] += X[7][i]*right_window_shape[(int) floor(tr_pos_l)];
    tr_pos_l += tr_scale_l;
}

for ( i = 0 ; i < n_short ; i++ ) {
    z[offset + n_short + i] = X[7][n_short + i];
}

tr_scale_r = 0.5*n_long/warpedTransLenRight*OS_FACTOR_WIN;
tr_pos_r = 0.5*tr_scale_r+.5;

tr_pos_r = (1.5*n_long-(float)wEnd-0.5*warpedTransLenRight)*tr_scale_r;
for (i=3*n_long-1-last_pos ; i<=wEnd;i++) {
    z[i] *= right_window_shape[floor(tr_pos_r)];
    tr_pos_r += tr_scale_r;
}

for (i=lsat_pos+1;i<2*n_long;i++)
    z[i] = 0.;

```

b) all others:

```

tw_windowing_long(X[][] , z[] , first_pos , last_pos , warpe_trans_len_left , warped_trans_len_right
, left_window_shape[] , right_window_shape[]) {

    for (i=0;i<first_pos;i++)
        z[i] = 0.;
    for (i=last_pos+1;i<N_f;i++)
        z[i] = 0.;

    tr_scale = 0.5*n_long/warped_trans_len_left*OS_FACTOR_WIN;
    tr_pos = (warped_trans_len_left+first_pos-N_f/4)+0.5)*tr_scale;

    for (i=N_f/2-1-first_pos;i>=first_pos;i--) {
        z[i] = X[0][i]*left_window_shape[floor(tr_pos)];
        tr_pos += tr_scale;
    }

    tr_scale = 0.5*n_long/warped_trans_len_right*OS_FACTOR_WIN;
    tr_pos = (3*N_f/4-last_pos-0.5*warped_trans_len_right)*tr_scale;

```

```

for (i=3*N_f/2-1-last_pos;i<=last_pos;i++) {
    z[i] = X[0][i]*right_window_shape[floor(tr_pos)];
    tr_pos += tr_scale;
}
}

```

7.10.3.5 Time-varying resampling

The windowed block $z[]$ is now resampled according to the sample positions using the following impulse response:

$$b[n] = I_0[\alpha]^{-1} \cdot I_0 \left[\alpha \sqrt{1 - \frac{n^2}{IP_LEN_2S^2}} \right] \cdot \frac{\sin\left(\frac{\pi n}{OS_FACTOR_RESAMP}\right)}{\frac{\pi n}{OS_FACTOR_RESAMP}}, \text{ for } 0 \leq n < IP_SIZE - 1$$

$$\alpha = 8$$

Before resampling, the windowed block is padded with zeros on both ends:

$$zp[n] = \begin{cases} 0 & , \text{for } 0 \leq n < IP_LEN_2S \\ z[n - IP_LEN_2S] & , \text{for } IP_LEN_2S \leq n < N_f + IP_LEN_2S \\ 0 & , \text{for } 2 \cdot N_f + IP_LEN_2S \leq n < N_f + 2 \cdot IP_LEN_2S \end{cases}$$

The resampling itself is described in the following pseudo code:

```

offset_pos=0.5;
num_samples_in = N_f+2*IP_LEN_2S;
num_samples_out = 3*n_long;
j_center = 0;
for (i=0;i<numSamplesOut;i++) {
    while (j_center<num_samples_in && sample_pos[j_center]-offset_pos<=i)
        j_center++;
    j_center--;
    y[i] = 0;
    if (j_center<num_samples_in-1 && j_center>0) {
        frac_time = floor((i-(sample_pos[j_center]-offset_pos))
            *(sample_pos[j_center+1]-sample_pos[j_center])
            *os_factor);
        j = IP_LEN_2S*os_factor+frac_time;

        for (k=j_center-IP_LEN_2S;k<=j_center+IP_LEN_2S;k++) {
            if (k>=0 && k<num_samples_in)
                y[i] += b[abs(j)]*zp[k];
            j -= os_factor;
        }
    }
    if (j_center<0)
        j_center++;
}

```

7.10.3.6 Overlapping and adding with previous window sequences

The overlapping and adding is the same for all sequences and can be described mathematically as follows:

$$out_{i,n} = \begin{cases} y'_{i,n} + y'_{i-1,n+n_long} + y'_{i-2,n+2 \cdot n_long} & , \text{for } 0 \leq n < n_long / 2 \\ y'_{i,n} + y'_{i-1,n+n_long} & , \text{for } n_long/2 \leq n < n_long \end{cases}$$

7.10.3.7 Memory update

The memory buffers needed for decoding the next frame are updated as follows:

$$\begin{aligned} \text{past_warp_contour}[n] &= \text{warp_contour}[n + n_long], \text{ for } 0 \leq n < 2 \cdot n_long \\ \text{cur_warp_sum} &= \text{new_warp_sum} \\ \text{last_warp_sum} &= \text{cur_warp_sum} \end{aligned}$$

Before decoding the first frame or if the last frame was encoded with the LPC domain coder, the memory states are set as follows:

$$\begin{aligned} \text{past_warp_contour}[n] &= 1, \text{ for } 0 \leq n < 2 \cdot n_long \\ \text{cur_warp_sum} &= n_long \\ \text{last_warp_sum} &= n_long \end{aligned}$$

7.11 MPEG Surround for mono to stereo upmixing

7.11.1 Tool description

MPEG Surround uses a compact parametric representation of the human's auditory cues for spatial perception to allow for a bit-rate efficient representation of a multi-channel signal. Although the coding of stereo signals based on a mono downmix is not explicitly specified in ISO/IEC 23003-1:2007, it is evident that such a 2-1-2 configuration may be realized in an efficient manner. In addition to CLD and ICC parameters, IPD parameters can be transmitted. The OPD parameters are estimated with given CLD and IPD parameters for efficient representation of phase information. IPD and OPD parameters are used to synthesize the phase difference to further improve stereo image.

A basic element of MPEG Surround coding is the OTT box, which performs exactly the required mono to stereo upmixing on the decoder side as shown in Figure 20.

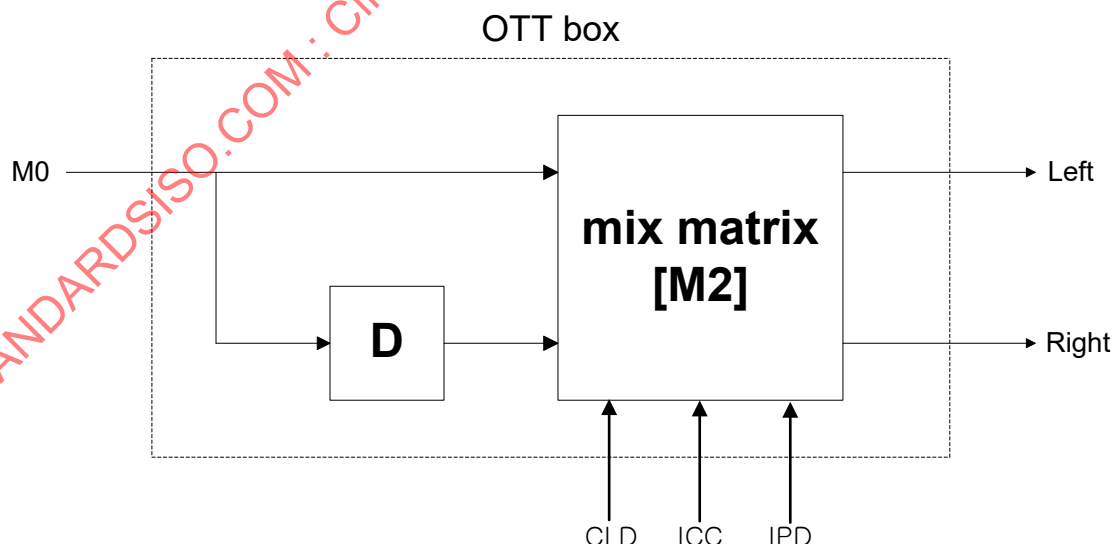


Figure 20 — OTT decoding block: two output signals with the correct spatial cues are generated by mixing a mono input signal M0 with the output of a decorrelator D that is fed with that mono input signal

In addition to the mode outlined above, residual coding can be employed with a residual having a limited or full bandwidth. This is illustrated in Figure 21.

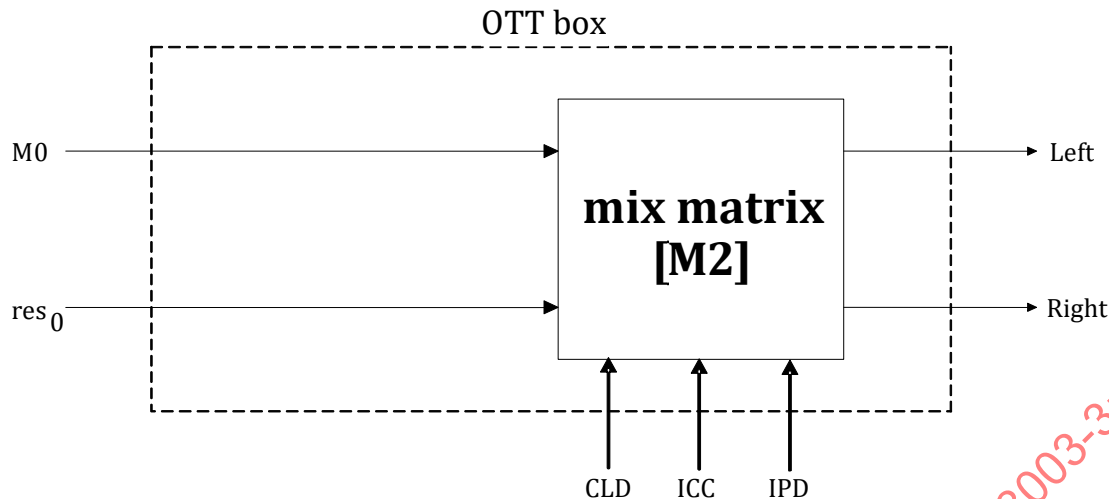


Figure 21 — OTT decoding block for residual coding: two output signals are generated by mixing a mono input signal M_0 and a residual signal res_0 using the CLD, ICC, and IPD parameters

Unlike the delay introduced by MPEG Surround decoder as defined in ISO/IEC 23003-1:2007, 4.5, only high quality decoding is supported in MPS212. It is noted that this implies that the delay of 5 QMF samples prior to the Nyquist analysis filterbanks shall not be inserted.

7.11.2 Decoding process

7.11.2.1 Lossless decoding of IPD parameters

The syntax element **bsPhaseCoding** in `Mps212Config()` indicates whether IPD coding is applied. In case that the syntax element **bsOttBandsPhasePresent** is decoded as 1, the number of IPD parameter bands is transmitted explicitly by **bsOttBandsPhase**. Otherwise, the number of IPD parameter bands is initialized to their default values using Table 109.

If residual coding is employed (**bsResidualCoding** == 1), the number of IPD parameters transmitted is equal to the larger of the two values **bsOttBandsPhase** and **bsResidualBands**.

In the following text `numBandsIPD` refers to the number of IPD parameter bands, i.e., the number of transmitted IPD parameters.

The syntax element, **bsPhaseMode** indicates whether the IPD parameters are available for the current `Mps212Data` frame. If the value of **bsPhaseMode** is set to zero, the IPD parameters are set to zero. Otherwise, the quantized IPD indices are losslessly decoded from the bitstream.

If decoding the IPD parameters, the syntax element, **bsQuantCoarseXXX[][]** means **bsQuantCoarseIPD[][]**.

The quantized IPD parameters are decoded using the lossless coding scheme as specified in ISO/IEC 23003-1:2007, 6.1.2 but with following changes:

- Due to the wrapping property of the phase parameter, the IPD quantized index is calculated using a modulo operation on the difference from the adjacent (either time or frequency axis) quantized IPD. The sign bit for the difference value in 1D Huffman coding is not necessary because the difference value is always positive after modulo operation. For the same reason, the sign information in 2D Huffman coding i.e., **bsSymBit[0]** in `SymmetryData()` is not necessary.
- In case that the fine quantization is applied as indicated by **bsQuantCoarseIPD**, the symbols are split into 3bit MSB and 1bit LSB. The upper symbol is decoded with 1D or 2D Huffman coding using coarse quantization and the LSB symbol is decoded with the syntax `LsbData()`. If the quantization level of the

previous frame is not the same as that of current frame, the quantized index of the previous frame is converted to the same precision as the current frame so that time differential coding can be done.

The decoding of the Mps212Data() data results in the parameter indices idxIPD[][] of the quantized IPD parameters:

idxIPD[pi][ps][pb] having values in the range 0 .. 15

where

pi = parameter instance which in the case of IPD decoding, used only in the 2-1-2 mode, has a value of 0.

ps = parameter set having values in the range 0 .. numParamSets-1,

pb = parameter band having values for IPD parameter in the range 0 .. numBandsIPD-1 and for other parameters in the range 0 .. numBands-1,

pg = parameter group having values in the range 0 .. dataBands-1.

In case of IPD parameters, the syntax element, **bsXXXdataMode[][]** in Table 62 means **bsIPDdataMode[][]**. Decode IPD parameter sets ps according to their **bsIPDdataMode[][]** as below.

```
while (ps=0; ps<numParamSet; ps++) {
    switch (bsIPDdataMode[pi][ps]) {
        case 0: /* default */
            for (pb=0; pb<numBandsIPD, pb++) {
                idxIPD[pi][ps][pb] = 0;
            }
            break;
        case 1: /* keep */
        case 2: /* interpolate */
            for (pb=0; pb<numBandsIPD, pb++) {
                idxIPD[pi][ps][pb] = idxIPD [pi][ps-1][pb];
            }
            break;
        case 3: /* coded */
            if (!paramHandled[ps]) {
                DecodeDataPair(); /* see ISO/IEC 23003-1, 6.1.2.3*/
            }
            break;
    }
}
```

First, the previous data is pre-processed for time-differential decoding:

```
setIdxStart = dataSetIdx[ps];
startBand = startBandIPD[pi];
stopBand = stopBandIPD[pi];
pbStride = pbStrideTable[bsFreqResStrideIPD[pi][setIdx]]; /* see ISO/IEC 23003-1 Table 70 */
dataBands = (stopBand - startBand - 1)/pbStride + 1; /* ANSI C integer math */
aGroupToBand = createMapping(startBand, stopBand, pbStride); /* see ISO/IEC 23003-1
subclause 6.1.2.4*/
for (pg=0; pg<dataBands; pg++) {
    pb = aGroupToBand[pg];
    tmp = idxIPD[pi][ps-1][pb];
    if (bsQuantCoarseIPD[pi][setIdx]) {
        tmp = tmp/2; /* ANSI C integer math */
    }
    idxIPDmsb[pi][setIdxStart-1][pg] = tmp;
}
```

Then, delta decoding is done in the following order:

```

if (!bsPcmCodingIPD[pi][setIdx]) {
    if (bsDataPairIPD[pi][setIdxStart]) {
        if ((bsDiffTypeIPD[pi][setIdx]==DIFF_TIME) &&
            (bsDiffTimeDirectionIPD[pi][setIdx]==FORWARDS)) {
            decodeDeltaData(setIdxStart+1);
            decodeDeltaData(setIdxStart);
        }
        else {
            decodeDeltaData(setIdxStart);
            decodeDeltaData(setIdxStart+1);
        }
    }
    else {
        decodeDeltaData(setIdxStart);
    }
} else {
    idxIPDnotMapped[pi][setIdx][pg] = bsIPDpcm[pi][setIdx][pg];
}

```

where the decodeDeltaData(setIdx) process is carried out as follows:

```

for (pg= 0; pg< dataBands; pg++) {
    switch (bsDiffTypeIPD[pi][setIdx]) {
        case DIFF_FREQ:
            if ( pg > 0 ) {
                idxIPDmsb[pi][setIdx][pg] =
                    (idxIPDmsb[pi][setIdx][pg-1] + bsIPDmsbDiff[pi][setIdx][pg])%8;
            } else {
                idxIPDmsb[pi][setIdx][pg] = bsIPDmsbDiff[pi][setIdx][pg];
            }
            break;
        case DIFF_TIME:
            if ( (pg > 0) || (mixedTimePairIPD[pi][setIdx]) ) {
                switch (bsDiffTimeDirectionIPD[pi][setIdx]) {
                    case BACKWARDS:
                        idxIPDmsb[pi][setIdx][pg] =
                            (idxIPDmsb[pi][setIdx-1][pg] + bsIPDmsbDiff[pi][setIdx][pg])%8 ;
                        break;
                    case FORWARDS:
                        /* assert that idxIPDmsb[pi][setIdx+1] is already available */
                        idxIPDmsb[pi][setIdx][pg] =
                            (idxIPDmsb[pi][setIdx+1][pg] + bsIPDmsbDiff[pi][setIdx][pg])%8;
                        break;
                }
            } else {
                idxIPDmsb[pi][setIdx][pg] = bsIPDmsbDiff[pi][setIdx][pg];
            }
        }
    }
    if (bsQuantCoarseIPD==1) {
        idxIPDnotMapped[pi][setIdx][pg] = idxIPDmsb[pi][setIdx][pg];
    }
    else {
        idxIPDnotMapped[pi][setIdx][pg] =
            2*idxIPDmsb[pi][setIdx][pg] + bsIPDlsb[pi][setIdx][pg];
    }
}

```

Finally, the following post-process is applied to the decoded data:

```

for (i=0; i<=bsDataPairIPD[pi][setIdxStart]; i++) {
    setIdx = setIdxStart+i;
    ps = paramSet[setIdx];
    paramHandled[ps] = 1;
    for (pg=0; pg<dataBands; pg++) {

```

```

tmp = idxIPDnotMapped[pi][setIdx][pg];
if (bsQuantCoarseIPD[pi][setIdx]) {
    tmp = tmp*2;
}
pbStart = aGroupToBand[pg];
pbStop = aGroupToBand[pg+1];
for (pb=pbStart; pb<pbStop; pb++) {
    idxIPD[pi][ps][pb] = tmp;
}
}
}

```

All parameters types are dequantized for all parameter bands $0 \leq m < M_{par}$ and all parameter sets $0 \leq l < L$ according to ISO/IEC 23003-1:2007, 6.1.8. For IPD parameters, the dequantization function uses Table 140 and will return a dequantized value according to chosen index.

Whenever parameter interpolation is used as signalled by $\mathbf{bsIPDdataMode}(pi, l, m) = 2$ for the corresponding indices $\mathbf{idxIPD}(pi, l, m)$, the dequantization function will also use the parameter time slot vector $\mathbf{t}$ and the previous and next parameter indices $\mathbf{idxIPD}(pi, l_{before}, m)$ and $\mathbf{idxIPD}(pi, l_{after}, m)$, respectively, to calculate the interpolated IPD indices according to:

$$\begin{aligned}
 \mathbf{idxIPD}_{before}(pi, l, m) &= \begin{cases} \mathbf{idxIPD}(pi, l_{before}, m) & , \text{if } \mathbf{idxIPD}(pi, l_{after}, m) - \mathbf{idxIPD}(pi, l_{before}, m) \leq 8 \\ \mathbf{idxIPD}(pi, l_{before}, m) + 16 & , \text{else} \end{cases} \\
 \mathbf{idxIPD}_{after}(pi, l, m) &= \begin{cases} \mathbf{idxIPD}(pi, l_{after}, m) & , \text{if } \mathbf{idxIPD}(pi, l_{before}, m) - \mathbf{idxIPD}(pi, l_{after}, m) \leq 8 \\ \mathbf{idxIPD}(pi, l_{after}, m) + 16 & , \text{else} \end{cases} \\
 \mathbf{idxIPD}(pi, l, m) &= \left(\mathbf{idxIPD}_{before}(pi, l, m) + \text{INT} \left(\frac{\mathbf{idxIPD}_{after}(pi, l, m) - \mathbf{idxIPD}_{before}(pi, l, m)}{\mathbf{t}(l_{after}) - \mathbf{t}(l_{before})} (\mathbf{t}(l) - \mathbf{t}(l_{before})) \right) \right) \bmod 16 \\
 l_{before} &< l < l_{after}
 \end{aligned}$$

where

l_{before} is the parameter set with the largest value smaller than l for which $\mathbf{bsIPDdataMode}(pi, l_{before}, m) \neq 2$ and where

l_{after} is the parameter set with the smallest value larger than l for which $\mathbf{bsIPDdataMode}(pi, l_{after}, m) \neq 2$ and where

$\mathbf{idxIPD}(pi, -1, m)$ refers to the last parameter set in the previous frame and $\mathbf{t}(-1)$ is set to the first parameter time slot in the current frame, hence equals zero.

Table 140 — IPD dequantization table

Index	0	1	2	3	4	5	6	7
IPD value	0	$\frac{\pi}{8}$	$\frac{\pi}{4}$	$\frac{3}{8}\pi$	$\frac{\pi}{2}$	$\frac{5}{8}\pi$	$\frac{3\pi}{4}$	$\frac{7}{8}\pi$
Index	8	9	10	11	12	13	14	15
IPD value	π	$\frac{9}{8}\pi$	$\frac{5}{4}\pi$	$\frac{11}{8}\pi$	$\frac{3}{2}\pi$	$\frac{13}{8}\pi$	$\frac{7}{4}\pi$	$\frac{15}{8}\pi$

7.11.2.2 OPD parameter estimation

The OPD parameters represent the phase difference between left and downmixed mono signal. Unlike the parametric stereo tool as defined in ISO/IEC 14496-3 (HE-AAC v2), only the IPD parameters are transmitted for efficient representation of phase information. With the given CLD and IPD parameters, the OPD parameters are estimated as:

$$OPD_{left}^{l,m} = \begin{cases} 0 & , \text{if } (IPD^{l,m} = \pi \text{ \& } CLD^{l,m} = 0) \\ \arctan \left(\frac{w_2^{l,m} \sin(IPD^{l,m})}{w_1^{l,m} \cdot 10^{\frac{CLD^{l,m}}{20}} + w_2^{l,m} \cos(IPD^{l,m})} \right) & , \text{otherwise} \end{cases}$$

with

$$w_1^{l,m} = (2 - \sqrt{ER^{l,m}}), w_2^{l,m} = \sqrt{ER^{l,m}},$$

$$ER^{l,m} = \sqrt{\frac{10^{\frac{CLD^{l,m}}{10}} + 1 + 2 \cdot \cos(IPD^{l,m}) \cdot ICC^{l,m} \cdot 10^{\frac{CLD^{l,m}}{20}}}{10^{\frac{CLD^{l,m}}{10}} + 1 + 2 \cdot ICC^{l,m} \cdot 10^{\frac{CLD^{l,m}}{20}}}}$$

where ER represents the energy ratio between a phase aligned and a non-phase aligned downmix.

7.11.2.3 Calculation of pre-matrix M1 and mix-matrix M2

7.11.2.3.1 General

The calculation of pre-matrix M1 and mix-matrix M2, which are interpolated versions of $R_1^{l,m}$, $G_1^{l,m}$, $H_1^{l,m}$ and $R_2^{l,m}$, is done according to ISO/IEC 23003-1:2007, 6.5, but with the modifications described in the following section. In case that IPD parameters are available, mix-matrix M2 is modified for phase synthesis.

7.11.2.3.2 Upmix without IPD coding

For the 2-1-2 configuration $R_1^{l,m}$ is defined according to:

$$R_1^{l,m} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

The $G_1^{l,m}$ matrix is defined as for the 5-1-5 configuration according to ISO/IEC 23003-1:2007, e.g., if no external downmix compensation is applied:

$$G_1^{l,m} = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

The matrix $H_1^{l,m}$ for the 2-1-2 configuration defaults to the unity matrix.

For the $R_2^{l,m}$ matrix, the elements are calculated from an equivalent model of one OTT box according to:

$$R_2^{l,m} = \begin{bmatrix} H11_{OTT}^{l,m} & H12_{OTT}^{l,m} \\ H21_{OTT}^{l,m} & H22_{OTT}^{l,m} \end{bmatrix}$$

7.11.2.3.3 Upmix with IPD/OPD coding

If **bsPhaseCoding** == 1 and **bsResidualCoding** == 0, then in the case that the IPD coding is enabled for the current frame, the phase correction angles from the IPD and estimated OPD for the two output channels are given for all parameter sets l and processing bands m :

$$\begin{aligned} \theta_1^{l,m} &= OPD_{left}^{l,m} \\ \theta_2^{l,m} &= OPD_{left}^{l,m} - IPD^{l,m} \end{aligned}$$

It is noted that due to the wrapping property of phase values, the correction angles $\theta_1^{l,m}$ and $\theta_2^{l,m}$ are calculated using a modulo 2π operation.

Adaptive smoothing is applied to the phase correction angles. The smoothed correction angles are calculated as follows:

$$\hat{\theta}_x^{l,m} = \text{smoothAngle}\left(\theta_x^{l,m}, \tilde{\theta}_x^{l-1,m}, \delta(l)\right)$$

where $x = 1$ or 2 ,

$$\text{smoothAngle}(\alpha, \alpha_{prev}, \delta) = \begin{cases} \delta\alpha + (1-\delta)\alpha_{prev} & , |\alpha - \alpha_{prev}| \leq \pi \\ \delta\alpha + (1-\delta)(\alpha_{prev} + 2\pi) & , \alpha - \alpha_{prev} > \pi \\ \delta(\alpha + 2\pi) + (1-\delta)\alpha_{prev} & , \alpha - \alpha_{prev} < -\pi \end{cases} \bmod 2\pi$$

and

$$\delta(l) = \begin{cases} (t(l)+1)/128 & , l = 0 \\ (t(l)-t(l-1))/128 & , l > 0 \end{cases}$$

Smoothing can be disabled by the encoder using the **bsOPDSmoothingMode** flag or shall be disabled by the decoder if the IPD resulting from the smoothed phase correction angles deviates from the transmitted IPD by more than a defined threshold, as shown here:

$$\tilde{\theta}_x^{l,m} = \begin{cases} \theta_x^{l,m}, (bsOPDSmoothingMode=0) \wedge (|\Delta IPD^{l,m}| > \vartheta) \\ \hat{\theta}_x^{l,m}, \text{else} \end{cases}$$

where

$$\vartheta = \begin{cases} \frac{50}{180}\pi & bsQuantCoarseIPD = 1 \\ \frac{25}{180}\pi & bsQuantCoarseIPD = 0 \end{cases}$$

and $\Delta IPD^{l,m}$ is the difference between the transmitted IPD and the IPD resulting from the smoothed angles, normalized to a range of $\pm \pi$:

$$\Delta IPD^{l,m} = \left(IPD^{l,m} - \left(\hat{\theta}_1^{l,m} - \hat{\theta}_2^{l,m} \right) + \pi \right) \bmod 2\pi - \pi$$

To obtain the phase correction angles for all time slots, a linear interpolation with unwrapping is performed:

$$\bar{\theta}_x^{n,m} = \begin{cases} (1 - \alpha(n, l)) \tilde{\theta}_x^{l-1,m} + \alpha(n, l) \tilde{\theta}_x^{l,m} & , \left| \tilde{\theta}_x^{l,m} - \tilde{\theta}_x^{l-1,m} \right| \leq \pi \\ (1 - \alpha(n, l)) \left(\tilde{\theta}_x^{l-1,m} + 2\pi \right) + \alpha(n, l) \tilde{\theta}_x^{l,m} & , \tilde{\theta}_x^{l,m} - \tilde{\theta}_x^{l-1,m} > \pi \\ (1 - \alpha(n, l)) \tilde{\theta}_x^{l-1,m} + \alpha(n, l) \left(\tilde{\theta}_x^{l,m} + 2\pi \right) & , \tilde{\theta}_x^{l,m} - \tilde{\theta}_x^{l-1,m} < -\pi \end{cases}$$

The phase synthesis is applied by modifying the mix-matrix M2 as follows:

$$\tilde{\mathbf{M}}_2^{n,k} = \begin{bmatrix} e^{j\bar{\theta}_1^{n,k}} & 0 \\ 0 & e^{j\bar{\theta}_2^{n,k}} \end{bmatrix} \begin{bmatrix} M_{11}^{n,k} & M_{12}^{n,k} \\ M_{21}^{n,k} & M_{22}^{n,k} \end{bmatrix}$$

7.11.2.3.4 Upmix with prediction-based IPD coding

If **bsResidualCoding** == 1, the matrix $R_2^{l,m}$ is defined as follows (where, if **bsPhaseCoding** == 1, the transmitted $IPD^{l,m}$ values are used, and where, if **bsPhaseCoding** == 0, the value $IPD = 0$ is used for all parameter sets l and processing bands m):

$$R_2^{l,m} = \begin{bmatrix} H11_{OTT}^{l,m} & H12_{OTT}^{l,m} \\ H21_{OTT}^{l,m} & H22_{OTT}^{l,m} \end{bmatrix} = \begin{cases} \frac{1}{2c^{l,m}} \begin{bmatrix} 1 - \alpha^{l,m} & 1 \\ 1 + \alpha^{l,m} & -1 \end{bmatrix} & , m < resBands \\ \frac{1}{2c^{l,m}} \begin{bmatrix} 1 - \alpha^{l,m} & \beta^{l,m} \\ 1 + \alpha^{l,m} & -\beta^{l,m} \end{bmatrix} & , \text{otherwise} \end{cases}$$

where

$$c^{l,m} = \min \left(\sqrt{\frac{CLD_{lin}^{l,m} + 1}{CLD_{lin}^{l,m} + 1 + 2 \cdot ICC^{l,m} \cdot \cos(IPD^{l,m}) \cdot \sqrt{CLD_{lin}^{l,m}}}}, 1.2 \right),$$

$$\alpha^{l,m} = \frac{1 - CLD_{lin}^{l,m} - 2j \cdot \sin(IPD^{l,m}) \cdot ICC^{l,m} \cdot \sqrt{CLD_{lin}^{l,m}}}{CLD_{lin}^{l,m} + 1 + 2 \cdot ICC^{l,m} \cdot \cos(IPD^{l,m}) \cdot \sqrt{CLD_{lin}^{l,m}}},$$

$$\beta^{l,m} = \frac{2 \cdot \sqrt{CLD_{lin}^{l,m} \cdot \left(1 - \left(ICC^{l,m} \right)^2 \right)}}{CLD_{lin}^{l,m} + 1 + 2 \cdot \cos(IPD^{l,m}) \cdot ICC^{l,m} \cdot \sqrt{CLD_{lin}^{l,m}}},$$

using

$$CLD_{lin}^{l,m} = 10^{\frac{CLD^{l,m}}{10}}.$$

It is noted that *resBands* refers to the value of *bsResidualBands*, i.e., the number of MPS parameter bands where residual coding is used.

In case $CLD_{lin}^{l,m}=1$, $ICC^{l,m}=1$ and $IPD^{l,m}=\pi$:

$$R_2^{l,m} = \begin{cases} \frac{1}{2c_{clip}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} & , m < resBands \\ \frac{1}{2c_{clip}} \begin{bmatrix} 1 & 0 \\ -1 & 0 \end{bmatrix} & , otherwise \end{cases}.$$

where $c_{clip}=1.2$

7.11.2.4 Transient steering decorrelator (TSD)

The decorrelator block **D** in the OTT decoding block (Figure 20) consists of a signal separator, two decorrelator structures, and a signal combiner as shown in Figure 22.

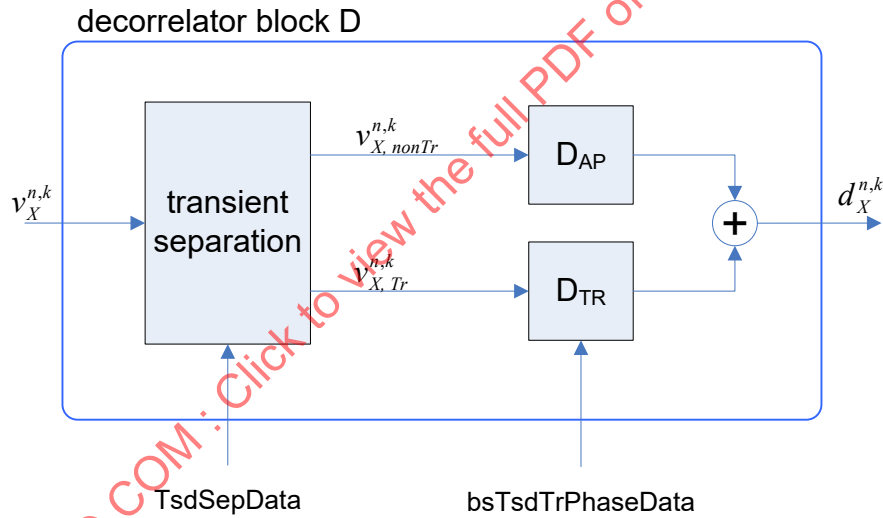


Figure 22 — Transient steering decorrelator block D

where

D_{AP} : all-pass decorrelator as defined in 7.11.2.5.

D_{TR} : Transient decorrelator.

If the TSD tool is active in the current frame, i.e., if (*bsTsdEnable*==1), the input signal is separated into a transient stream $v_{X,Tr}^{n,k}$ and a non-transient stream $v_{X,nonTr}^{n,k}$ according to:

$$v_{X,Tr}^{n,k} = \begin{cases} v_X^{n,k} & , \text{ if } TsdSepData(n) = 1, 7 \leq k \\ 0 & , \text{ otherwise} \end{cases}$$

$$v_{X,nonTr}^{n,k} = \begin{cases} 0 & , \text{ if } TsdSepData(n)=1, 7 \leq k \\ v_X^{n,k} & , \text{ otherwise} \end{cases}$$

The per-slot transient separation flag $TsdSepData(n)$ is decoded from the variable length code word **bsTsdCodedPos** by $TsdTrPos_dec()$ as described below. The code word length of **bsTsdCodedPos**, i.e., $nBitsTsdCW$, is calculated according to:

$$nBitsTsdCW = \text{ceil} \left(\log_2 \left(\frac{\text{numSlots}}{\text{bsTsdNumTrSlots} + 1} \right) \right)$$

Decoding of the TSD transient slot separation data **bsTsdCodedPos** into $TsdSepData(n)$, an array of length **numSlots** consisting of '1's for coded transient positions and '0's otherwise, is defined as follows:

Position decoding function $TsdTrPos_dec(bsTsdCodedPos)$:

```
s = bsTsdCodedPos;
p = bsTsdNumTrSlots+1;
N = numSlots;

for (k=0; k<N; k++)
{
    TsdSepData[k]=0;
}
for (k=N-1; k>=0; k--)
{
    if (p > k) {
        for (;k>=0; k--)
            TsdSepData[k]=1;
        break;
    }
    c = k-p+1;
    for (h=2; h<=p; h++) {
        c *= k - p + h;
        c /= h;
    }
    if (s >= (int)c) { /* c is long long for up to 32 slots */
        s -= c;
        TsdSepData[k]=1;
        p--;
        if (p == 0)
            break;
    }
}
```

If the TSD tool is disabled in the current frame, i.e., if $(bsTsdEnable==0)$, the input signal is processed as if $TsdSepData(n)=0$ for all n .

Transient signal components are processed in a transient decorrelator structure D_{TR} as follows:

$$d_{X,Tr}^{n,k} = \begin{cases} e^{j\phi_{TSD}^n} \cdot v_{X,Tr}^{n,k} & , \text{ if } bsTsdEnable=1 \\ 0 & , \text{ otherwise} \end{cases},$$

where

$$\phi_{TSD}^n = \pi \cdot 0.25 \cdot bsTsdTrPhaseData(n).$$

The non-transient signal components are processed in all-pass decorrelator D_{AP} as defined in 7.11.2.5, yielding the decorrelator output for non-transient signal components,

$$d_{X,nonTr}^{n,k} = D_{AP} \{ v_{X,nonTr}^{n,k} \}.$$

The decorrelator outputs are added to form the decorrelated signal containing both transient and non-transient components,

$$d_X^{n,k} = d_{X,Tr}^{n,k} + d_{X,nonTr}^{n,k}.$$

7.11.2.5 All-pass decorrelator

7.11.2.5.1 General

As described in ISO/IEC 23003-1:2007, 6.6, the de-correlation filters consist of a frequency-dependent pre-delay followed by all-pass (IIR) sections.

For the 2-1-2 configuration, the frequency axis is divided into up to four different regions according to *bsDecorrConfig* but only one decorrelator is used, $X = 0$.

In each frequency region the length of the delay is defined as:

$$d_{X,delay}^{n,k} = \begin{cases} v_X^{n-11,k} & , k \in k_0 \\ v_X^{n-10,k} & , k \in k_1 \\ v_X^{n-5,k} & , k \in k_2 \\ v_X^{n-2,k} & , k \in k_3 \end{cases}$$

The delayed hybrid subband domain samples are then filtered according to ISO/IEC 23003-1:2007, 6.6.2, using the following lattice coefficients:

- For region k_0 , the length of the coefficient vector is given by $L = 10$, and the lattice coefficients $l_{X,0}^n$ are defined according to Table 141.
- For region k_1 , the length of the coefficient vector is given by $L = 8$, and the lattice coefficients $l_{X,1}^n$ are defined according to Table 142.
- For region k_2 , the length of the coefficient vector is given by $L = 3$, and the lattice coefficients $l_{X,2}^n$ are defined according to Table 143.
- For region k_3 , the length of the coefficient vector is given by $L = 2$, and the lattice coefficients $l_{X,3}^n$ are defined according to Table 144.

Table 141 — Lattice coefficients $l_{X,0}^n$ for region k_0

	lattice coefficients for region k_0
0	-0.6135
1	-0.3819
2	-0.2331
3	-0.1467
4	-0.0074
5	0.0281
6	0.1061
7	-0.2914
8	0.1576
9	0.0898

Table 142 — Lattice coefficients $l_{X,1}^n$ for region k_1

	lattice coefficients for region k_1
0	-0.2874
1	-0.0732
2	0.1000
3	-0.1121
4	0.0822
5	0.0202
6	-0.0521
7	-0.1221

Table 143 — Lattice coefficients $l_{X,2}^n$ for region k_2

	lattice coefficients for region k_2
0	0.1358
1	-0.0373
2	0.0357

Table 144 — Lattice coefficients $l_{X,3}^n$ for region k_3

	lattice coefficients for region k_3
0	0.0352
1	-0.0130

7.11.2.5.2 Fractional delay decorrelator

The use of fractional delay in the decorrelator is optional. The filter coefficients are derived from the lattice coefficients in a different manner depending on whether fractional delay is used or not. For a fractional delay decorrelator, a fractional delay is applied by adding a frequency dependent phase-offset to the lattice coefficients.

The lattice coefficients $\phi_X^{n,k}$ are calculated as shown in Table 145 with q^k and phase coefficients ϕ_X^n as defined in ISO/IEC 23003-1:2007, Table 92 and Table A.30 respectively.

Table 145 — Calculation of lattice coefficients

k	Normal decorrelator	Fractional delay decorrelator	n
k_0	$\phi_X^{n,k} = l_{X,0}^n$	$\phi_X^{n,k} = \exp\left(\frac{j}{2} \cdot \phi_X^n \cdot q^k\right) \cdot l_{X,0}^n$	0,...,9
k_1	$\phi_X^{n,k} = l_{X,1}^n$	$\phi_X^{n,k} = \exp\left(\frac{j}{2} \cdot \phi_X^n \cdot q^k\right) \cdot l_{X,1}^n$	0,...,7
k_2	$\phi_X^{n,k} = l_{X,2}^n$	$\phi_X^{n,k} = \exp\left(\frac{j}{2} \cdot \phi_X^n \cdot q^k\right) \cdot l_{X,2}^n$	0,1,2
k_3	$\phi_X^{n,k} = l_{X,3}^n$	$\phi_X^{n,k} = \exp\left(\frac{j}{2} \cdot \phi_X^n \cdot q^k\right) \cdot l_{X,3}^n$	0,1

7.11.2.6 Modification of core decoder output

If **bsResidualCoding** == 1 and **bsPseudoLr** == 1, the time domain output from the decoded CPE is rotated into the DMX/RES domain using a mid/side transform prior to any SBR or MPS processing block as described by the following equation.

$$\begin{bmatrix} CPE_{left} \\ CPE_{right} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \times \begin{bmatrix} CPE_{left} \\ CPE_{right} \end{bmatrix}$$

7.11.2.7 SBR decoding

If **bsResidualCoding** == 0, mono SBR decoding is invoked prior to MPS decoding (as shown in Figure 23). The DMX input of the MPS decoder is fed by the 64 QMF band output from the SBR decoder.

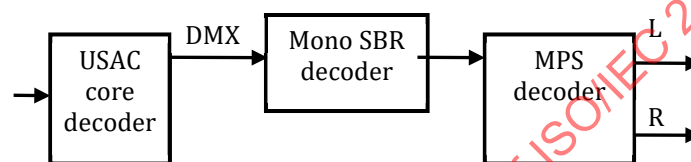


Figure 23 — **bsResidualCoding** == 0

If **bsResidualCoding** == 1 and **bsStereoSbr** == 0, mono SBR decoding is invoked prior to MPS decoding (as shown in Figure 24). The DMX input to the MPS decoder is fed by the 64 QMF band output from the SBR decoder. The RES input to the MPS decoder is fed by the 32 (16, 24, depending on **sbrRatioIndex**) QMF band analysis of the RES output from the core decoder, with the upper 32 (resp. 48, 40) QMF bands set to zero (as described in ISO/IEC 23003-1:2007, 6.3.3 for downsampled MPS decoder operation).

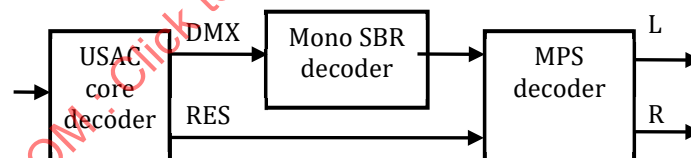


Figure 24 — **bsResidualCoding** == 1, **bsStereoSbr** == 0

If **bsResidualCoding** == 1 and **bsStereoSbr** == 1, MPS decoding is invoked prior to stereo SBR decoding (as shown in Figure 25), so that SBR is applied to the left/right stereo signal. It is noted that this implies a different synchronization between the core signal and the SBR data as compared to the situation when **bsStereoSbr** == 0, due to the 384 samples delay of the hybrid analysis filterbank in the MPS decoder which cannot share the 6 QMF sample look-ahead with the SBR decoder in this configuration. The MPS decoder is fed by the 32 (16, 24, depending on **sbrRatioIndex**) QMF band analysis of the output of the core decoder, with the upper 32 (resp. 48, 40) QMF bands set to zero (as described in ISO/IEC 23003-1:2007, 6.3.3 for downsampled MPS decoder operation).

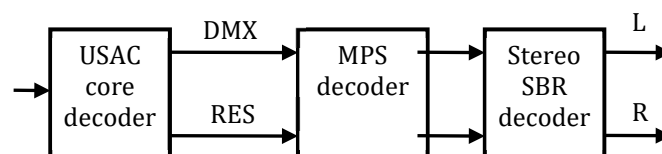


Figure 25 — **bsResidualCoding** == 1, **bsStereoSbr** == 1

MPS212 decoding in USAC is always done in combination with SBR decoding, using one of the three configurations shown above. The output of this combined MPS212 and SBR decoding is always a 64 QMF band representation of the stereo output signal, independent from the output sampling frequency of the USAC decoder.

7.12 AVQ decoding

Algebraic vector quantization (AVQ) is used to quantize two sets of parameters in LPD mode: the coefficients of the LPC filter (in the form of ISFs) and the DCT coefficients in the FAC correction at the junction between an ACELP frame and an MDCT frame. AVQ quantizes blocks (or vectors) of 8 dimensions. So in LPC quantization, two 8-dimensional blocks are quantized since the LPC filter has order 16. Alternatively, when applied to quantize the FAC correction, the number of 8-dimensional blocks of DCT coefficients quantized with AVQ depends on the size of the FAC window. Before looking at the decoding steps we will first give some definitions.

The quantizer used in the AVQ tool is based on the rotated Gosset lattice denoted by RE_8 , a regular arrangement of points in 8 dimensions. The RE_8 lattice is defined as follows:

$$RE_8 = 2D_8 \cup \{2D + (1,1,1,1,1,1,1,1)\}$$

where D_8 is the 8-dimensional lattice with integer components whose sum is even (or equal to 0 modulo 2). Hence, $2D_8$ is populated by 8-dimensional vectors with integer components whose sum is 0 modulo 4. Also, lattice $2D_8 + (1,1,1,1,1,1,1,1)$ is simply $2D_8$ shifted by vector $(1,1,1,1,1,1,1,1)$. So RE_8 is the union of all points in $2D_8$ and in $2D_8 + (1,1,1,1,1,1,1,1)$. Two example vectors in RE_8 are $(1,1,-1,1,1,-1,-1,-1)$ and $(0,2,0,0,0,0,0,2)$.

Points in a lattice can be generated using the generator matrix for that lattice. For a lattice in n dimensions, the generator matrix is an $n \times n$ matrix. The generator matrix of lattice RE_8 is given by:

$$G = \begin{bmatrix} 4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 2 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 2 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 2 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 2 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

If k is an 8-dimensional line vector with integer components, then the matrix product kG is a lattice point in RE_8 . For example, using $k = (1,0,0,0,0,0,0,0)$, we get $c = kG = (4,0,0,0,0,0,0,0)$ which satisfies $\text{sum}(k * G) = 0$ modulo 4 so it is a point in the lattice. Or if $k = (1,0,0,0,0,0,0,-1)$, then $c = kG = (3,-1,-1,-1,-1,-1,-1,-1)$ which is also a point in lattice RE_8 . And so on.

Any lattice as the RE_8 lattice has an infinite number of lattice points which theoretically extend to infinity in all dimensions of the lattice. In the AVQ tool of USAC, to form codebooks with finite rate usable for vector quantization, the lattice is spherically limited and embedded in four so-called base codebooks: Q_0 , Q_2 , Q_3 and Q_4 . Q_0 has only one entry (0-bit codebook) which is the origin vector $(0,0,0,0,0,0,0,0)$ to indicate that the vector is not quantized. Q_2 is the smallest codebook covering 256 vectors (8 bits) around the origin (Q_0). Q_3 is a larger codebook with 4096 vectors (12 bits) and is embedded with Q_2 meaning that Q_2 is a subset of Q_3 . Q_4 is the biggest codebook covering 65536 vectors (16 bits) and is not embedded with Q_3 meaning that Q_4 and Q_3 together cover all the base codebook space. Hence, a base codebook Q_n is a $4n$ bit codebook, that is Q_n comprises exactly 2^{4n} lattice vectors. Note that in the AVQ there is no Q_1 (considered not optimal). Instead of adding many codebooks to cover a wide range of subsets in RE_8 , an additional algebraic quantization is used as an extension of Q_3 or Q_4 . This

additional quantization, scalable with steps of 8 bits, replaces Q_5 , Q_7 and so on up to Q_{35} when used on top of Q_3 and Q_6 , Q_8 and so on up to Q_{36} when used on top of Q_4 . The extension, called Voronoi extension, is explained below.

According to the properties of RE_8 , it can be shown that all points of the lattice lie on a succession of concentric spheres with specific radii. As an example, two such concentric spheres are drawn in Figure 26 below using a 2-dimensional codebook for illustration.

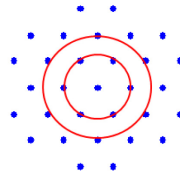


Figure 26 — Concentric spheres in a 2-dimensional AVQ codebook illustration

Obviously, all lattice points on one of those concentric spheres have the same length. Since permutations of the components of a given vector produce other vectors of same length, all permutations of some lattice point lie on the same sphere. This gives rise to the notion of *leader*, a central concept used for enumerating (and thus transmitting) the lattice points in the base codebooks, and thus used in the AVQ tool. A leader is defined as an 8-dimensional vector which is part of the lattice and whose components are sorted in descending order of magnitude. There will be two kinds of leaders: absolute leaders, with all components positive or zero, and signed leaders, with components also taking positive and negative sign. To take an example, $(2,2,0,0,0,0,0,0)$ and $(1,1,1,1,1,1,1,1)$ are the two absolute leaders on the first sphere of the lattice. Furthermore, there are 3 signed leaders corresponding to the absolute leader $(2,2,0,0,0,0,0,0)$, namely $(2,2,0,0,0,0,0,0)$, $(2,0,0,0,0,0,0,-2)$ and $(0,0,0,0,0,0,-2,-2)$. And there are 5 signed leaders corresponding to the absolute leader $(1,1,1,1,1,1,1,1)$, namely $(1,1,1,1,1,1,1,1)$, $(1,1,1,1,1,1,-1,-1)$, $(1,1,1,1,-1,-1,-1,-1)$, $(1,1,-1,-1,-1,-1,-1,-1)$ and $(-1,-1,-1,-1,-1,-1,-1,-1)$. It can be verified, with the definitions given above, that any permutation of these signed leaders is a point in the lattice RE_8 .

Decoding a vector in one of the base codebooks will thus require determining, from the received parameters in the bitstream, the identity of the codebook (Q_2 , Q_3 or Q_4) and then the absolute and signed leader and finally the permutation of the signed leader components to provide the identity of the lattice point selected at the encoder.

Through adaptive bit allocation, the encoder can select larger or smaller lattice codebooks to encode a given 8-dimensional block of coefficients. The spherical enumeration and leader concept could be used to construct even larger codebooks than the base codebooks Q_2 , Q_3 and Q_4 . However, beyond these base codebooks a technique called the *Voronoi extension* is applied. Suppose that a vector x had to be quantized, and that x lied outside the largest base codebook as shown here in red (in Figure 27, the Voronoi or nearest-neighbour regions around each lattice point in the base codebook are shown):

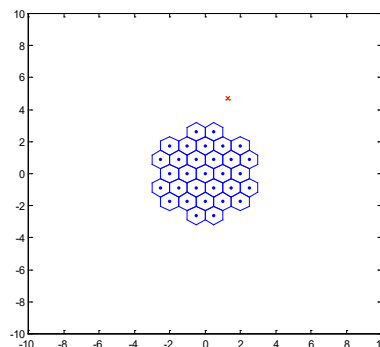


Figure 27 — Vector x lies outside of the largest base codebook

Then, to allow quantization of vector x , the base codebook is first scaled up by a factor of m , like in Figure 28, with a scale factor of 2.

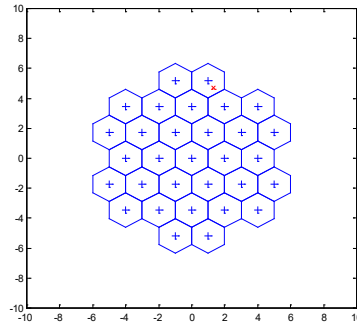


Figure 28 — Scaled base codebook with vector x falling within the codebook space

Now vector x lies “inside” the base codebook (actually inside the Voronoi region of one of the vectors of the scaled base codebook). However the Voronoi regions have been enlarged so the expanded region will now cover more than one lattice point, in the case of RE_g , the Voronoi region will cover $16^m=256$ points and use $4m=8$ bits for a scale factor of $m = 2$. Then, each time a base codebook is enlarged by a factor of two, the Voronoi region needs 8 additional bits in order to cover all RE_g lattice points inside the codebook. Also, because of the regular structure of the lattice, the Voronoi extension retains the lattice structure. That is, the extended codebook points and the additional codebook points from the Voronoi extension are all lattice points in RE_g .

To decode the lattice point nearest to vector x selected at the encoder, the decoder will require to determine, from the received parameters in the bitstream, the identity of the base codebook (Q_2 , Q_3 or Q_4), then the scaling factor m for the base codebook (if the Voronoi extension is used), then the decoded point c in the base codebook (with the leader and permutation technique discussed above), and finally the vector from the Voronoi extension codebook, v . The decoded lattice point will then be obtained as:

$$B = m c + v$$

Hence, the description of any lattice point using the Voronoi extension method uses two components, one from the scaled base codebook and the other from the Voronoi extension. Otherwise, when no Voronoi extension is applied, a lattice point is simply described as vector c , an element in one of the (unscaled) based codebooks Q_0 , Q_2 , Q_3 or Q_4 (with Q_0 used only to indicate the all zero vector).

With these definitions we can now turn to the actual decoding steps for the AVQ tool.

For each 8-dimensional block of coefficients quantized with the AVQ tool, three parameters are received at the decoder:

- a codebook number qn ;
- a vector index I ;
- and possibly a Voronoi extension index k , depending on the value of qn (if $qn > 4$, a Voronoi index k is received for the 8-dimensional block encoded, otherwise only the codebook number qn and the vector index I are received and used for decoding that block of coefficients).

If $qn \leq 4$ (i.e., if no Voronoi extension index k is received) then decoding indices qn and I will produce an 8-dimensional block of coefficients $B = c$. Otherwise, if $qn > 4$, then decoding qn , I and k will produce an 8-dimensional block of coefficients $B = m c + v$. The significance of m , y and v is as described above.

In a first step, if $qn = 0$ then $c = (0,0,0,0,0,0,0,0)$ that is the decoded 8-dimensional block of coefficients is set to 0 in all its components. In this case, the following decoding steps are not applied.

The scaling factor m is obtained as follows:

- if $qn \leq 4$, no scaling factor is used (no Voronoi extension, use only base codebook c);
- if $qn > 4$, $m = 2^r$ with exponent $r = 1$ when qn is in $\{5,6\}$, $r = 2$ when qn is in $\{7,8\}$, $r = 3$ when qn is in $\{9,10\}$, and so on up to $r = 16$ when qn is in $\{35,36\}$.

Hence the scaling factors for the Voronoi extension, when applied, are integer powers of 2.

Next we describe how the indices l and k are decoded to produce, respectively, the 8-dimensional vectors c (entry from base codebook) and v (Voronoi extension).

First, a base codebook index n and the level of the Voronoi extension are computed from the codebook index qn as follows:

- if $qn \leq 4$, then $n = qn$ and there is no Voronoi extension (k is not even present in the bitstream);
- if $qn > 4$, then $n = 3$ if qn is odd and $n = 4$ if qn is even (so only Q_3 or Q_4 is used as base codebook for the Voronoi extension).

Since qn is a positive integer (including 0 but excluding 1), the base codebook index n is in $\{0, 2, 3, 4\}$. To recall, each base codebook Q_n comprises 2^{4n} entries (lattice points). So Q_0 has 1 entry, namely the origin $[0,0,0,0,0,0,0,0]$ of the lattice. Q_2 has 256 entries (or 256 lattice points). Q_3 has 4096 entries and Q_4 has 65536 entries. Consequently, index l comprises $4n$ bits and uniquely identifies one lattice point in Q_n . Knowing the base codebook index n , the decoding of index l follows steps 1 to 6 below:

- 1) From the value of the received vector index l , determine the *absolute leader*. This absolute leader identification is done by comparing index l to the cardinality offset table for absolute leaders of base codebook Q_n . The absolute leader will be identified as the position in the cardinality offset table which has the closest and lesser or equal value to l . The cardinality offset table of base codebooks Q_2 and Q_3 is $I_3 = \{0, 128, 240, 256, 1376, 2400, 3744, 3856, 4080\}$ - Q_2 uses only a subset of these. The cardinality offset table of base codebook Q_4 is $I_4 = \{0, 1792, 5376, 5632, 12800, 21760, 22784, 31744, 38912, 45632, 52800, 53248, 57728, 60416, 61440, 61552, 62896, 63120, 64144, 64368, 64480, 64704, 64720, 64944, 65056, 65280, 65504, 65520\}$. So, for example, if $n = 3$ and index $l = 467$, the closest and lesser or equal value in the cardinality offset table I_3 is 256. Select the absolute leader "number 3", since the value 256 is at position 3 (starting counting at position 0) in the cardinality offset table.

- 2) Reconstruct the absolute leader by a table lookup in the absolute leader table Da:

Table 146 — Absolute leader table, Da

1	1	1	1	1	1	1	1
2	2	0	0	0	0	0	0
2	2	2	2	0	0	0	0
3	1	1	1	1	1	1	1
4	0	0	0	0	0	0	0
2	2	2	2	2	2	0	0
3	3	1	1	1	1	1	1
4	2	2	0	0	0	0	0
2	2	2	2	2	2	2	2
3	3	3	1	1	1	1	1
4	2	2	2	2	0	0	0
4	4	0	0	0	0	0	0
5	1	1	1	1	1	1	1
3	3	3	3	1	1	1	1
4	2	2	2	2	2	2	0
4	4	2	2	0	0	0	0
5	3	1	1	1	1	1	1
6	2	0	0	0	0	0	0
4	4	4	0	0	0	0	0
6	2	2	2	0	0	0	0
6	4	2	0	0	0	0	0
7	1	1	1	1	1	1	1
8	0	0	0	0	0	0	0
6	6	0	0	0	0	0	0
8	2	2	0	0	0	0	0
8	4	0	0	0	0	0	0
9	1	1	1	1	1	1	1
10	2	0	0	0	0	0	0
8	8	0	0	0	0	0	0
10	6	0	0	0	0	0	0
12	0	0	0	0	0	0	0
12	4	0	0	0	0	0	0
10	10	0	0	0	0	0	0
14	2	0	0	0	0	0	0
12	8	0	0	0	0	0	0
16	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0

Each line in table Da contains the 8 components of an absolute leader.

For example, if in step 1 the absolute leader “number 3” is selected, then reconstructing the absolute leader means selecting the third line of table Da, namely the 8-dimensional vector $y_a = [2, 2, 2, 2, 0, 0, 0, 0]$.

- 3) Search for the identifier of the signed leader by comparing index I to the cardinality offset table of signed leaders I_s given below (table I_s is a 1-dimensional table). The signed leader will be identified as the position in table I_s which has the closest and lesser or equal value to I .

Is = {
 0, 1, 29, 99, 127, 128, 156, 212,
 256, 326, 606, 1026, 1306, 1376, 1432, 1712,
 1880, 1888, 1896, 2064, 2344, 240, 248, 0,
 28, 196, 616, 1176, 1596, 1764, 1792, 1820,
 2240, 2660, 2688, 3024, 4144, 4480, 4508, 4928,
 5348, 2400, 2568, 2904, 3072, 3240, 3576, 5376,
 5377, 5385, 5413, 5469, 5539, 5595, 5623, 5631,
 5632, 5912, 6472, 6528, 6696, 8376, 9216, 10056,
 11736, 11904, 11960, 12520, 12800, 13080, 14200, 15880,
 17000, 17280, 17560, 18680, 20360, 21480, 3744, 3772,
 3828, 21760, 21768, 21936, 22216, 22272, 22328, 22608,
 22776, 22784, 22854, 23274, 23344, 24464, 25584, 26004,
 28524, 28944, 30064, 31184, 31254, 31674, 31744, 31800,
 32136, 32976, 34096, 34936, 35272, 35328, 35384, 35720,
 36560, 37680, 38520, 38856, 38912, 39332, 40172, 40592,
 41432, 43112, 43952, 44372, 45212, 45632, 45968, 47088,
 47424, 47480, 48320, 49160, 49216, 49272, 50112, 50952,
 51008, 51344, 52464, 3856, 3912, 3968, 4024, 52800,
 52856, 53024, 53192, 53248, 53528, 54368, 55208, 55488,
 55768, 56608, 57448, 57728, 58064, 58400, 58736, 59072,
 59408, 59744, 60080, 60416, 60472, 60752, 60920, 60928,
 60936, 61104, 61384, 4080, 4088, 61440, 61468, 61524,
 61552, 61720, 62056, 62224, 62392, 62728, 62896, 62952,
 63008, 63064, 63120, 63128, 63296, 63576, 63632, 63688,
 63968, 64136, 64144, 64200, 64256, 64312, 64368, 64396,
 64452, 64480, 64536, 64592, 64648, 64704, 64712, 64720,
 64776, 64832, 64888, 64944, 64972, 65028, 65056, 65112,
 65168, 65224, 65280, 65336, 65392, 65448, 65504, 65512,
 65520, 65528};

So taking again the example in Step 1 where codebook number $n = 3$ and vector index $I = 467$, the closest and lesser or equal entry in table Is is 326. This value of 326 is at position 9 in table Is . To know which signed leader this corresponds to, it is required to know which absolute leaders, in order, are used to populate codebook Q_n , and to look at both Da and Is tables. Table $A3 = \{0, 1, 4, 2, 3, 7, 11, 17, 22\}$ indicates the position of the absolute leaders from table Da to populate codebook Q_3 . And table $A4 = \{5, 6, 8, 9, 10, 12, 13, 14, 15, 16, 18, 19, 20, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36\}$ indicates the position of the absolute leaders from table Da to populate codebook Q_4 . So, to continue with the example using $n = 3$ and index $I = 467$, the first absolute leader is $[1, 1, 1, 1, 1, 1, 1]$, which has five signed leaders as given above. These first five signed leaders map to the values 1, 29, 99, 127 and 128 respectively in table Is . We continue in table Is up to the 9th element (with value 326). So, according to table $A3$, the next absolute leader in Q_3 is $[3, 1, 1, 1, 1, 1, 1]$, which has 8 signed leaders: $[3, 1, 1, 1, 1, 1, -1]$, $[3, 1, 1, 1, 1, -1, -1]$, $[3, 1, 1, -1, -1, -1, -1]$, $[3, -1, -1, -1, -1, -1, -1]$, $[1, 1, 1, 1, 1, 1, -3]$, $[1, 1, 1, 1, 1, -1, -3]$ and $[1, 1, 1, -1, -1, -1, -3]$ and $[1, -1, -1, -1, -1, 1, -3]$. These eight signed leaders map to the next 8 values in table Is , namely 156, 212, 256, 326, 606, 1026, 1306 and 1376. Advance to the ninth position in table Is and thus to the ninth signed leader forming codebook Q_3 , then pick the fourth of these signed leaders, that is vector $[3, -1, -1, -1, -1, -1, 1]$. It is a specific permutation of the elements of this signed leader that will form the decoded lattice vector y (see Step 5).

- 4) Calculate the rank of the permutation, obtained as the difference between the received vector index I and the value in table Is closest (but lesser or equal) to I . So, for example, if the received index was $I = 467$, then its closest (and lesser) value in table Is is 326 and therefore the rank of the permutation (for the signed leader identified in step 3) is $467 - 326 = 101$. The rank of permutation can take any value between 0 and $P_{total} - 1$ where P_{total} is the total number of different permutations for the signed leader selected in step 3.
- 5) Using the selected signed leader from Step 3 and the *rank* of permutation from Step 4, apply the proper permutation to the elements of the signed leader to obtain the decoded lattice vector c from the base codebook. To do this, the elements of the signed leader are seen as forming an alphabet. So first, the number q of different symbols in the alphabet is computed, along with the number of occurrences of each symbol in the signed leader. For example, for the signed leader $[3, -1, -1, -1, -1, -1, 1]$ we have $q = 2$, $a = [3, -1]$ and $w = [1, 7]$, where vector a contains the alphabet and vector w contains the number of occurrences

of each element of a in the signed leader. The product B of the elements in vector w is also calculated. So, taking the same example as above, $B = 1 \cdot 7 = 7$. If $q = 1$ then the signed leader is actually the decoded lattice point (since all elements of the signed leader are equal). Otherwise, the following algorithm is applied to position each element of alphabet a into proper position (i.e., apply the correct permutation to the signed leader):

- Set $\text{target} = \text{rank} \cdot B$;
- Set $\text{fac_B} = 1$;
- For i going from 0 to 7 inclusively do the following:
 - $\text{fac} = \text{fac_B} \cdot (7-i)!$;
 - $j = -1$;
 - iteratively increment j by 1 and remove the value $\text{fac} \cdot w[j]$ from target as long as target is positive or 0;
 - set element $c[i] = a[j]$;
 - increment target by $\text{fac} \cdot w[j]$;
 - multiply fac_B by $w[j]$;
 - decrement $w[j]$ by 1.

At the end of this loop, the 8-dimensional vector c contains the properly permuted elements of the signed leader to form the desired decoded base codebook vector.

- 6) One last step is required if a Voronoi index k was also received (recall that this happens only if the codebook index $qn > 4$). The Voronoi index k is actually a set of 8 integers (it can be seen as an 8-dimensional vector of integers), all in the range $0..m-1$ where $m = 2^r$ is the Voronoi extension scaling factor. The exponent $r = 1$ when qn is in $\{5,6\}$, $r = 2$ when qn is in $\{7,8\}$, $r = 3$ when qn is in $\{9,10\}$, and so on up to $r = 16$ when qn is in $\{35,36\}$. Upon receiving the Voronoi index k , or actually the 8 integers in vector k , and knowing the scaling factor m , decoding the Voronoi extension requires applying the following four substeps:

- Decode the lattice point corresponding to k using the generator matrix, i.e., calculate vector $v = k \cdot G$ where k is the 8-dimensional line vector containing the Voronoi extension indices and G is the generator matrix of the RE_8 lattice.
- Shift vector v by $a = (2,0,0,0,0,0,0,0)$ and divide this shifted vector by the scaling factor m to produce vector $z = (v - a) / m$. Note that z will have integer components.
- Find the nearest neighbour of vector z in the RE_8 lattice. Call y this nearest neighbour. Because of the construction of lattice RE_8 , this nearest neighbour is either in $2D_8$ or in $2D_8 + (1,1,1,1,1,1,1,1)$.
- Remove $m \cdot y$ from v to produce the Voronoi extension vector. So $v = v - m \cdot y$ is the Voronoi extension vector.

The complete decoded lattice point for the 8-dimensional block of coefficients that was encoded using the AVQ tool is obtained as:

$$m \cdot c + v$$

recalling that the base codevector c was obtained in step 5.

7.13 LPC-filter

7.13.1 Tool description

In the ACELP mode, transmitted parameters include LPC filters, adaptive and fixed-codebook indices, adaptive and fixed-codebook gains. In the TCX mode, transmitted parameters include LPC filters, energy parameters, and quantization indices of MDCT coefficients. This subclause describes the decoding of the LPC filters.

7.13.2 Definition of elements

lpc_set	LPC coefficient set index which goes from 0 (LPC0) up to 4 (LPC4) correspondingly.
mode_lpc	Coding mode of the subsequent LPC parameters set.
qn[k]	Binary code associated with the corresponding codebook numbers n_k
lpc_first_approximation_index[lpc_set]	A vector index for the first approximation of LPC filter parameters of the LPC filter set lpc_set.
I	The rank I_k of a selected lattice point.
kv[lpc_set][k][8]	The AVQ refinement voronoi extension indices for LPC coefficient set lpc_set.

7.13.3 Number of LPC filters

The actual number of LPC filters nb_lpc which are encoded within the bitstream depends on the ACELP/TCX mode combination of the USAC frame. The ACELP/TCX mode combination is extracted from the field **lpc_mode** which in turn determines the coding modes, mod[k] for $k=0$ to 3, for each of the 4 subframes composing the USAC frame. The mode value is 0 for ACELP, 1 for short TCX ($coreCoderFrameLength/4$ samples), 2 for medium size TCX ($coreCoderFrameLength/2$ samples), 3 for long TCX ($coreCoderFrameLength$ samples). See also the definition of lpc_mode and mod[] in 6.2.10.2.

In addition to the 1 to 4 LPC filters of the superframe, an optional LPC0 is transmitted for the first super-frame of each segment encoded using the LPD core codec. This is indicated to the LPC decoding procedure by a flag first_lpd_flag set to 1. In case of first_lpd_flag==0, LPC0 shall be equal to LPC4 of the previous super frame.

The order in which the LPC filters are normally found in the bitstream is: LPC4, the optional LPC0, LPC2, LPC1, and LPC3. The condition for the presence of a given LPC filter within the bitstream is summarized in Table 147.

Table 147 — Condition for the presence of a given LPC filter in the bitstream

LPC filter	Present if
LPC0	first_lpd_flag=1
LPC1	mod[0]<2
LPC2	mod[2]<3
LPC3	mod[2]<2
LPC4	Always

The bitstream is parsed to extract the quantization indices corresponding to each of the LPC filters required by the ACELP/TCX mode combination. The following subclauses describes the operations needed to decode one of the LPC filters.

7.13.4 General principle of the inverse quantizer

Inverse quantization of an LPC filter is performed as described in Figure 29. The LPC filters are quantized using the line spectral frequency (LSF) representation. A first-stage approximation is computed as described in 7.13.6.

An optional algebraic vector quantized (AVQ) refinement is then calculated as described in 7.13.7. The quantized LSF vector is reconstructed by adding the first-stage approximation and the inverse-weighted AVQ contribution. The presence of an AVQ refinement depends on the actual quantization mode of the LPC filter, as explained in 7.13.5.

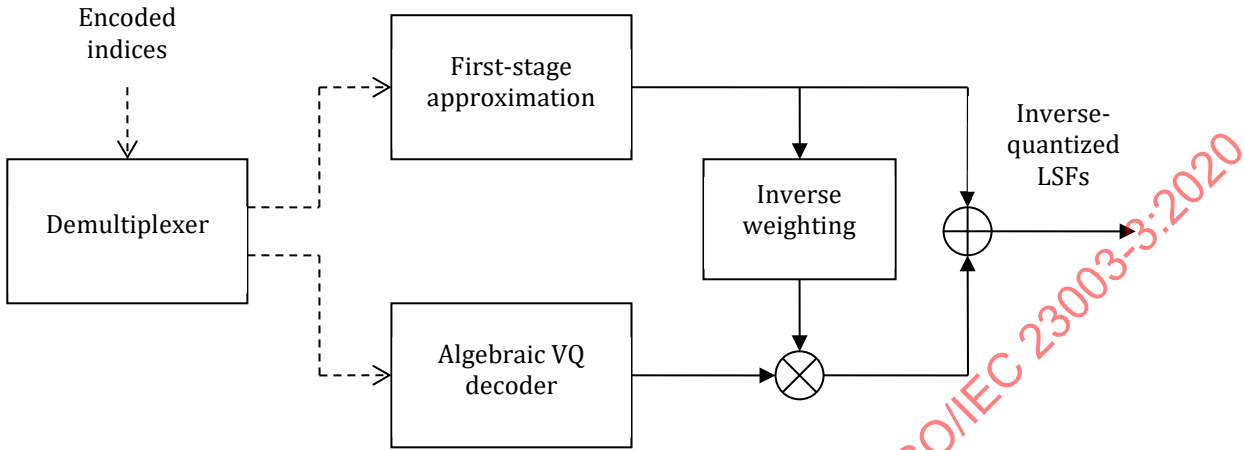


Figure 29 — Principle of the weighted algebraic LPC inverse quantizer

The inverse-quantized LSF vector is subsequently converted into a vector of LSP (line spectral pair) parameters, then interpolated and converted again into LPC parameters.

7.13.5 Decoding of the LPC quantization mode

LPC4 is always quantized using an absolute quantization approach. The other LPC filters can be quantized using either an absolute quantization approach, or one of several relative quantization approaches. For these LPC filters, the first information extracted from the bitstream is the quantization mode. This information is denoted **mode_lpc** and is signalled in the bitstream using a variable-length binary code as indicated in Table 148.

Table 148 — Possible absolute and relative quantization modes, corresponding bitstream signalling of mode_lpc and coding modes for codebook numbers n_k

Pos. in bitstream	Present if	Filter	Quantization mode	mode_lpc	Binary code	n_k mode
1.	always	LPC4	Absolute	0	(none)	0
2.	first_lpd_flag=1	LPC0	Absolute	0	0	0
			Relative to LPC4	1	1	3
3.	mod[2]<3	LPC2	Absolute	0	0	0
			Relative to LPC4	1	1	3
4.	mod[0]<2	LPC1	Absolute	0	10	0
			Relative to (LPC0+LPC2)/2 ^a	1	11	1
			Relative to LPC2	2	0	2
5.	mod[2]<2	LPC3	Absolute	0	10	0
			Relative to (LPC2+LPC4)/2	1	0	1
			Relative to LPC2	2	110	2
			Relative to LPC4	3	111	2

^a In this mode, there is no second-stage AVQ quantizer.

7.13.6 First-stage approximation

For each LPC filter, the quantization mode determines how the first-stage approximation of Figure 29 is computed.

For the absolute quantization mode (**mode_lpc**=0), an 8-bit index corresponding to a stochastic VQ-quantized first stage approximation is extracted from the bitstream. The first-stage approximation is then computed by a simple table look-up.

For relative quantization modes, the first-stage approximation is computed using already inverse-quantized LPC filters, as indicated in the fourth column of Table 148. For example, for LPC0 there is only one relative quantization mode for which the inverse-quantized LPC4 filter constitutes the first-stage approximation. For LPC1, there are two possible relative quantization modes, one where the inverse-quantized LPC2 constitutes the first-stage approximation, the other for which the average between the inverse-quantized LPC0 and LPC2 filters constitutes the first-stage approximation. As all other operations related to LPC quantization, computation of the first-stage approximation is done in the LSF domain.

7.13.7 AVQ refinement

7.13.7.1 General

The next information extracted from the bitstream is related to the AVQ refinement needed to build the inverse-quantized LSF vector. The only exception is for LPC1: the bitstream contains no AVQ refinement when this filter is encoded relatively to $(LPC0+LPC2)/2$.

The AVQ is based on an 8-dimensional RE_8 lattice vector quantizer. Decoding the LPC filters involves decoding the two 8-dimensional sub-vectors $\hat{B}_k$, $k=1$ and 2, of the weighted residual LSF vector.

The AVQ information for these two subvectors is extracted from the bitstream. It comprises two encoded codebook numbers **qn1** and **qn2**, and the corresponding AVQ indices. These parameters are decoded as follows.

7.13.7.2 Decoding of codebook numbers

The first parameters extracted from the bitstream in order to decode the AVQ refinement are the two codebook numbers n_k , $k=1$ and 2, for each of the two subvectors mentioned above. The way the codebook numbers are encoded depends on the LPC filter (LPC0 to LPC4) and on its quantization mode (absolute or relative). As shown in Table 148, there are four different ways to encode n_k . The details on the codes used for n_k are given below.

n_k modes 0 and 3:

The codebook number n_k is encoded as a variable length code **qn[k]**, as follows:

$Q_2 \rightarrow$ the code for n_k is 00

$Q_3 \rightarrow$ the code for n_k is 01

$Q_4 \rightarrow$ the code for n_k is 10

Others: the code for n_k is 11 followed by:

$Q_5 \rightarrow 0$

$Q_6 \rightarrow 10$

$Q_0 \rightarrow 110$

$Q_7 \rightarrow 1110$
 $Q_8 \rightarrow 11110$
 etc.

n_k mode 1:

The codebook number n_k is encoded as a unary code **qn[k]**, as follows:

$Q_0 \rightarrow$ unary code for n_k is 0
 $Q_2 \rightarrow$ unary code for n_k is 10
 $Q_3 \rightarrow$ unary code for n_k is 110
 $Q_4 \rightarrow$ unary code for n_k is 1110
 etc.

n_k mode 2:

The codebook number n_k is encoded as a variable length code **qn[k]**, as follows:

$Q_2 \rightarrow$ the code for n_k is 00
 $Q_3 \rightarrow$ the code for n_k is 01
 $Q_4 \rightarrow$ the code for n_k is 10

Others: the code for n_k is 11 followed by:

$Q_0 \rightarrow 0$
 $Q_5 \rightarrow 10$
 $Q_6 \rightarrow 110$
 etc.

7.13.7.3 Decoding of AVQ indices

Decoding the LPC filters involves decoding the AVQ parameters describing each 8-dimensional quantized sub-vector $\hat{B}_k$ of the weighted residual LSF vectors. AVQ decoding is described in detail in 7.12.

7.13.7.4 Computation of the LSF weights

At the encoder, the weights applied to the components of the residual LSF vector before AVQ quantization are:

$$w(i) = \frac{1}{W} * \frac{400}{\sqrt{d_i \cdot d_{i+1}}}, \quad i = 0..15$$

with:

$$\begin{aligned} d_0 &= LSF1st[0] \\ d_{16} &= SF / 2 - LSF1st[15] \\ d_i &= LSF1st[i] - LSF1st[i-1], i = 1..15 \end{aligned}$$

where LSF_{1st} is the 1st stage LSF approximation and W is a scaling factor which depends on the quantization mode (Table 149).

Table 149 — Normalization factor W for AVQ quantization

Filter	Quantization mode	W
LPC4	Absolute	60
LPC0	Absolute	60
	Relative LPC4	63
LPC2	Absolute	60
	Relative LPC4	63
LPC1	Absolute	60
	Relative (LPC0+LPC2)/2	65
	Relative LPC2	64
LPC3	Absolute	60
	Relative (LPC2+LPC4)/2	65
	Relative LPC2	64
	Relative LPC4	64

The corresponding inverse weighting shall be applied at the decoder to retrieve the quantized residual LSF vector.

7.13.7.5 Reconstruction of the inverse-quantized LSF vector

The inverse-quantized LSF vector is obtained by, first, concatenating the two AVQ refinement subvectors $\hat{B}_1$ and $\hat{B}_2$ decoded as explained in 7.13.7.2 and 7.13.7.3 to form one single weighted residual LSF vector, then, applying to this weighted residual LSF vector the inverse of the weights computed as explained in 7.13.7.4 to form the residual LSF vector, and then again, adding this residual LSF vector to the first-stage approximation computed as in 7.13.6.

7.13.8 Reordering of quantized LSFs

Inverse-quantized LSFs are reordered and a minimum distance between adjacent LSFs of 50 Hz is introduced before they are used.

7.13.9 Conversion into LSP parameters

The inverse quantization procedure described so far results in the set of LPC parameters in the LSF domain. The LSFs are then converted to the cosine domain (LSPs) using the relation $q_i = \cos(\omega_i)$, $i=1, \dots, 16$ with ω_i being the line spectral frequencies (LSF).

7.13.10 Interpolation of LSP parameters

For each ACELP frame, although only one LPC filter corresponding to the end of the frame is transmitted, linear interpolation is used to obtain a different filter in each subframe ($N_{sfr} = \text{coreCoderFrameLength}/256$ filters per ACELP frame). The interpolation is performed between the LPC filter corresponding to the end of the previous frame and the LPC filter corresponding to the end of the ACELP frame. Let $LSP^{(new)}$ be the new available LSP vector and $LSP^{(old)}$ the previously available LSP vector. The interpolated LSP vectors for the N_{sfr} subframes are given by:

$$LSP_i = \left(\frac{2N_{sfr} - 1}{2N_{sfr}} - \frac{i}{N_{sfr}} \right) LSP^{(old)} + \left(\frac{1}{2N_{sfr}} + \frac{i}{N_{sfr}} \right) LSP^{(new)}, \text{ for } i=0, \dots, N_{sfr}-1$$

The interpolated LSP vectors are used to compute a different LP filter at each subframe using the LSP to LP conversion method described in 7.13.11.

7.13.11 LSP to LP conversion

For each subframe, the interpolated LSP coefficients are converted into LP filter coefficients a_k , which are used for synthesizing the reconstructed signal in the subframe. By definition, the LSPs of a 16th order LP filter are the roots of the two polynomials:

$$F'_1(z) = A(z) + z^{-17} A(z^{-1})$$

and

$$F'_2(z) = A(z) - z^{-17} A(z^{-1})$$

which can be expressed as:

$$F'_1(z) = (1 + z^{-1}) F_1(z)$$

and

$$F'_2(z) = (1 - z^{-1}) F_2(z)$$

with

$$F_1(z) = \prod_{i=1,3,\dots,15} (1 - 2q_i z^{-1} + z^{-2})$$

and

$$F_2(z) = \prod_{i=2,4,\dots,16} (1 - 2q_i z^{-1} + z^{-2})$$

where $q_i, i = 1, \dots, 16$ are the LSFs in the cosine domain also called LSPs. The conversion to the LP domain is done as follows. The coefficients of $F_1(z)$ and $F_2(z)$ are found by expanding the equations above knowing the quantized and interpolated LSPs. The following recursive relation is used to compute $F_1(z)$:

```

for  $i = 1$  to 8
     $f_1(i) = -2q_{2i-1}f_1(i-1) + 2f_1(i-2)$ 
    for  $j = i-1$  down to 1
         $f_1(j) = f_1(j) - 2q_{2i-1}f_1(j-1) + f_1(j-2)$ 
    end
end

```

with initial values $f_1(0) = 1$ and $f_1(-1) = 0$. The coefficients of $F_2(z)$ are computed similarly by replacing q_{2i-1} by q_{2i} .

Once the coefficients of $F_1(z)$ and $F_2(z)$ are found, $F_1(z)$ and $F_2(z)$ is multiplied by $1+z^{-1}$ and $1-z^{-1}$, respectively, to obtain $F'_1(z)$ and $F'_2(z)$; that is

$$f'_1(i) = f_1(i) + f_1(i-1), \quad i = 1, \dots, 8$$

$$f'_2(i) = f_2(i) - f_2(i-1), \quad i = 1, \dots, 8$$

Finally, the LP coefficients are computed from $f'_1(i)$ and $f'_2(i)$ by

$$a_i = \begin{cases} 0.5f'_1(i) + 0.5f'_2(i), & i = 1, \dots, 8 \\ 0.5f'_1(17-i) - 0.5f'_2(17-i), & i = 9, \dots, 16 \end{cases}$$

This is directly derived from the equation $A(z) = (F'_1(z) + F'_2(z))/2$, and considering the fact that $F'_1(z)$ and $F'_2(z)$ are symmetric and asymmetric polynomials, respectively.

7.13.12 LPC initialization at decoder start-up

In frames where the first decoded frame is LPD and the initial filter LPC0 is not transmitted within the bitstream, the LPD core decoder is reset as for a regular start-up. In particular, the ACELP decoder is initialized as described in 7.14.3. Additionally, the LSF vector corresponding to the LPC filter LPC0 is set to the value specified in Table 151 before inverse LPC quantization.

Right after inverse LPC quantization, the LSF vector corresponding to LPC0 is reset as follows:

$$LSF_0 = \frac{\text{mean_lsf} + LSF_i}{2},$$

where mean_lsf is the mean LSF vector specified in Table 151 and LSF_i is the LSF vector corresponding to the LPC filter of frame i , i being determined as defined in Table 150.

Table 150 — Value of i for calculating LSF_0

Condition	Value of i
$\text{mod}[0] < 2$	1
$\text{mod}[0] = 2$	2
$\text{mod}[0] = 3$	4

This operation corresponds to setting the LSF vector corresponding to LPC0 to average between the mean LSF vector and the nearest decoded LSF vector (which depends on the coding mode).

Table 151 — Mean LSF vector for initialization

j	mean_lsf(j)
1	394,21
2	754,45
3	1209,89
4	1580,47
5	1953,97
6	2325,80
7	2684,41
8	3038,39
9	3392,56
10	3744,71
11	4118,14
12	4483,09
13	4862,21
14	5219,69
15	5594,41
16	5945,73

7.14 ACELP

7.14.1 General

The following describes the decoding of one ACELP frame which comprises *coreCoderFrameLength*/4 samples.

7.14.2 Definition of elements

mean_energy Quantized mean excitation energy per frame.

Table 152 — Mean excitation energy $\bar{E}$

mean_energy	decoded mean excitation energy, $\bar{E}$
0	18 dB
1	30 dB
2	42 dB
3	54 dB

acb_index[sfr] For each subframe indicates the adaptive codebook index.

ltp_filtering_flag[sfr] Adaptive codebook excitation filtering flag.

icb_index[sfr] For each subframe indicates the innovation codebook index.

gains[sfr] Quantized gains of the adaptive codebook and innovation codebook contribution to the excitation.

sfr denotes the number of subframes within one ACELP frame and is equal to *coreCoderFrameLength*/256.

7.14.3 ACELP initialization at USAC decoder start-up

At the start-up of the USAC decoder, the ACELP internal state (which contains the set of all static variables used by ACELP and updated at every frame) is properly reset. Specifically, buffers used to store memories of past signals are set to zero. This includes the past excitation buffer which is used to build the adaptive codebook. Memories of gain values are also set to zero, and memories of pitch values are set to 64.

7.14.4 Setting of the ACELP excitation buffer using the past FD synthesis and LPC0

In case of a transition from FD to LPD, the past excitation buffer $u'(n)$ and the buffer containing the past pre-emphasized synthesis $\hat{s}(n)$ are updated using the past FD synthesis (including FAC or the overlapped TCX-signal) and LPC0 prior to the decoding of the ACELP excitation. For this the FD synthesis is pre-emphasized by applying the pre-emphasis filter $(1 - 0.68z^{-1})$, and the result is copied to $\hat{s}(n)$. The resulting pre-emphasized synthesis is then filtered by the analysis filter $\hat{A}(z)$ using LPC0 to obtain the excitation signal $u'(n)$.

7.14.5 Decoding of CELP excitation

If the mode in a frame is a CELP mode, the excitation consists of the addition of scaled adaptive codebook and fixed codebook vectors. In each subframe, the excitation is constructed by repeating the following steps.

7.14.5.1 Decoding of adaptive codebook excitation, `acb_index[]`

The received pitch index (adaptive codebook index) is used to find the integer and fractional parts of the pitch lag.

When the ACELP frame length is equal to 256, the pitch value is encoded on 9 bits for the first and third subframes and on 6 bits for the second and fourth subframes. When the ACELP frame length is equal to 192, the pitch value is encoded on 9 bits for the first subframe only and on 6 bits for the two other subframes.

The pitch value for a subframe is encoded using a multi-segment scalar quantizer, each segment having a different fractional resolution.

When the pitch value is encoded on 9 bits, a fractional pitch delay is used with resolutions $\frac{1}{4}$ in the range $[T_{\text{MIN}}, T_{\text{FR2}} - \frac{1}{4}]$, resolutions $\frac{1}{2}$ in the range $[T_{\text{FR2}}, T_{\text{FR1}} - \frac{1}{2}]$, and integers only in the range $[T_{\text{FR1}}, T_{\text{MAX}}]$. T_{MIN} , T_{FR2} , T_{FR1} and T_{MAX} are the boundaries of the segments of the quantizers which depend on the sampling frequency F_s at which the ACELP coder operates according to the formula:

$$T_{\text{MIN}} = \text{round}(34 * F_s / 12800)$$

$$T_{\text{FR2}} = 162 * T_{\text{MIN}}$$

$$T_{\text{FR1}} = 160$$

$$T_{\text{MAX}} = 27 + 6 * T_{\text{MIN}}$$

When the pitch value is encoded with 6 bits, a pitch resolution of $1/4$ is always used in the range $[T_1 - 8, T_1 + 7\frac{3}{4}]$, where T_1 is the rounded down integer of the fractional pitch lag of the previous subframe. To be able to use as many different pitch lags as possible T_1 has to be between $T_{\text{MIN}} + 8$ and $T_{\text{MAX}} - 7$. So in case $T_1 < T_{\text{MIN}} + 8$ set $T_1 = T_{\text{MIN}} + 8$, just as if $T_1 > T_{\text{MAX}} - 7$ set $T_1 = T_{\text{MAX}} - 7$.

The initial adaptive codebook excitation vector $v'(n)$ is found by interpolating the past excitation $u'(n)$ at the pitch delay and phase (fraction) using an FIR interpolation filter.

The adaptive codebook excitation is computed for the subframe size of 64 samples plus one extra sample for the filtering operation as described in the following sentence.

The received adaptive filter index (`ltp_filtering_flag[]`) is then used to decide whether the filtered adaptive codebook is $v(n) = v'(n)$ or $v(n) = 0.18v'(n + 1) + 0.64v'(n) + 0.18v'(n - 1)$.

7.14.5.2 Decoding of innovation codebook excitation, `icb_index[]`

The received algebraic codebook index is used to extract the positions and amplitudes (signs) of the excitation pulses and to find the algebraic codevector $c(n)$ (also called fixed codebook excitation vector, or innovative excitation). That is:

$$c(n) = \sum_{i=0}^{N_p-1} b_i \delta(n-m_i)$$

where b_i are the pulse amplitudes (1 or -1), m_i are the pulse positions, and N_p is the number of pulses in a codevector.

The algebraic codebook structure and the pulse indexing procedures which will help understanding the decoding of the algebraic codebook excitation are given in 7.14.5.2.1.

7.14.5.2.1 Algebraic codebook structure

The 64 positions in the codevector (subframe length) are divided into 4 tracks of interleaved positions, with 16 positions in each track. The different codebooks at the different rates are constructed by placing a certain number of signed pulses in the tracks (from 1 to 4 pulses per track). The codebook index, or codeword, represents the pulse positions and signs in each track.

The tracks and corresponding pulse positions are shown in Table 153:

Table 153 — Tracks and pulse positions

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

Since there are 16 positions in a track, the pulse position is encoded with 4 bits and the pulse sign is encoded with 1 bit giving 5 bits for a single pulse per track. As it will be shown below, two signed pulses per track are encoded with 9 bits, 3 signed pulses per track are encoded with 13 bits, and 4 signed pulses per track are encoded with 16 bits.

Depending on the coding mode, the following codebooks are used:

- 12-bit codebook with 2 pulses i_0 and i_1 . Pulse i_0 can be selected from either track 0 or 2, pulse i_1 can be selected from either track 1 or 3 ($5 \times 2 + 2$).
- 16-bit codebook with 3 pulses on three tracks. One pulse on track 0, one pulse on track 2 and one pulse on either track 1 or 3 (selected track signalled by a 1 bit field), which amounts to $(5 \times 3 + 1) = 16$ bits.
- 20-bit codebook with one pulse per track (5×4).
- 28-bit codebook with 2 pulses in the first two tracks and 1 pulse in the other tracks ($9 \times 2 + 5 \times 2$).
- 36-bit codebook with 2 pulses per track (9×4).
- 44-bit codebook with 3 pulses in the first two tracks and 2 pulses in the other tracks ($13 \times 2 + 9 \times 2$).

- 52-bit codebook with 3 pulses per track (13×4).
- 64-bit codebook with 4 pulses per track (16×4).

Below, the procedure to encode and decode 1 to 4 pulses per track is described. In the description there are 4 tracks per subframe, with 16 positions per track and pulse spacing of 4 as in the table above. The codebook index is obtained by concatenating the indices of the pulses in the 4 tracks. For example, the 20-bit codebook is obtained by concatenating the 5-bit indices of the pulses in the 4 tracks.

7.14.5.2.2 Decoding 1 signed pulse per track

The pulse position index is encoded with 4 bits and the sign index with 1 bit. The position index is given by the pulse position in the subframe divided by the pulse spacing (integer division). The division remainder gives the track index. For example, a pulse at position 31 has a position index of $31/4 = 7$ and it belongs to the track with index 3.

The sign of the decoded pulse is positive if the value of the sign index is 0, otherwise the sign of the decoded pulse is negative.

The index of the signed pulse is given by:

$$I_{1p} = p + s \times 2^M$$

where p is the position index ($m/4$), s is the sign index, and $M=4$ is the number of bits per track.

To decode the ACELP codevector, p and s are extracted from the received index. The pulse position is given by $m = p \times 4 + t$ where t is the track index (0 to 3). The pulse amplitude is given by $b=1$ if $s=0$ else $b=-1$.

7.14.5.2.3 Decoding 2 signed pulses per track

In case of two pulses per track of $K=2^M$ potential positions (here $M=4$), each pulse needs 1 bit for the sign and M bits for the position, which gives a total of $2M+2$ bits. However, some redundancy exists due to the unimportance of the pulse ordering. For example, placing the first pulse at position p and the second pulse at position q is equivalent to placing the first pulse at position q and the second pulse at position p . One bit can be saved by encoding only one sign and deducing the second sign from the ordering of the positions in the index. Here the index is given by:

$$I_{2p} = p_1 + p_0 \times 2^M + s_0 \times 2^{2M}$$

where s_0 is the sign index of the pulse at position index p_0 . If the two signs are equal then the smaller position is set to p_0 and the larger position is set to p_1 . On the other hand, if the two signs are not equal then the larger position is set to p_0 and the smaller position is set to p_1 .

To decode the ACELP codevector, p_0 , p_1 , and s_0 are extracted from the received index I_{2p} . The pulse positions are given by $m_i = p_i \times 4 + t$ where t is the track index (0 to 3). The pulse amplitude b_0 is given by $b_0=1$ if $s_0=0$ else $b_0=-1$. The pulse amplitude b_1 is given by $b_1 = b_0$ if $p_0 > p_1$ else $b_1 = -b_0$.

7.14.5.2.4 Decoding 3 signed pulses per track

In case of three pulses per track with 2^M positions, the pulse positions and signs are encoded $3M+1$ bits. A simple way of indexing the pulses is to divide the track positions in two sections (or halves) and identify a section that contains at least two pulses. The number of positions in the section is $K/2 = 2^M/2 = 2^{M-1}$, which can be represented with $M-1$ bits. The two pulses in the section containing at least two pulses are encoded with the procedure for encoding 2 signed pulses (described above) which requires $2(M-1)+1$ bits and the remaining pulse which can be anywhere in the track (in either section) is encoded with the $M+1$ bits. Finally, the index of the

section that contains the two pulses is encoded with 1 bit. Thus the total number of required bits is $2(M-1)+1 + M+1 + 1 = 3M+1$.

Note that if the two pulses belong to the upper half, they need to be shifted to the range (0-7) before encoding them using $2 \times 3 + 1$ bits. This can be done by masking the $M-1$ least significant bits (LSB) with a mask consisting of $M-1$ ones (which corresponds to the number 7 in this case).

The index of the 3 signed pulses is given by:

$$I_{3p} = I_{2p} + k \times 2^{2M-1} + I_{1p} \times 2^{2M}$$

where I_{2p} is the index of the two pulses in the same section, k is the section index (0 or 1), and I_{1p} is the index of the third pulse in the track.

To decode the ACELP codevector, the received index I_{3p} is used to extract the values of I_{2p} , I_{1p} , and k . The values of m_0 , m_1 , b_0 and b_1 are found using the procedure for decoding 2 pulses in a track with length $M/2$ which is 8 in this case. Note that before computing m_0 and m_1 the section of the track containing the two pulses is taken into consideration by incrementing p_0 and p_1 by 8 if $k=1$ (which shifts the positions to the upper half). The third pulse position and amplitude m_2 and b_2 are found by decoding I_{1p} using the procedure for 1 pulse per track described above.

7.14.5.2.5 Decoding 4 signed pulses per track

The 4 signed pulses in a track of length $K=2^M$ are encoded using $4M$ bits. Similar to the case of 3 pulses, the K positions in the track are divided into 2 sections (two halves) where each section contains $K/2=8$ positions. Here we denote the sections as Section A with positions 0 to $K/2-1$ and Section B with positions $K/2$ to $K-1$. Each section can contain from 0 to 4 pulses. Table 154 shows the 5 cases representing the possible number of pulses in each section:

Table 154 — Possible number of pulses in track Sections

case	Pulses in section A	Pulses in section B	Bits needed
0	0	4	$4M-3$
1	1	3	$4M-2$
2	2	2	$4M-2$
3	3	1	$4M-2$
4	4	0	$4M-3$

In cases 0 or 4, the 4 pulses in a section of length $K/2=2^{M-1}$ can be encoded using $4(M-1)+1=4M-3$ bits (this will be explained below).

In cases 1 or 3, the 1 pulse in a section of length $K/2=2^{M-1}$ can be encoded with $M-1+1 = M$ bits and the 3 pulses in the other section can be encoded with $3(M-1)+1 = 3M-2$ bits. This gives a total of $4M-2$ bits.

In case 2, the pulses in a section of length $K/2=2^{M-1}$ can be encoded with $2(M-1)+1 = 2M-1$ bits. Thus for both sections, $4M-2$ bits are required.

Now the case index can be encoded with 2 bits (4 possible cases) assuming cases 0 and 4 are combined. Then for cases 1, 2, or 3, the number of needed bits is $4M-2$. This gives a total of $4M-2 + 2 = 4M$ bits. For cases 0 or 4, one bit is needed for identifying either case, and $4M-3$ bits are needed for encoding the 4 pulses in the section. Adding the 2 bits needed for the general case, this gives a total of $1+4M-3+2= 4M$ bits.

The index of the 4 signed pulses is given by:

$$I_{4p} = I_{AB} + k \times 2^{4M-2}$$

where k is the case index (2 bits), and I_{AB} is the index of the pulses in both sections for each individual case.

For cases 0 and 4, I_{AB} is given by:

$$I_{AB_{0,4}} = I_{4p_section} + j \times 2^{4M-3}$$

where j is a 1-bit index identifying the section with 4 pulses and $I_{4p_section}$ is the index of the 4 pulses in that section (which requires $4M-3$ bits).

For case 1, I_{AB} is given by:

$$I_{AB_{1}} = I_{3p_B} + I_{1p_A} \times 2^{3(M-1)+1}$$

where I_{3p_B} is the index of the 3 pulses in Section B ($3(M-1)+1$ bits) and I_{1p_A} is the index of the pulse in Section A ($(M-1)+1$ bits).

For case 2, I_{AB} is given by:

$$I_{AB_{2}} = I_{2p_B} + I_{2p_A} \times 2^{2(M-1)+1}$$

where I_{2p_B} is the index of the 2 pulses in Section B ($2(M-1)+1$ bits) and I_{2p_A} is the index of the two pulses in Section A ($2(M-1)+1$ bits).

Finally, for case 3, I_{AB} is given by:

$$I_{AB_{3}} = I_{1p_B} + I_{3p_A} \times 2^M$$

where I_{1p_B} is the index of the pulse in Section B ($(M-1)+1$ bits) and I_{3p_A} is the index of the 3 pulses in Section A ($3(M-1)+1$ bits).

For cases 0 and 4, it was mentioned that the 4 pulses in one section are encoded using $4(M-1)+1$ bits. This is done by further dividing the section into 2 subsections of length $K/4=2^{M-2}$ ($=4$ in this case); identifying a subsection that contains at least 2 pulses; coding the 2 pulses in that subsection using $2(M-2)+1=2M-3$ bits; coding the index of the subsection that contains at least 2 pulses using 1 bit; and coding the remaining 2 pulses, assuming that they can be anywhere in the section, using $2(M-1)+1=2M-1$ bits. This gives a total of $(2M-3)+(1)+(2M-1) = 4M-3$ bits.

To decode the ACELP codevector, the value of k extracted from the received index I_{4p} is used to determine the case to which belongs extracted value I_{AB} . Then from the definitions of I_{AB_x} above, the procedures to decode 1, 2, or 3 pulses in a track are used to find all pulse positions and signs.

7.14.5.2.6 Pitch sharpening

Once the pulse positions and signs are decoded, and the excitation codevector $c(n)$ is found, a pitch sharpening procedure is performed. First $c(n)$ is filtered by a pre-emphasis filter defined as follows:

$$F_{emph}(z) = 1 - 0.3 z^{-1}$$

The pre-emphasis filter has the role of reducing the excitation energy at low frequencies. Next, a periodicity enhancement is performed by means of an adaptive pre-filter with a transfer function defined as:

$$F_p(z) = \begin{cases} 1 & , \text{if } n < \min(T, 64) \\ (1 + 0.85z^{-T}) & , \text{if } T < 64 \text{ and } T \leq n < \min(2T, 64) \\ 1 / (1 - 0.85z^{-T}) & , \text{if } 2T < 64 \text{ and } 2T \leq n < 64 \end{cases}$$

where n is the subframe index ($n=0, \dots, 63$), and where T is a rounded version of the integer part T_0 and fractional part $T_{0,\text{frac}}$ of the pitch lag and is given by:

$$T = \begin{cases} T_0 + 1 & , \text{if } T_{0,\text{frac}} > 2 \\ T_0 & , \text{otherwise} \end{cases}$$

The adaptive pre-filter $F_p(z)$ colors the spectrum by damping inter-harmonic frequencies, which are annoying to the human ear in the case of voiced signals.

7.14.5.3 Decoding of the adaptive and innovative codebook gains, gains[]

The received 7-bit index per subframe directly provides the adaptive codebook gain $\hat{g}_p$ and the fixed-codebook gain correction factor $\hat{\gamma}$. The fixed codebook gain is then computed by multiplying the gain correction factor by an estimated fixed codebook gain.

The estimated fixed-codebook gain g'_c is found as follows. First, the average innovation energy is found by:

$$E_i = 10 \log \left(\frac{1}{N} \sum_{i=0}^{N-1} c^2(i) \right)$$

Then the estimated gain G'_c in dB is found by:

$$G'_c = \bar{E} - E_i$$

where $\bar{E}$ is the decoded mean excitation energy per frame. The mean innovative excitation energy in a frame, $\bar{E}$, is encoded with 2 bits per frame (18, 30, 42 or 54 dB) as **mean_energy**.

The prediction gain in the linear domain is given by:

$$g'_c = 10^{0.05 G'_c} = 10^{0.05(\bar{E} - E_i)}$$

The quantized fixed-codebook gain is given by:

$$\hat{g}_c = \hat{\gamma} \cdot g'_c$$

7.14.5.4 Computing the reconstructed excitation

The following steps are for $n = 0, \dots, 63$. The total excitation is constructed by:

$$u'(n) = \hat{g}_p v(n) + \hat{g}_c c(n)$$

where $c(n)$ is the codevector from the fixed-codebook after filtering it through the adaptive pre-filter $F(z)$. The excitation signal $u'(n)$ is used to update the content of the adaptive codebook. The excitation signal $u'(n)$ is then

post-processed as described in the next section to obtain the post-processed excitation signal $u(n)$ used at the input of the synthesis filter $1/\hat{A}(z)$.

7.14.6 Excitation postprocessing

7.14.6.1 General

Before signal synthesis, a post-processing of excitation elements is performed as follows.

7.14.6.2 Gain smoothing for noise enhancement

In ACELP frames a nonlinear gain smoothing technique is applied to the fixed-codebook gain $\hat{g}_c$ in order to enhance excitation in noise. Based on the stability and voicing of the speech segment, the gain of the fixed-codebook vector is smoothed in order to reduce fluctuation in the energy of the excitation in case of stationary signals. This improves the performance in case of stationary background noise. The voicing factor is given by:

$$\lambda = 0.5(1-r_v)$$

with

$$r_v = (E_v - E_c)/(E_v + E_c),$$

where E_v and E_c are the energies of the scaled pitch codevector and scaled innovation codevector, respectively (r_v gives a measure of signal periodicity). Note that since the value of r_v is between -1 and 1 , the value of λ is between 0 and 1 . Note that the factor λ is related to the amount of unvoicing with a value of 0 for purely voiced segments and a value of 1 for purely unvoiced segments.

A stability factor θ is computed based on a distance measure between the adjacent LP filters. Here, the factor θ is related to the LSF distance measure. The LSF distance is given by:

$$LSF_{dist} = \sum_{i=0}^{15} (f_i - f_i^{(p)})^2$$

where f_i are the LSFs in the present frame, and $f_i^{(p)}$ are the LSFs in the past frame. The stability factor θ is given by:

$$\theta = 1.25 - LSF_{dist} / 400000, \quad \text{constrained by } 0 \leq \theta \leq 1.$$

The LSF distance measure is smaller in case of stable signals. As the value of θ is inversely related to the LSF distance measure, then larger values of θ correspond to more stable signals. The gain-smoothing factor S_m is given by:

$$S_m = \lambda \theta.$$

The value of S_m approaches 1 for unvoiced and stable signals, which is the case of stationary background noise signals. For purely voiced signals or for unstable signals, the value of S_m approaches 0 . An initial modified gain g_0 is computed by comparing the fixed-codebook gain $\hat{g}_c$ to a threshold given by the initial modified gain from the previous subframe, g_{-1} . If $\hat{g}_c$ is larger or equal to g_{-1} , then g_0 is computed by decrementing $\hat{g}_c$ by 1.5 dB bounded by $g_0 \geq g_{-1}$. If $\hat{g}_c$ is smaller than g_{-1} , then g_0 is computed by incrementing $\hat{g}_c$ by 1.5 dB constrained by $g_0 \leq g_{-1}$.

Finally, the gain is updated with the value of the smoothed gain as follows:

$$\hat{g}_{sc} = S_m g_0 + (1 - S_m) \hat{g}_c.$$

7.14.6.3 Pitch enhancer

A pitch enhancer scheme modifies the total excitation $u'(n)$ by filtering the fixed-codebook excitation through an innovation filter whose frequency response emphasizes the higher frequencies and reduces the energy of the low frequency portion of the innovative codevector, and whose coefficients are related to the periodicity in the signal. A filter of the form:

$$F_{inno}(z) = -c_{pe}z + 1 - c_{pe}z^{-1}$$

is used where $c_{pe} = 0.125(1 + r_v)$, with r_v being a periodicity factor given by $r_v = (E_v - E_c)/(E_v + E_c)$ as described above. The filtered fixed-codebook codevector is given by:

$$c'(n) = \begin{cases} c(0) - c_{pe}c(1) & , \text{if } n = 0 \\ c(n) - c_{pe}(c(n+1) + c(n-1)) & , \text{if } 0 < n < 63 \\ c(63) - c_{pe}c(62) & , \text{if } n = 63 \end{cases}$$

and the updated post-processed excitation is given by:

$$u(n) = \hat{g}_p v(n) + \hat{g}_{sc} c'(n)$$

The above procedure can be done in one step by updating the excitation as follows:

$$u(n) = \begin{cases} \hat{g}_p v(0) + \hat{g}_{sc} c(0) - \hat{g}_{sc} c_{pe} c(1) & , \text{if } n = 0 \\ \hat{g}_p v(n) + \hat{g}_{sc} c(n) - \hat{g}_{sc} c_{pe} (c(n+1) + c(n-1)) & , \text{if } 0 < n < 63 \\ \hat{g}_p v(63) + \hat{g}_{sc} c(63) - \hat{g}_{sc} c_{pe} c(62) & , \text{if } n = 63 \end{cases}$$

7.14.7 Synthesis

The LP synthesis is performed by filtering the post-processed excitation signal $u(n)$ through the LP synthesis filter $1/\hat{A}(z)$. The interpolated LP filter per subframe is used in the LP synthesis filtering. The reconstructed signal in a subframe is given by:

$$\hat{s}(n) = u(n) - \sum_{i=1}^{16} \hat{a}_i \hat{s}(n-i), n = 0, \dots, 63$$

The synthesized signal is then de-emphasized by filtering through the filter $1/(1-0.68z^{-1})$ (inverse of the pre-emphasis filter applied at the encoder input).

7.14.8 Writing in the output buffer

At the output of the post-processing, the $N = \text{coreCoderFrameLength}/4$ synthesized coefficients from ACELP are written in the output buffer *out*. In case the previous coding was either FD mode or MDCT-based TCX, the tool FAC is applied first as described in 7.16. The output buffer is updated as follows:

$$\text{out}[i_{out} + n] = S_E[n]; \forall 0 \leq n < N = \text{coreCoderFrameLength}/4$$

i_{out} indexes the output buffer *out* and is incremented by the number N of written samples

7.15 MDCT based TCX

7.15.1 Tool description

When the **core_mode** is equal to 1 and when one or more of the three TCX modes is selected as the “linear prediction-domain” coding, i.e., one of the 4 array entries of **mod[]** is greater than 0, the MDCT based TCX tool is used. The MDCT based TCX receives the quantized spectral coefficients from the arithmetic decoder described in 7.4. First, any nulls or notches in the quantized coefficients are filled by a comfort noise. LPC based frequency-domain noise shaping (FDNS) is then applied to the resulting spectral coefficients and an inverse MDCT transformation is performed to obtain the time-domain synthesis signal.

lg	Number of quantized spectral coefficients output by the arithmetic decoder.
noise_factor	Noise level quantization index.
noise level	Level of noise injected in reconstructed spectrum.
noise[]	Vector of generated noise.
global_gain	Re-scaling gain quantization index.
g	Re-scaling gain.
rms	Root mean square of the decoded spectrum, rr[] .
x[]	Output of the IMDCT.
z[]	Decoded windowed signal in time domain.
out[]	Synthesized time domain signal.
x_tcx_invquant[win][bin]	TCX spectral coefficient for window win , and coefficient bin after noiseless decoding of the spectral data. See also 7.1.
r[]	Reconstructed spectral coefficients vector including synthetic comfort noise.

7.15.2 Decoding process

The MDCT-based TCX requests from the arithmetic decoder a number of quantized spectral coefficients, **lg**, which is determined by the **mod[]** value. This value also defines the window length and shape which will be applied in the inverse MDCT. The window is composed of three parts, a left side overlap of **L** samples, a middle part of ones of **M** samples and a right overlap part of **R** samples. To obtain an MDCT window of length $2 * lg$, **ZL** zeros are added on the left and **ZR** zeros on the right side. In case of a transition from or to a **SHORT_WINDOW** the corresponding overlap region **L** or **R** needs to be reduced to $coreCoderFrameLength/8$ in order to adapt to the shorter window slope of the **SHORT_WINDOW**. Consequently the region **M** and the corresponding zero region **ZL** or **ZR** need to be expanded by $coreCoderFrameLength/16$ samples each.

Table 155 — Number of spectral coefficients as a function of **mod[] and **coreCoderFrameLength (ccfl)****

value of mod[x]	Number lg of spectral coefficients	ZL	L	M	R	ZR
1	$ccfl/4$	0	$ccfl/4$	0	$ccfl/4$	0
2	$ccfl/2$	$ccfl/8$	$ccfl/4$	$ccfl/4$	$ccfl/4$	$ccfl/8$
3	$ccfl$	$3 * ccfl/8$	$ccfl/4$	$6 * ccfl/8$	$ccfl/4$	$3 * ccfl/8$

The MDCT window is given by:

$$W(n) = \begin{cases} 0 & ,\text{for } 0 \leq n < ZL \\ W_{SIN_LEFT,L}(n - ZL) & ,\text{for } ZL \leq n < ZL + L \\ 1 & ,\text{for } ZL + L \leq n < ZL + L + M \\ W_{SIN_RIGHT,R}(n - ZL - L - M) & ,\text{for } ZL + L + M \leq n < ZL + L + M + R \\ 0 & ,\text{for } ZL + L + M + R \leq n < 2lg \end{cases}$$

The quantized spectral coefficients, `x_tcx_invquant[]`, delivered by the arithmetic decoder are completed by a comfort noise. The level of the injected noise is determined by the decoded `noise_factor` as follows:

$$\text{noise_level} = 0.0625 * (8 - \text{noise_factor})$$

The `x_tcx_invquant[]` and the comfort noise are combined to form the reconstructed spectral coefficients vector, `r[]`, in a way that the runs of 8 consecutive zeros in `x_tcx_invquant[]` are replaced by the noise components. A run of 8 non-zeros are detected according to the following pseudo code:

```
for(i=0; i<lg/6; i++) {
    rl[i] = 1;
}

for(i=lg/6; i<lg; i += 8) {
    int k, maxK = min(lg, i+8);
    float tmp = 0.f;

    for(k=i; k<maxK; k++){
        tmp += x_tcx_invquant[k] * x_tcx_invquant[k];
    }

    if(tmp != 0.f){
        for(k=i; k<maxK; k++){
            rl[k] = 1;
        }
    } else {
        for(k=i; k<maxK; k++){
            rl[k] = 0;
        }
    }
}
```

One obtains the reconstructed spectrum as follows:

$$r[i] = \begin{cases} \text{randomSign()} \cdot \text{noise_level}, & ,\text{if } rl[i] = 0 \\ x_tcx_invquant[i], & ,\text{otherwise} \end{cases}$$

A spectrum de-shaping is applied to the reconstructed spectrum according to the following steps:

1. calculate the energy E_m of the 8-dimensional block at index m for each 8-dimensional block of the first quarter of the spectrum.
2. compute the ratio $R_m = \sqrt{E_m/E_I}$, where I is the block index with the maximum value of all E_m .
3. if $R_m < 0.1$, then set $R_m = 0.1$.
4. if $R_m < R_{m-1}$, then set $R_m = R_{m-1}$.

Each 8-dimensional block belonging to the first quarter of spectrum are then multiplying by the factor R_m .

Prior to applying the inverse MDCT, the two quantized LPC filters corresponding to both extremities of the MDCT block (i.e., the left and right folding points) are retrieved, their weighted versions are computed, and the

corresponding decimated (64 points, regardless of the transform length) spectrums are computed. These weighted LPC spectrums are computed by applying an ODFT to the LPC filter coefficients. A complex modulation is applied to the LPC coefficients before computing the ODFT so that the ODFT frequency bins are perfectly aligned with the MDCT frequency bins. For example, the weighted LPC synthesis spectrum of a given LPC filter $\hat{A}(z)$ is computed as follows:

$$X_o[k] = \sum_{n=0}^{2M-1} x_t[n] e^{-j \frac{2\pi k}{2M} n}$$

with

$$x_t[n] = \begin{cases} \hat{w}[n] e^{-j \frac{\pi}{2M} n} & , \text{ if } 0 \leq n < \text{lpc_order} + 1 \\ 0 & , \text{ if } \text{lpc_order} + 1 \leq n < 2M \end{cases}$$

where $\hat{w}[n]$, $n = 0 \dots \text{lpc_order} + 1$, are the coefficients of the weighted LPC filter given by:

$$\hat{W}(z) = \hat{A}(z/\gamma_1) \quad \text{with } \gamma_1 = 0.92$$

The gains $g[k]$ can be calculated from the spectral representation $X_o[k]$ of the LPC coefficients according to:

$$g[k] = \sqrt{\frac{1}{X_o[k] X_o^*[k]}} \quad \forall k \in \{0, \dots, M-1\}$$

where $M = \text{coreCoderFrameLength}/16$ is the number of bands in which the calculated gains are applied.

Let $g1[k]$ and $g2[k]$, $k=0 \dots M-1$, be the decimated LPC spectrums corresponding respectively to the left and right folding points computed as explained above. The inverse FDNS operation consists in filtering the reconstructed spectrum $rr[i]$ using the recursive filter:

$$rr[i] = a[i] \cdot r[i] + b[i] \cdot rr[i-1], \quad i=0 \dots \lg-1,$$

where $a[i]$ and $b[i]$ are derived from the left and right gains $g1[k]$, $g2[k]$ using the formulae:

$$a[i] = 2 \cdot g1[k] \cdot g2[k] / (g1[k] + g2[k]),$$

$$b[i] = (g2[k] - g1[k]) / (g1[k] + g2[k]).$$

In the above, the variable k is equal to $i/(\lg/M)$ to take into consideration the fact that the LPC spectrums are decimated.

The reconstructed spectrum $rr[]$ is fed into an inverse MDCT. The non-windowed output signal, $x[]$, is re-scaled by the gain, g , obtained by an inverse quantization of the decoded `global_gain` index:

$$g = \frac{10^{\text{global_gain}/28}}{\frac{2}{\sqrt{\lg}} \cdot \text{rms}}$$

Where rms is calculated as:

$$rms = \sqrt{\frac{\sum_{k=0}^{lg-1} r^2[k]}{lg}}$$

The synthesized time-domain signal is then rescaled and windowed as follows:

$$z[n] = x[n] \cdot w[n] \cdot g; \forall 0 \leq n < N$$

N corresponds to the MDCT window size, i.e., $N = 2lg$.

When the previous coding mode was either FD mode or MDCT based TCX, a conventional overlap and add is applied between the current decoded windowed signal $z_{i,n}$ and the previous decoded windowed signal $z_{i-1,n}$, where the index i counts the number of already decoded MDCT windows. The final time domain synthesis out is obtained by the following formulae.

In case $z_{i-1,n}$ comes from FD mode:

$$out[i_{out} + n] = \begin{cases} z_{i-1, \frac{N_l}{2} + n}; & \forall 0 \leq n < \frac{N_l}{4} - \frac{L}{2} \\ z_{i, \frac{N-N_l}{4} + n} + z_{i-1, \frac{N_l}{2} + n}; & \forall \frac{N_l}{4} - \frac{L}{2} \leq n < \frac{N_l}{4} + \frac{L}{2} \\ z_{i, \frac{N-N_l}{4} + n}; & \forall \frac{N_l}{4} + \frac{L}{2} \leq n < \frac{N_l}{4} + \frac{N}{2} - \frac{R}{2} \end{cases}$$

N_l is the size of the window sequence coming from FD mode. i_{out} indexes the output buffer out and is incremented by the number $\frac{N_l}{4} + \frac{N}{2} - \frac{R}{2}$ of written samples.

In case $z_{i-1,n}$ comes from MDCT based TCX:

$$out[i_{out} + n] = \begin{cases} z_{i, \frac{N}{4} - \frac{L}{2} + n} + z_{i-1, \frac{3*N_{i-1}}{4} - \frac{L}{2} + n}; & \forall 0 \leq n < L \\ z_{i, \frac{N}{4} - \frac{L}{2} + n}; & \forall L \leq n < \frac{N+L-R}{2} \end{cases}$$

N_{i-1} is the size of the previous MDCT window. i_{out} indexes the output buffer out and is incremented by the number $(N+L-R)/2$ of written samples.

When the previous coding mode was ACELP, the FAC tool is applied as described in 7.16.

The reconstructed synthesis $out[i_{out} + n]$ is then filtered through the pre-emphasis filter $(1 - 0.68z^{-1})$. The resulting pre-emphasized signal is filtered by the analysis filter $\hat{A}(z)$ in order to obtain the excitation signal.

The calculated excitation updates the ACELP adaptive codebook and allows switching from TCX to ACELP in a subsequent frame. The signal is reconstructed by de-emphasizing the pre-emphasized signal by applying the filter $1/(1 - 0.68z^{-1})$. Note that the analysis filter coefficients used are those that correspond to the end of the given TCX frame.

Note also that the length of the TCX synthesis is given by the TCX frame length (without the overlap): $\text{coreCoderFrameLength}/4$, $\text{coreCoderFrameLength}/2$ or $\text{coreCoderFrameLength}$ samples for the mod[] of 1, 2 or 3 respectively.

7.16 Forward aliasing cancellation (FAC) tool

7.16.1 Tool description

The following describes forward-aliasing cancellation (FAC) operations which are performed during transitions between ACELP and transform coded frames (TC) in order to get the final synthesis signal. The goal of FAC is to cancel the time-domain aliasing and windowing introduced by TC and which cannot be cancelled by the preceding or following ACELP frame. Here the notion of TC includes MDCT over long and short blocks (in FD mode) as well as MDCT-based TCX (in LPD mode).

Figure 30 represents the different intermediate signals which are computed in order to obtain the final synthesis signal for the TC frame, which is positioned between the markers LPC1 and LPC2 in the figure. In the example shown, the TC frame is assumed to be both preceded and followed by an ACELP frame. In the other cases (for example, an ACELP frame followed by more than one TC frame, or more than one TC frame followed by an ACELP frame) only the required signals are computed. In Figure 30, the term “FAC synthesis” is used to indicate the decoded FAC signal, which is added at the boundary (beginning or end) of a decoded TC frame when it is adjacent to an ACELP frame.

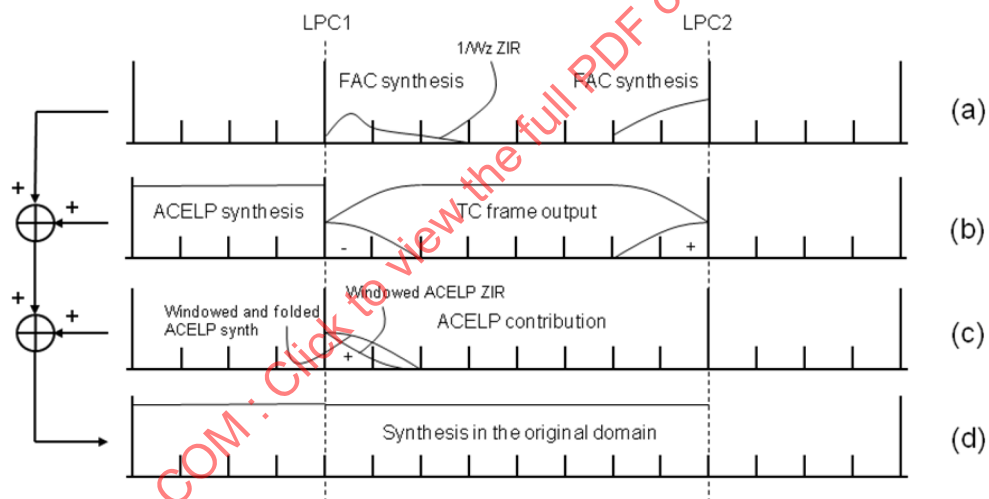


Figure 30 — FAC decoding operations for transitions from and to ACELP

7.16.2 Definition of elements

fac_gain	7 bit gain index.
qn[i]	Codebook number in the AVQ tool.
FAC[i]	FAC data.
fac_length	Length of the FAC transform ($\text{coreCoderFrameLength}/16$ for transitions from and to EIGHT_SHORT_SEQUENCES, $\text{coreCoderFrameLength}/8$ otherwise).
use_gain	Indicates the use of explicit gain information.
code_book_index[i][0]	The AVQ refinement code book indices corresponding to each kv[i][0] .
kv[i][0][8]	The AVQ refinement voronoi extension indices.

7.16.3 Decoding process

1. Decode AVQ parameters:

- The FAC information is encoded in the transform (DCT) domain in 8-dimensional blocks using the algebraic vector quantization (AVQ) tool of 7.12. In the following, this encoded FAC information is referred to as the “FAC spectral data”.
- For $i=0 \dots \text{FAC transform length}$:
 - A codebook number $qn[i]$ is encoded using a modified unary code.
 - The corresponding FAC data $\text{FAC}[i]$ is encoded with $4 \cdot qn[i]$ bits.
- After decoding the AVQ parameters of the FAC spectral data, a vector $\text{FAC}[i]$ (FAC data) for $i=0, \dots, \text{fac_length}$ is therefore extracted from the bitstream.

2. Apply a gain factor g to the FAC data:

- For transitions with MDCT-based TCX (so, in the case of ACELP to TCX or TCX to ACELP transitions), the gain of the corresponding tcx_coding element is used.
- For other transitions (so, in the case of ACELP to FD mode TC frames and from FD mode TC frames to ACELP), a gain information fac_gain has been retrieved from the bitstream (encoded using a 7-bits scalar quantizer). The gain g is calculated as $g = 10^{\text{fac_gain}/28}$ using that gain information.

3. In the case of transitions between MDCT based TCX and ACELP, a spectrum de-shaping is applied to the first quarter of the FAC spectral data. The de-shaping gains are those computed for the corresponding MDCT based TCX as explained in 7.15.2 so that the quantization noise of FAC and MDCT-based TCX have the same shape.

4. Compute the inverse DCT-IV to the gain-scaled FAC data to obtain the equivalent time-domain samples.

- The FAC transform length, fac_length , is by default equal to $\text{coreCoderFrameLength}/8$.
- For transitions with short blocks, this length is reduced to $\text{coreCoderFrameLength}/16$.

In the case of transitions between ACELP and FD mode, a multiplicative factor of $(2/\text{fac_length})$ is applied to the output of the inverse DCT-IV.

5. In the case of transition to and from TC frames, apply the weighted synthesis filter $1/\hat{W}(z)$ to get the decoded FAC signal, termed “FAC synthesis” in Figure 30. The resulting signal is represented on line (a) in Figure 30.

- The weighted synthesis filter is based on the LPC filter which corresponds to the folding point (in Figure 30 it is identified as LPC1 for transitions from ACELP to the TC frame and LPC2 for transitions from the TC frame to ACELP; for transitions from TC frames in FD mode to ACELP, the weighted synthesis filter is based on the transmitted LPC0).
- The same LPC weighting factor is used as for ACELP operations:

$$\hat{W}(z) = A(z/\gamma_1) \quad , \text{ where } \gamma_1 = 0.92$$

- In this filtering operation, the initial memory of the weighted synthesis filter $1/\hat{W}(z)$ is set to 0.
- As shown on line (c) of Figure 30, for transitions from ACELP to a TC frame, the windowed zero-input response (ZIR) of the weighted synthesis filter (taking fac_length samples) is added to the decoded FAC signal, the ZIR acting as a signal prediction for the beginning of the TC frame.

6. Furthermore, in the case of transitions from ACELP to a TC frame, compute the windowed past ACELP synthesis (taking fac_length samples), fold it and add to it the windowed ZIR signal (also as shown on line (c) of Figure 30). The ZIR response is computed using the LPC filter at LPC1 of Figure 30. The window applied to the fac_length past ACELP synthesis samples is:

$$\text{sine}[n + \text{fac_length}] * \text{sine}[\text{fac_length} - 1 - n], \quad n = -\text{fac_length} \dots -1,$$

and the window applied to the ZIR is:

$$1 - \text{sine}[n + \text{fac_length}]^2, \quad n = 0 \dots \text{fac_length} - 1,$$

where $\text{sine}[n]$ is a quarter of a sine cycle:

$$\text{sine}[n] = \sin((n+0.5)*\pi/(4*\text{fac_length})), \quad n = 0 \dots 2*\text{fac_length}-1.$$

The resulting signal is represented on line (c) in Figure 30 and denoted as the ACELP contribution (this ACELP contribution being formed of the sum of the windowed ZIR and the folded ACELP synthesis from the end of the previous frame).

7. Add the following three components:

- FAC synthesis (line (a) in Figure 30);
 - the TC frame (line (b) in Figure 30);
 - in the case of transitions from ACELP: the ACELP contribution (line (c) in Figure 30);
- in order to obtain the synthesis signal (which is represented as line (d) in Figure 30).

7.16.4 Writing in the output buffer

The output synthesis buffer is updated differently according to the type of transition. In case of transitions from FD mode to ACELP, the output buffer *out* is updated as follows:

$$\text{out}[i_{\text{out}} + n] = \begin{cases} z_{i-1, \frac{N_l}{2}+n}; & \forall 0 \leq n < \frac{N_l}{4} - \text{fac_length} \\ \text{FAC}[\text{fac_length} - \frac{N_l}{4} + n] + z_{i-1, \frac{N_l}{2}+n}; & \forall \frac{N_l}{4} - \text{fac_length} \leq n < \frac{N_l}{4} \end{cases}$$

N_l is the size of the previous window sequence. i_{out} indexes the output buffer *out* and is incremented by the number $N_l/4$ of written samples.

In case of transitions from ACELP to FD mode, the output buffer *out* is updated as follows:

$$\text{out}[i_{\text{out}} + n] = z_{i, \frac{N_l}{4}+n} + \text{FAC}[n] + \text{ACELP}[n]; \quad \forall 0 \leq n < \frac{N_l}{4}$$

N_{l-1} is the size of the previous MDCT window. i_{out} indexes the output buffer *out* and is incremented by the number $N_l/4$ of written samples.

In case of transitions from MDCT-based TCX to ACELP, the output buffer *out* is updated as follows:

$$\text{out}[i_{\text{out}} + n] = \text{FAC}[n] + z_{i-1, \frac{3*N_{l-1}}{4} - \text{fac_length} + n}; \quad \forall 0 \leq n < \text{fac_length}$$

N_{l-1} is the size of the previous MDCT window. i_{out} indexes the output buffer *out* and is incremented by the number *fac_length* of written samples.

In case of transitions from ACELP to MDCT-based TCX, the output buffer *out* is updated as follows:

$$\text{out}[i_{\text{out}} + n] = z_{i, \frac{N}{4}+n} + \text{FAC}[n] + \text{ACELP}[n]; \quad \forall 0 \leq n < \frac{N-R}{2}$$

i_{out} indexes the output buffer *out* and is incremented by the number $(N-R)/2$ of written samples.

7.17 Post-processing of the synthesis signal

The described bass post filtering is applied to the synthesis signal after overlap-and-add and FAC operations over all ACELP frames as well as for the duration of a FAC transform window in the places where this is applied.

After LP synthesis, the reconstructed signal can be post-processed using low-frequency pitch enhancement. The received bass-post filter control information controls whether bass-post filtering which results in a pitch enhancement in the low frequency range is enabled or not. For speech signals, the post processing filter reduces inter-harmonic noise in the decoded signal, which leads to an improved quality. However, for music signals, which are commonly of multi-pitch nature, the post filtering may suppress signal components that reside below the dominating pitch frequency or between its harmonics. For the post filtering a two-band decomposition is used and adaptive filtering is applied only to the lower band. This results in a total post-processing that is mostly targeted at frequencies near the first harmonics of the synthesized signal.

To avoid additional delay due to bass-post filtering, bass-post filter operation is modified for high values of T . Therefore, T_{lim} is defined as follows.

In case of LPD:

- For the first $\frac{M}{2} + 64$ samples of a superframe:

$$T_{lim} = M - L_{fac} - N_z$$

- For the last $\frac{M}{2} - 64$ samples of a superframe:

$$T_{lim} = 2M - L_{fac_next} - N_z$$

In case of FD (the FAC-area):

$$T_{lim} = \frac{M}{2} - N_z$$

Where $M = \text{coreCoderFrameLength}$, L_{fac} is the length of the FAC area from the last frame of the current superframe. With $L_{fac} = 0$ for ACELP and $L_{fac} = 96/128$ for TCX ($\text{coreCoderFrameLength} = 768/1024$). L_{fac_next} is the length of the FAC area from the last frame of the next superframe. N_z is the number of samples of the superframe up to and including the sample currently being bass post filtered.

The signal is processed in two branches. In the higher branch the decoded signal is filtered by a high-pass filter to produce the higher band signal s_H . In the lower branch, the decoded signal is first processed through an adaptive pitch enhancer, and then filtered through a low-pass filter to obtain the lower band post-processed signal s_{LEF} . The post-processed decoded signal is obtained by adding the lower band post-processed signal and the higher band signal. The object of the pitch enhancer is to reduce the inter-harmonic noise in the decoded signal, which is achieved here by a time-varying linear filter with a transfer function:

$$H_E(z) = (1 - \alpha) + \frac{\alpha}{2}z^T + \frac{\alpha}{2}z^{-T}$$

and described by the following equation:

$$s_{LE}(n) = (1 - \alpha)\hat{s}(n) + \frac{\alpha}{2}\hat{s}(n - T) + \frac{\alpha}{2}\hat{s}(n + T)$$

where α is a coefficient that controls the inter-harmonic attenuation, T is the pitch period of the input signal $\hat{s}(n)$, and $s_{LE}(n)$ is the output signal of the pitch enhancer. Parameters T and α vary with time and are given by the pitch tracking module. With a value of $\alpha = 0.5$, the gain of the filter is exactly 0 at frequencies $1/(2T), 3/(2T), 5/(2T)$, etc.; i.e., at the mid-point between the harmonic frequencies $1/T, 2/T, 3/T$, etc. When α approaches 0, the attenuation between the harmonics produced by the filter decreases.

To confine the post-processing to the low frequency region, the enhanced signal s_{LE} is low pass filtered to produce the signal s_{LEF} which is added to the high-pass filtered signal s_H to obtain the post-processed synthesis signal s_E .

An alternative procedure equivalent to that described above is used which eliminates the need of high-pass filtering. This is achieved by representing the post-processed signal $s_E(n)$ in the z-domain as:

$$S_E(z) = \hat{S}(z) - \alpha \hat{S}(z) P_{LT}(z) H_{LP}(z)$$

where $P_{LT}(z)$ is the transfer function of the long-term predictor filter given by:

$$P_{LT}(z) = \begin{cases} 1 - 0.5z^T - 0.5z^{-T} & , \text{if } T \leq T_{\lim} \\ 1 - z^{-T} & , \text{if } T > T_{\lim} \end{cases}$$

and $H_{LP}(z)$ is the transfer function of the low-pass filter.

Thus, the post-processing is equivalent to subtracting the scaled low-pass filtered long-term error signal from the synthesis signal $\hat{s}(n)$.

The value T is given by the received closed-loop pitch lag in each subframe (the fractional pitch lag rounded to the nearest integer). A simple tracking for checking pitch doubling is performed. If the normalized pitch correlation at delay $T/2$ is larger than 0.95 then the value $T/2$ is used as the new pitch lag for post-processing.

The factor α is given by:

$$\alpha = 0.5 g_{PF} \text{ constrained to } 0 \leq \alpha \leq 0.5$$

where g_{PF} is a gain which is updated at every sub-frame and is computed from the synthesis signal x as follows using the decoded pitch lag T_p :

$$g_{PF} = \min \left(\frac{\sum_{i=0}^{63} (x_i - x_{i-T_p})^2}{\sum_{i=0}^{63} x_{i-T_p}^2}, g_{PFmax} \right)$$

Where g_{PFmax} is defined as:

$$g_{PFmax} = \begin{cases} \sqrt{\frac{\sum_{i=0}^{\min(T_{\lim}-T, 63)} x_i^2}{\sum_{i=0}^{\min(T_{\lim}-T, 63)} x_{i+T_p}^2}} & , \text{if } T \leq T_{\lim} \\ 1 & , \text{if } T > T_{\lim} \end{cases}$$

g_{PFmax} is used to avoid problems on signal bursts.

Note that in TCX mode and during frequency domain coding the value of α is set to zero. During transitions between TCX and ACELP the FAC area ($\text{coreCoderFrameLength}/8$ samples) is postfiltered using the nearest decoded pitch lag (T_p) from the ACELP frame. For transitions between FD mode to and from ACELP the FAC area (either $\text{coreCoderFrameLength}/16$ for transitions from and to EIGHT_SHORT_SEQUENCES, or $\text{coreCoderFrameLength}/8$ for all other cases) is postfiltered using the nearest decoded pitch lag (T_p) from the ACELP frame. The bass post-filter operates on an ACELP subframe grid (blocks of 64 samples). When $\text{coreCoderFrameLength}=768$, the FAC area is not an integer multiple of the subframe: It is equal to 48 samples (0.75 subframes) for transitions from and to EIGHT_SHORT_SEQUENCES and equal to 96 samples (1.5 subframes) otherwise. In these cases, subframes that are only partly included in the FAC area are postfiltered in their entirety using the same filtering parameters. Therefore, when $\text{coreCoderFrameLength}=768$, one entire subframe is postfiltered for transitions from and to EIGHT_SHORT_SEQUENCES and two entire subframes are postfiltered in all other cases.

A FAC area is postfiltered if and only if the adjacent ACELP frame is also postfiltered. In particular, this means that the FAC area is also postfiltered if the `bpf_control_info` for an ACELP frame is set to 1 and the `bpf_control_info` for an adjacent TCX frame is set to 0 (on superframe borders). In contrast, the FAC area is never postfiltered if the `bpf_control_info` for the adjacent ACELP subframe is set to 0.

A linear phase FIR low-pass filter with 25 coefficients is used, with a cut-off frequency at $5F_s/256$ kHz (the filter delay is 12 samples).

7.18 Audio pre-roll

7.18.1 General

The *AudioPreRoll()* syntax element is used to transmit audio information of previous frames along with the data of the present frame. The additional audio data can be used to compensate the decoder startup delay (pre-roll), thus enabling random access at stream access points (SAP) that make use of *AudioPreRoll()*.

A *UsacExtElement()* with the `usacExtElementType` of ID_EXT_ELE_AUDIOPREROLL shall be used to transmit the *AudioPreRoll()*.

For carriage of USAC streams in ISO base media file format as specified in ISO/IEC 14496-12, further requirements are applicable and shall be utilized in accordance with Annex H.

7.18.2 Semantics

configLen	Size of the configuration syntax element in bytes.
Config()	The decoder configuration syntax element. In the context of this standard this shall be the <i>UsacConfig()</i> as defined in 5.2. The <i>Config()</i> field may be transmitted to be able to respond to changes in the audio configuration (e.g., switching of streams).
applyCrossfade	If this flag is set to 1, a linear crossfade shall be applied in case of configuration change, as defined in 7.18.3.3.
reserved	Reserved bit shall be zero.
numPreRollFrames	The number of pre-roll access units (AUs) transmitted as audio pre-roll data. The reasonable number of AUs depends on the decoder start-up delay.
auLen	AU length in bytes.
AccessUnit()	The pre-roll AU(s).

The pre-roll data carried in the extension element may be excluded from buffer requirement restrictions, i. e. the buffer requirements may not be satisfied.

In order to use *AudioPreRoll()* for both random access and bitrate adaptation the following restrictions apply:

- The first element of every frame shall be an extension element (*UsacExtElement*) of type *ID_EXT_ELE_AUDIOPREROLL*.
- The corresponding *UsacExtElement()* shall be configured as specified in Table 156.
- Consequently, if pre-roll data is present, this *UsacFrame()* shall start with the following bit sequence:
 - “1”: *usacIndependencyFlag*.
 - “1”: *usacExtElementPresent* (referring to audio pre-roll extension element).
 - “0”: *usacExtElementUseDefaultLength* (referring to audio pre-roll extension element).
- If no *AudioPreRoll()* is transmitted, the extension payload shall not be present (*usacExtElementPresent* = 0).
- The pre-roll frames with index “0” shall be independently decodable, i.e., *usacIndependencyFlag* shall be set to “1”.
- In access units that are embedded as pre-roll in an *AudioPreRoll()* extension the *usacExtElementPresent* field for extensions of type *ID_EXT_ELE_AUDIOPREROLL* shall be 0.

Table 156 — Setup of *UsacExtElementConfig()* for *AudioPreRoll()*

Bitstream field	Value
<i>usacExtElementType</i>	<i>ID_EXT_ELE_AUDIOPREROLL</i>
<i>usacExtElementConfigLength</i>	0
<i>usacExtElementDefaultLengthPresent</i>	0
<i>usacExtElementPayloadFrag</i>	0

7.18.3 Decoding process

7.18.3.1 General

This subclause describes the decoding process for both random access/immediate play-out and bitrate adoption scenarios.

7.18.3.2 Random access and immediate play-out

Random access and immediate play-out is possible at every frame that utilizes the *AudioPreRoll()* structure as specified in this subclause. The following pseudo code describes the decoding process:

```

if(usacIndependencyFlag == 1){
    if(usacExtElementPresent == 1){

        /* In this case usacExtElementUseDefaultLength shall be 0! */
        if(usacExtElementUseDefaultLength != 0) goto error;

        /* Not used */
        getUsacExtElementPayloadLength();

        /* Check for presence of config and re-initialize if necessary */
        int configLen = getConfigLen();
        if(configLen > 0){

```

```

    config c = getConfig(configLen);
    ReConfigureDecoder(c);
}

/* Get pre-roll AUs and decode, discard output samples */
int numPreRollFrames = getNumPreRollFrames();
for(auIdx = 0; auIdx < numPreRollFrames; auIdx++) {
    int auLen = getAuLen();
    AU nextAU = getPreRollAU(auLen);
    DecodeAU(nextAU);
}
}
}
/* Internal decoder states are initialized at this point. Continue normal decoding */

```

7.18.3.3 Bitrate adaption

Bitrate adaption may be utilized by switching between different encoded representations of the same audio content. The *AudioPreRoll()* structure as specified in this subclause may be used for that purpose. The decoding process in case of bitrate adaption is specified by the following pseudo code:

```

if(usacIndependencyFlag == 1){
    if(usacExtElementPresent == 1{

        /* In this case usacExtElementUseDefaultLength shall be 0! */
        if(usacExtElementUseDefaultLength != 0) goto error;

        /* Not used */
        getUsacExtElementPayloadLength();

        int configLen = getConfigLen();
        if(configLen > 0){
            config newConfig = getConfig(configLen);

            /* Configuration did not change, skip AudioPreRoll and continue decoding as
normal */
            if(newConfig == currentConfig){
                SkipAudioPreRoll();
                goto finish;
            }

            /* Configuration changed, prepare for bitstream switching */
            outSamplesFlush = FlushDecoder();
            ReConfigureDecoder(newConfig);

            /* Get pre-roll AUs and decode, discard output samples */
            int numPreRollFrames = getNumPreRollFrames();
            for(auIdx = 0; auIdx < numPreRollFrames; auIdx++) {
                int auLen = getAuLen();
                AU nextAU = getPreRollAU(auLen);
                DecodeAU(nextAU);
            }

            /* Get "regular" AU and decode */
            AU au = UsacFrame();
            outSamplesFrame = DecodeAU(au);
        }
    }
}

```

```

/* Apply crossfade only on the output samples*/
If(applyCrossfade) {
    for(i = 0; i < 128; i++){
        outSamples[i] = outSamplesFlush[i] * (1-i/127) +
            outSamplesFrame[i] * (i/127)
    }
} else {
    for(i = 0; i < 128; i++) {
        outSamples[i] = outSamplesFrame[i];
    }
}
for(i = 128; i < outputFrameLength; i++){
    outSamples[i] = outSamplesFrame[i];
}
}
}

```

If a configuration change is detected by the decoder the following steps shall be applied:

- Flush the internal decoder states and buffers (FlushDecoder()), i.e., decode a hypothetical access unit composed of all zero samples. Store the resulting output samples (outSamplesFlush) in a temporary buffer.
- Re-initialize the decoder with the new configuration (ReConfigureDecoder()).
- Decode all contained pre-roll AUs and discard the resulting output.
- Decode the current AU (UsacFrame()). Store the resulting output samples (outSamplesFrame) in a temporary buffer.
- In case **applyCrossfade** is set to 1 and operates in the time domain, a linear cross-fade of length 128 on outSamplesFlush and outSamplesFrame shall be applied to avoid switching artifacts.

8 Conformance testing

8.1 General

This clause specifies conformance criteria for both bitstreams and decoders compliant with the USAC standard as defined in this document. This is done to assist implementers and to ensure interoperability.

8.2 USAC conformance testing

8.2.1 Profiles

Profiles are defined in 4.5. Some conformance criteria apply to USAC in general, while others are specific to certain profiles and their respective levels. Conformance shall be tested for the level of the profile with which a given bitstream or decoder claims to comply.

In addition to the conformance requirements described in this clause, a decoder which claims to comply with the Extended HE AAC Profile shall fulfil conformance for the HE AAC v2 profile according to ISO/IEC 14496-26.

8.2.2 Conformance tools and test procedure

8.2.2.1 General

To test USAC compliant audio decoders, this document provides a number of conformance test sequences. Supplied sequences cover all profiles as defined in 4.5. For a given test sequence, testing can be performed by comparing the output of a decoder under test with a reference waveform. For some test sequences, the decoder requires additional input parameters, so-called decoder settings, which are defined in 8.5. In cases where the decoder under test is followed by additional operations (e.g., quantizing a signal to a 16 bit output signal) the conformance point is prior to such additional operations, i.e., it is permitted to use the actual decoder output (e.g., with more than 16 bit) for conformance testing.

Measurements are carried out relative to full scale where the output signals of the decoders are normalized to be in the range between -1.0 and $+1.0$.

In ISO/IEC 14496-26 a set of test methods is defined to test the output of the decoder under test against the reference output. RMS/LSB Measurement, Segmental SNR and PNS conformance criteria are used for the comparison. A particular test method for a certain test sequence is specified in 8.5.

For elements producing output that cannot be tested with the methods described in ISO/IEC 14496-26 specific conformance testing procedures are described in 8.5.

8.2.2.2 Conformance data

All test sequences and an MS Excel™ worksheet ("Usac_Conformance_Tables.xlsx") that lists all test sequences for each module are accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>.

NOTE All conformance test sequences for ISO/IEC 23003-3 are accessible using this link. All electronic attachments to the first edition of this document (and its Amendments) are replaced by those at this link.

For all conformance test sequences, the file names are composed of several parts which convey information about:

- which module of the decoder is tested;
- which channelConfigurationIndex is employed;
- which test conditions apply to the test sequence;
- which coreSbrFrameLengthIndex applies to the test sequence;
- which sampling frequency is signalled in the test sequence.

The file naming convention given in Table 157 shall be used.

Table 157 — File name conventions

Module	File	File name
Frequency domain coding (FD mode), 8.3.4	compressed mp4	Fd_<cCI>_c<cSFLI>_<testCase>_<uSFI>.mp4
	reference wav	Fd_<cCI>_c<cSFLI>_<testCase>_<uSFI>.wav
Linear predictive domain coding (LPD mode), 8.3.5	compressed mp4	Lpd_<cCI>_c<cSFLI>_<testCase>_<uSFI>.mp4
	reference wav	Lpd_<cCI>_c<cSFLI>_<testCase>_<uSFI>.wav
Combined core coding tools, 8.3.6	compressed mp4	Cct_<cCI>_c<cSFLI>_<testCase>_<uSFI>.mp4
	reference wav	Cct_<cCI>_c<cSFLI>_<testCase>_<uSFI>.wav
Enhanced spectral band replication (eSBR), 8.3.7	compressed mp4	eSbr_<cCI>_c<cSFLI>_<testCase>_<uSFI>.mp4
	reference wav	eSbr_<cCI>_c<cSFLI>_<testCase>_<uSFI>.wav
MPEG Surround 2-1-2, 8.3.10	compressed mp4	Mps_<cCI>_c<cSFLI>_fr<bsFR>_Sc<sCI>_<testCase>_<uSFI>.mp4
	reference wav	Mps_<cCI>_c<cSFLI>_fr<bsFR>_Sc<sCI>_<testCase>_<uSFI>.wav
Bitstream extensions	compressed mp4	Ext_<cCI>_c<cSFLI>_<testCase>_<uSFI>.mp4
	reference wav	Ext_<cCI>_c<cSFLI>_<testCase>_<uSFI>_<decoderSetting>.wav

<cCI>

channelConfigurationIndex as described in Table 73.

<testCase>

Setup string. May consist of a concatenation of one or more abbreviations as listed in Table 158. If no setup string is specified the basic test conditions apply. If no testCase is added, only one single underline character shall occur at that position.

<cSFLI>

coreSbrFrameLengthIndex as described in 6.1.1.1.

<uSFI>

usacSamplingFrequencyIndex as described in Table 75. If the sampling rate is specified explicitly and signalled by means of the escape value index the sampling rate value in Hz is placed in the file name instead of the index value, e.g., "Lpd_1_c1_Bpf_6000.mp4" for a sampling frequency of 6000 Hz.

<bsFR>

bsFreqRes as described in ISO/IEC 23003-1:2007, Table 39.

<sCI>

stereoConfigIndex as described in Table 77.

<decoderSetting>

Setup string. May consist of a concatenation of one or more abbreviations as listed in Table 159. If no decoderSetting is added, no underline character shall occur after <uSFI>.

Table 158 — Test conditions and abbreviations

FD core mode	
Test condition	Abbrev.
FD window switching test condition	Win
Noise filling test condition	Nf
Tns test condition	Tns
Varying max_sfb test condition	Sfb
Handling of extensions condition	Ex
Context adaptive arithmetic coder test condition	Ac
Non-meaningful FD window switching test condition	Nmf
M/S stereo test condition	Ms
Complex prediction stereo test condition	Cp

LPD core mode	
Test condition	Abbrev.
LPC coding test condition	Lpc
ACELP core mode test condition	Ace
TCX and noise filling test condition	Tcx
LPD mode coverage and FAC test condition	Lpd
Bass-post filter test condition	Bpf
AVQ test condition	Avq

Combined core coding	
Test condition	Abbrev.
FD-LPD transition and FAC test condition	Flt
FD/TCX noise filling test condition	Cnf
Bass-post filter test condition	Cbf
synchron. FD-LPD transition and FAC test condition	Flts
asynchron. FD-LPD transition and FAC test condition	Flta
Context adaptive arithmetic coder test condition	CAC

eSbr	
Test condition	Abbrev.
QMF accuracy test condition	Qma
Envelope adjuster accuracy and SBR preprocessing test condition	Eaa
Header and grid control test condition	Hgt
Inverse filtering test condition	Ift
Additional sine test (missing harmonics) test condition	Ast
Sampling rate test condition	Sr
Channel mode test condition	Cm
interTes test condition	Tes
PVC test condition	Pvc
Harmonic transposition (QMF) test condition	Htg
Harmonic transposition (crossproducts) test condition	Xp
Transposer toggle test condition	Ttt
Envelope shaping toggle (PVC on/off) test condition	Est
Varying crossover frequency test condition	Xo
stereoConfigIndex test condition	Mps

MPEG Surround 212	
Test condition	Abbrev.
TSD test condition	Tsd
Rate mode test condition	Rm
Phase coding test condition	Pc
Decorrelator configuration. test condition	Dc
DMX gain test condition	Dm
Bands phase test condition	Bp<X>
Pseudo lr test condition	Plr
Residual bands test condition	Rb<X>
Temporal Shaping Enabling test condition	Tse<X>
Smoothing mode test condition	Smg

Bitstream extensions	
Test condition	Abbrev.
AudioPreRoll() and streamID condition, immediate play-out frame (IPF)	I-foo-<x>
Loudness normalization test condition	Ln
Dynamic range control test condition	Drc<x>

Table 159 — Decoder setting conditions

Decoder setting	Abbrev.
Target loudness	Lou-<x>
DRC effect type request	Eff-<x>

8.3 USAC bitstreams

8.3.1 General

8.3.1.1 Characteristics

Characteristics of bitstreams specify the constraints that are applied by the encoder in generating the bitstreams. These syntactic and semantic constraints may, for example, restrict the range or the values of parameters that are encoded directly or indirectly in the bitstreams. The constraints applied to a given bitstreams may or may not be known a priori.

8.3.1.2 Test procedure

Each USAC bitstream shall meet the syntactic and semantic requirements specified in this document. The present subclause defines the conformance criteria that shall be fulfilled by a compliant bitstream. These criteria are specified for the syntactic elements of the bitstream and for some parameters decoded from the USAC bitstream payload.

For each tool a set of semantic tests to be performed on the bitstreams is described. To verify whether the syntax is correct is straightforward and therefore not defined herein after. In the description of the semantic tests it is assumed that the tested bitstreams contains no errors due to transmission or other causes. For each test the condition or conditions that shall be satisfied are given, as well as the prerequisites or conditions in which the test can be applied.

8.3.2 USAC configuration

8.3.2.1 Characteristics

Encoders may apply restrictions to the following parameters of the bitstream:

- a) usacSamplingFrequencyIndex;
- b) usacSamplingFrequency;
- c) coreSbrFrameLengthIndex;
- d) channelConfigurationIndex;
- e) presence of configuration extensions;
- f) numOutChannels;
- g) bsOutputChannelPos;
- h) numElements;
- i) stereoConfigIndex;
- j) use of time warped MDCT;
- k) use of noise filling in FD mode;
- l) use of the eSBR harmonic transposer;
- m) use of the eSBR inter-TES tool;

- n) use of the eSBR PVC tool;
- o) SBR default header, for details see 8.3.7;
- p) MPS config, for details see 8.3.10.

8.3.2.2 Test procedure

8.3.2.2.1 UsacConfig()

usacSamplingFrequencyIndex	Shall be encoded with a non-reserved value specified in Table 72. For further profile and level dependent restrictions see 8.3.11.
usacSamplingFrequency	No restrictions apply. For profile and level dependent restrictions see 8.3.11.
coreSbrFrameLengthIndex	No restrictions apply.
channelConfigurationIndex	Shall be encoded with a non-reserved value specified in Table 73. For further profile and level dependent restrictions see 8.3.11. In the case of channelConfigurationIndex==0 further restrictions apply as described in 8.3.2.2.2.
usacConfigExtensionPresent	No restrictions apply.

8.3.2.2.2 UsacChannelConfig()

numOutChannels	No restrictions apply. For profile and level dependent restrictions see 8.3.11.
bsOutputChannelPos	A bsOutputChannelPos of value 3 or 26 (LFE speaker positions) shall be associated with an LFE channel. Any other value shall be associated with a main audio channel.

8.3.2.2.3 UsacDecoderConfig()

numElements	The value of this data element shall be such that the accumulated sum of all channels contained in the bitstream complies with the restrictions outlined in 8.3.2.2.1.
usacElementType	No restrictions apply. For profile and level dependent restrictions see 8.3.11.

8.3.2.2.4 UsacSingleChannelElementConfig()

No restrictions are applicable to this bitstream element.

8.3.2.2.5 UsacChannelPairElementConfig()

NOTE The UsacChannelPairElementConfig() element and all included elements might only be present when coding more than one output channel (see restrictions applying to UsacConfig() in 8.3.2.2.1).

stereoConfigIndex	No restrictions apply.
--------------------------	------------------------

8.3.2.2.6 UsacLfeElementConfig()

No restrictions are applicable to this bitstream element.

8.3.2.2.7 UsacCoreConfig()

tw_mdct No restrictions apply. For profile and level dependent restrictions see 8.3.11.

noiseFilling No restrictions apply.

8.3.2.2.8 SbrConfig()

harmonicSBR No restrictions apply.

bs_interTes No restrictions apply.

bs_pvc No restrictions apply.

8.3.2.2.9 SbrDfltHeader()

dflt_start_freq No restrictions apply.

dflt_stop_freq No restrictions apply.

dflt_header_extra1 No restrictions apply.

dflt_header_extra2 No restrictions apply.

dflt_freq_scale No restrictions apply.

dflt_alter_scale No restrictions apply.

dflt_nose_bands No restrictions apply.

dflt_limiter_bands No restrictions apply.

dflt_limiter_gains No restrictions apply.

dflt_interpol_freq No restrictions apply.

dflt_smoothing_mode No restrictions apply.

8.3.2.2.10 Mps212Config()

bsFreqRes Shall not be encoded with a value of 0.

bsFixedGainDMX No restrictions apply.

bsTempShapeConfig No restrictions apply.

bsDecorrConfig Shall not be encoded with a value of 3.

bsHighRateMode No restrictions apply.

bsPhaseCoding No restrictions apply.

bsOttBandsPhasePresent No restrictions apply.

bsOttBandsPhase Shall not be encoded with a value larger than the value of numBands as given by ISO/IEC 23003-1:2007, 5.2, Table 39 and depends on bsFreqRes.

bsResidualBands Shall not be encoded with a value larger than the value of numBands as given by ISO/IEC 23003-1:2007, 5.2, Table 39 and depends on bsFreqRes.

bsPseudoLr No restrictions apply.

bsEnvQuantMode Shall be 0.

8.3.2.2.11 UsacExtElementConfig()

usacExtElementType	No restrictions apply.
usacExtElementConfigLength	No restrictions apply.
usacExtElementDefaultLengthPresent	No restrictions apply.
usacExtElementDefaultLength	No restrictions apply.
usacExtElementPayloadFrag	No restrictions apply.

8.3.2.2.12 UsacConfigExtension()

numConfigExtensions	No restrictions apply.
usacConfigExtType[]	No restrictions apply.
usacConfigExtLength[]	No restrictions apply.
fill_byte	Should be '10100101'.

8.3.3 Framework**8.3.3.1 Characteristics**

Encoders may apply restrictions to the following parameters of the bitstream:

- a) signalling of independently decodable frames;
- b) presence of extension elements;
- c) core_mode;
- d) presence of TNS.

8.3.3.2 Test procedure**8.3.3.2.1 UsacFrame()**

usacIndependencyFlag	No restrictions apply.
-----------------------------	------------------------

8.3.3.2.2 UsacSingleChannelElement

No restrictions are applicable to this bitstream element.

8.3.3.2.3 UsacChannelPairElement

No restrictions are applicable to this bitstream element.

8.3.3.2.4 UsacLfeElement

No restrictions are applicable to this bitstream element.

8.3.3.2.5 UsacExtElement

usacExtElementPresent	No restrictions apply.
usacExtElementUseDefaultLength	No restrictions apply.
usacExtElementPayloadLength	No restrictions apply.
usacExtElementStart	No restrictions apply.
usacExtElementStop	No restrictions apply.
usacExtElementSegmentData	No restrictions apply.

8.3.3.2.6 UsacCoreCoderData

core_mode	No restrictions apply.
tns_data_present	No restrictions apply.

8.3.4 Frequency domain coding (FD mode)

8.3.4.1 Characteristics

Encoders may apply restrictions to the following parameters of the bitstream:

- a) use of noise filling;
- b) window_shape;
- c) M/S Stereo;
- d) use of TNS;
- e) complex prediction stereo coding;
- f) max_sfb;
- g) use of time warped MDCT;
- h) use of long blocks;
- i) use of short blocks.

8.3.4.2 Test procedure

8.3.4.2.1 fd_channel_stream

global_gain	No restrictions apply.
noise_level	No restrictions apply.
noise_offset	No restrictions apply.
fac_data_present	Shall be 0, if the core_mode of the preceding frame of the same channel was 0 or if mod[3] of the preceding frame of the same channel was > 0.

8.3.4.2.2 ics_info

window_sequence A conformant bitstream shall consist of only meaningful window_sequence transitions. However, decoders are required to handle non-meaningful window_sequence transitions as well. The meaningful window_sequence transitions are shown in Table 138.

window_shape A compliant bitstream shall set window_shape to 0 if the next block is encoded in LPD coding mode. However, decoders are required to handle both window_shapes for all transitions.

max_sfb Shall be $\leq$ num_swb_long or num_swb_short as appropriate for window_sequence and sampling frequency and core coder frame length.

scale_factor_grouping No restrictions apply.

8.3.4.2.3 tw_data

tw_data_present No restrictions apply.

tw_ratio No restrictions apply.

8.3.4.2.4 scale_factor_data

hcod_sf Shall only be encoded with the values listed in the scalefactor Huffman table. Shall be encoded such that the decoded scalefactors $sf[g][sfb]$ are within the range of zero to 255, both inclusive.

8.3.4.2.5 tns_data

n_filt No restrictions apply.

coef_res No restrictions apply.

length Shall be small enough such that the lower bound of the filtered region, does not exceed the start of the array containing the spectral coefficients.

order Shall not exceed the values listed in Table 135.

direction No restrictions apply.

coef_compress No restrictions apply.

coef No restrictions apply.

8.3.4.2.6 ac_spectral_data

arith_reset_flag No restrictions apply.

8.3.4.2.7 StereoCoreToolInfo

tns_active No restrictions apply.

common_window No restrictions apply.

common_max_sfb No restrictions apply.

max_sfb1 Shall be $\leq$ num_swb_long or num_swb_short as appropriate for window_sequence and sampling frequency and core coder frame length.

ms_mask_present No restrictions apply.

ms_used	No restrictions apply.
common_tw	No restrictions apply.
common_tns	No restrictions apply.
tns_on_lr	No restrictions apply.
tns_present_both	No restrictions apply.
tns_data_present	No restrictions apply.

8.3.4.2.8 cplx_pred_data

cplx_pred_all	No restrictions apply.
cplx_pred_used	No restrictions apply.
pred_dir	No restrictions apply.
complex_coef	No restrictions apply.
use_prev_frame	Shall be 0 if the core transform length of previous frame is different from the core transform length of the current frame or if the core_mode of the previous frame is 1.
delta_code_time	No restrictions apply.
hcod_sf	No restrictions apply.

8.3.5 Linear predictive domain coding (LPD mode)

8.3.5.1 Characteristics

Encoders may apply restrictions to the following parameters of the bitstream:

- a) **acelp_core_mode**;
- b) **lpd_mode** (use of ACELP, short TCX, medium TCX, and long TCX);
- c) activation of bass-post filter.

8.3.5.2 Test procedure

8.3.5.2.1 lpd_channel_stream

acelp_core_mode	Shall be encoded with a value in the range of 0 to 5, both inclusive.
lpd_mode	Shall be encoded with a non-reserved value listed in Table 94.
bpf_control_info	No restrictions apply.
core_mode_last	Shall be encoded with the value of data element core_mode of the previous frame.
fac_data_present	Shall be 0, if the core_mode of the preceding frame of the same channel was 0 and mod[0] of the current frame is > 0, or if mod[0] of the current frame is > 0 and mod[3] of the preceding frame of the same channel was > 0.
short_fac_flag	Shall be encoded with a value of 1 if the window_sequence of the previous frame was 2 (EIGHT_SHORT_SEQUENCE). Otherwise short_fac_flag shall be encoded with a value of 0.

8.3.5.2.2 lpc_data

lpc_first_approximation_index No restrictions apply.

8.3.5.2.3 qn_data

qn The codebook number shall be encoded as described in 7.13.7.2.

qn_base No restrictions apply.

qn_ext No restrictions apply.

8.3.5.2.4 get_mode_lpc

binary_code Shall be encoded with the values listed in Table 148 in the column binary code.

8.3.5.2.5 code_book_indices

code_book_index No restrictions apply.

kv No restrictions apply.

8.3.5.2.6 acelp_coding

mean_energy No restrictions apply.

acb_index The adaptive codebook index shall be encoded as described in 7.14.5.1.

ltf_filtering_flag No restrictions apply.

icb_index The innovation codebook excitation shall be encoded as described in 7.14.5.2.

gains No restrictions apply.

8.3.5.2.7 tcx_coding

noise_factor No restrictions apply.

global_gain No restrictions apply.

arith_reset_flag No restrictions apply.

8.3.6 Common core coding tools**8.3.6.1 Characteristics**

Encoders may apply restrictions to the following parameters of the bitstream:

- a) use of context adaptive arithmetic coder reset.

8.3.6.2 Test procedure**8.3.6.2.1 arith_data**

acod_m Shall be encoded as described in 7.4.3.

acod_r Shall be encoded as described in 7.4.3.

s No restrictions apply.

8.3.6.2.2 fac_data

fac_gain No restrictions apply.

8.3.7 Enhanced spectral band replication (eSBR)

8.3.7.1 Characteristics

Encoders may apply restrictions to the following parameters of the bitstream:

- a) use of the eSBR harmonic transposer;
- b) use of Crossproducts in eSBR harmonic transposer;
- c) use of the eSBR inter-TES tool;
- d) choice of SBR ratio;
- e) choice of amplitude resolution;
- f) choice of SBR crossover band;
- g) use of SBR preprocessing (prewhitening);
- h) use of the eSBR PVC tool.

8.3.7.2 Test procedure

8.3.7.2.1 General

The present subclause defines the conformance criteria that shall be fulfilled by a compliant bitstream that utilize the enhanced SBR tool.

8.3.7.2.2 UsacSbrData

sbrInfoPresent No restrictions apply.
sbrHeaderPresent No restrictions apply.
sbrUseDfltHeader No restrictions apply.

8.3.7.2.3 SbrInfo

bs_amp_res No restrictions apply.
bs_xover_band Shall define a value that does not exceed the limits defined in ISO/IEC 14496-3:2019, 4.6.18.3.6.
bs_sbr_preprocessing No restrictions apply.
bs_pvc_mode Shall be encoded with a non-reserved value specified in Table 101.

8.3.7.2.4 SbrHeader

bs_start_freq Shall define a frequency band that does not exceed the limits defined in 7.5.5 and ISO/IEC 14496-3:2019, 4.6.18.3.6.
bs_stop_freq Shall define a frequency band that does not exceed the limits defined in 7.5.5 and ISO/IEC 14496-3:2019, 4.6.18.3.6.

bs_header_extra1	No restrictions apply.
bs_header_extra2	No restrictions apply.
bs_freq_scale	No restrictions apply.
bs_alter_scale	No restrictions apply.
bs_noise_bands	Shall define a value that does not exceed the limits defined in ISO/IEC 14496-3:2019, 4.6.18.3.6.
bs_limiter_bands	No restrictions apply.
bs_limiter_gains	No restrictions apply.
bs_interpol_freq	No restrictions apply.
bs_smoothing_mode	No restrictions apply.

8.3.7.2.5 sbr_single_channel_element

sbrPatchingMode	No restrictions apply.
sbrOversamplingFlag	No restrictions apply.
sbrPitchInBinsFlag	No restrictions apply.
sbrPitchInBins	No restrictions apply.
bs_add_harmonic_flag	No restrictions apply.

8.3.7.2.6 sbr_channel_pair_element

bs_coupling	No restrictions apply.
sbrPatchingMode	No restrictions apply.
sbrOversamplingFlag	No restrictions apply.
sbrPitchInBinsFlag	No restrictions apply.
sbrPitchInBins	No restrictions apply.
bs_add_harmonic_flag	No restrictions apply.

8.3.7.2.7 sbr_grid

bs_frame_class	Shall define a value that does not exceed the limits defined in 7.5.1.3 and ISO/IEC 14496-3:2019, 4.6.18.3.6.
tmp	(Determines bs_num_env), no restrictions apply.
bs_freq_res	No restrictions apply.
bs_pointer	Shall be encoded with a value listed in ISO/IEC 14496-3:2019, Table 4.193.

The restrictions defined in ISO/IEC 14496-26:2010, 7.17.1.2.1.3 sbr_grid() shall be applied to the following corresponding bitstream elements:

bs_var_bord_0	
bs_var_bord_1	
bs_num_rel_0	
bs_num_rel_1	
bs_noise_position	Shall be chosen so that the time slot borders for noise floors fall within the leading and trailing SBR frame borders (i.e., the SBR frame boundaries).
bs_var_len_hf	Shall be encoded with a non-reserved value specified in Table 102.

8.3.7.2.8 sbr_envelope

bs_env_start_value_balance	No restrictions apply.
bs_env_start_value_level	No restrictions apply.
bs_codeword	Shall be encoded as defined in sbr_huff_dec() in ISO/IEC 14496-3:2019, 4.A.6.1.

Additionally, the restrictions defined in ISO/IEC 14496-26:2010, 7.17.1.2.1.5 sbr_envelope() apply.

8.3.7.2.9 dtdf

bs_df_env	No restrictions apply.
bs_df_noise	No restrictions apply.

8.3.7.2.10 sbr_sinusoidal_coding

bs_add_harmonic	No restrictions apply.
bs_sinusoidal_position_flag	No restrictions apply.
bs_sinusoidal_position	Shall be chosen so that the position of the starting time slot for sinusoidals fall within the SBR frame boundaries.

8.3.7.2.11 sbr_invf

No restrictions are applicable to this bitstream element.

8.3.7.2.12 sbr_noise

The restrictions defined in ISO/IEC 14496-26:2010, 7.17.1.2.1.6 sbr_noise() apply.

8.3.8 eSBR – Predictive vector coding (PVC)

8.3.8.1 Characteristics

Encoders may apply restrictions to the following parameters of the bitstream:

- a) activation of PVC;
- b) use of IDs from the previous frame;
- c) length.

8.3.8.2 Test procedures for pvc_envelope

divMode	No restrictions apply.
nsMode	No restrictions apply.
Reuse_pvcID	Shall be 0 if the bs_pvc_mode of the preceding SBR frame was 0.
pvcID	No restrictions apply.
length	Shall be chosen so that the time slot borders for pvcid fall within the SBR frame boundaries.
grid_info	The first grid_info (grid_info[0]) shall be 1 if the bs_pvc_mode of the preceding SBR frame was 0.

8.3.9 eSBR – Inter temporal envelope shaping (inter-TES)

8.3.9.1 Characteristics

Encoders may apply restrictions to the following parameters of the bitstream:

- a) activation of inter-TES.

8.3.9.2 Test procedure for sbr_envelope

bs_temp_shape No restrictions apply.

bs_inter_temp_shape_mode No restrictions apply.

8.3.10 MPEG Surround 2-1-2

8.3.10.1 Characteristics

Encoders may apply restrictions to the following parameters of the bitstream:

- a) use of phase coding;
- b) use of residual coding;
- c) use of pseudo LR;
- d) use of transient steering decorrelator.

8.3.10.2 Test procedure

8.3.10.2.1 Mps212Data

bsIndependencyFlag No restrictions apply.

8.3.10.2.2 FramingInfo

bsFramingType No restrictions apply.

bsNumParamSets Shall have a value not larger than $(\text{numSlots}-1)/4$, where the division shall be interpreted as an ANSI C integer division.

bsParamSlot Shall be in the range 0..numSlots-1.

8.3.10.2.3 OttData

bsPhaseMode No restrictions apply.

bsOPDSmoothingMode No restrictions apply.

8.3.10.2.4 SmgData

bsSmoothMode No restrictions apply.

bsSmoothTime No restrictions apply.

bsFreqResStrideSmg No restrictions apply.

bsSmgData No restrictions apply.

8.3.10.2.5 TempShapeData

bsTsdEnable	No restrictions apply.
bsTempShapeEnable	No restrictions apply.
bsTempShapeEnableChannel	No restrictions apply.

8.3.10.2.6 TsdData

bsTsdNumTrSlots	Shall be encoded with 4 or 5 bits depending on numSlots.
bsTsdCodedPos	No restrictions apply.
bsTsdTrPhaseData	No restrictions apply.

8.3.10.2.7 EcData

bsXXXdataMode	Shall fulfil the requirements outlined in ISO/IEC 23003-1:2007, 6.1.13. Shall not be encoded with a value of 2 if residual coding is applied. Shall have the value 0 or 3 if ps==0 and bsindependencyflag is set to 1.
bsDataPairXXX	Shall have the value 0 if setidx == datasets-1. No further restrictions apply.
bsQuantCoarseXXX	No restrictions apply.
bsFreqResStrideXXX	No restrictions apply.

8.3.10.2.8 EcDataPair

bsPcmCodingXXX	No restrictions apply.
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8.3.10.2.9 GroupedPcmData

bsPcmWord	No restrictions apply.
------------------	------------------------

8.3.10.2.10 DiffHuffData

bsDiffType	No restrictions apply.
bsCodingScheme	No restrictions apply.
bsPairing	No restrictions apply.
bsDiffTimeDirection	No restrictions apply.

8.3.10.2.11 HuffData1D

hcodFirstband_XXX	bsCodeW shall have a value out of a set of values as defined by column 'codeword' in ISO/IEC 23003-1:2007, Tables A.2 and A.3, for CLD and ICC respectively. For IPD, in Table A.2. Shall have a length as defined by the corresponding entry in column 'length'.
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hcod1D_XXX_YY	bsCodeW shall have a value out of a set of values as defined by column 'codeword' in ISO/IEC 23003-1:2007, Tables A.5 and A.6, for CLD and ICC respectively. For IPD, in Table A.3. Shall have a length as defined by the corresponding entry in column 'length'.
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bsSign	Do not apply to the encoding of IPD parameters. No further restrictions apply.
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8.3.10.2.12 HuffData2DFreqPair, HuffData2DTimePair

hcodLavIdx	bsCodeW shall have a value out of a set of values as defined by column 'codeword' in ISO/IEC 23003-1:2007, Tables A.24, and shall have a length as defined by the corresponding entry in column 'length'.
hcod2D_XXX_YY_ZZ_LL_escape	bsCodeW shall have a value out of a set of values as defined by column 'codeword' in ISO/IEC 23003-1:2007, Tables A.8 and A.9, for CLD and ICC respectively. For IPD, in Table A.4. Shall have a length as defined by the corresponding entry in column 'length'.
hcod2D_XXX_YY_ZZ_LL	bsCodeW shall have a value out of a set of values as defined by column 'codeword' of the applicable table in ISO/IEC 23003-1:2007, Tables A.11 to A.18, for CLD and ICC. For IPD, in Tables A.5 to A.8. Shall have a length as defined by the corresponding entry in column 'length'.

8.3.10.2.13 SymmetryData

bsSymBit	No restrictions apply.
-----------------	------------------------

8.3.10.2.14 LsbData

bsLsb	No restrictions apply.
--------------	------------------------

8.3.11 Configuration Extensions**8.3.11.1 streamId()**

streamIdentifier	No restrictions apply.
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8.3.11.2 loudnessInfoSet()

The loudnessInfoSet() bitstream structure shall be restricted as specified in ISO/IEC 23003-4.

8.3.12 AudioPreRoll**8.3.12.1.1 Recursive presence of AudioPreRoll extension payload**

An access unit which is part of an AudioPreRoll shall not have usacExtElementPresent equal to 1 for the extension payload type ID_EXT_ELE_AUDIOPREROLL. That means there shall be no recursively embedded AudioPreRoll extension payload.

8.3.12.1.2 AudioPreRoll()

configLen	No restrictions apply.
applyCrossfade	No restrictions apply.
reserved	Should be 0.
numPreRollFrames	Shall not be larger than 3.
auLen	No restrictions apply.

8.3.13 DRC

8.3.13.1 uniDrcConfig()

The uniDrcConfig bitstream structure shall be restricted as specified in ISO/IEC 23003-4.

8.3.13.2 uniDrcGain()

The uniDrcGain bitstream structure shall be restricted as specified in ISO/IEC 23003-4.

8.3.14 Restrictions depending on profiles and levels

8.3.14.1 General

Depending on the profile and level associated with the USAC bitstream, further restrictions may apply.

8.3.14.2 Baseline USAC profile

8.3.14.2.1 usacSamplingFrequencyIndex

For Baseline USAC Profile usacSamplingFrequencyIndex shall be encoded with a value specified in Table 160.

Table 160 — Specification of usacSamplingFrequencyIndex and usacSamplingFrequency in baseline USAC profile

	Level				
	1	2	3	4	5
usacSamplingFrequencyIndex/ usacSamplingFrequency	0x03...0x0c, 0x11...0x1b 0x1f / ≤ 48000	0x03...0x0c, 0x11...0x1b 0x1f / ≤ 48000	0x03...0x0c, 0x11...0x1b 0x1f / ≤ 48000	0x00...0x0c, 0x0f...0x1b 0x1f / ≤ 96000	N / A

Furthermore, for the baseline USAC profile the employed sampling rates shall be one out of those listed in Table 3.

8.3.14.2.2 channelConfigurationIndex

For baseline USAC profile channelConfigurationIndex shall be encoded with a value specified in Table 161.

Table 161 — Specification of channelConfigurationIndex in baseline USAC profile

	Level				
	1	2	3	4	5
channelConfigurationIndex	0, 1	0, 1, 2, 8	0..6, 8..10	0..6, 8..10	N / A

8.3.14.2.3 numOutChannels

For baseline USAC profile numOutChannels shall be encoded with a value specified in Table 162. Further restrictions apply to the number of main audio channels (channels conveyed in UsacSCEs and UsacCPEs) and LFE channels (conveyed in UsacLFEs) as shown in Table 162.

**Table 162 — Specification of numOutChannels
for baseline USAC profile**

	Level				
	1	2	3	4	5
numOutChannels	≤ 1	≤ 2	≤ 6	≤ 6	N / A
number of main audio channels	≤ 1	≤ 2	≤ 5	≤ 5	N / A
number of LFE channels	0	0	≤ 1	≤ 1	N / A

8.3.14.2.4 usacElementType

For the baseline USAC profile usacElementType shall take values such that the number of main audio channels and LFE channels comply with the restrictions outlined in 0.

8.3.14.2.5 tw_mdct

For baseline USAC profile tw_mdct shall be encoded with 0.

8.3.14.2.6 tw_data

tw_data should not be present in baseline USAC profile complying bitstreams, due to restrictions of bitstream element tw_mdct.

8.3.14.3 Extended HE AAC profile**8.3.14.3.1 usacSamplingFrequencyIndex**

For extended HE AAC profile usacSamplingFrequencyIndex shall be encoded with a value specified in Table 163.

**Table 163 — Specification of usacSamplingFrequencyIndex
and usacSamplingFrequency in extended HE AAC profile**

	Level				
	1	2	3	4	5
usacSamplingFrequencyIndex/ usacSamplingFrequency	N / A	0x03...0x0c, 0x11...0x1b 0x1f / ≤ 48000	0x03...0x0c, 0x11...0x1b 0x1f / ≤ 48000	0x03...0x0c, 0x11...0x1b 0x1f / ≤ 48000	0x03...0x0c, 0x11...0x1b 0x1f / ≤ 48000

8.3.14.3.2 channelConfigurationIndex

For extended HE AAC profile channelConfigurationIndex shall be encoded with a value specified in Table 164.

**Table 164 — Specification of channelConfigurationIndex
in extended HE AAC profile**

	Level				
	1	2	3	4	5
channelConfigurationIndex	N / A	0, 1, 2, 8	0, 1, 2, 8	0, 1, 2, 8	0, 1, 2, 8

8.3.14.3.3 numOutChannels

For extended HE AAC profile numOutChannels shall be encoded with a value specified in Table 165.

**Table 165 — Specification of numOutChannels
for extended HE AAC profile**

	Level				
	1	2	3	4	5
numOutChannels	N / A	≤ 2	≤ 2	≤ 2	≤ 2

8.3.14.3.4 tw_mdct

For extended HE AAC profile tw_mdct shall be encoded with 0.

8.3.14.3.5 tw_data

The bitstream element tw_data should not be present in extended HE AAC profile complying bitstreams, due to restrictions of bitstream element tw_mdct.

8.4 USAC decoders

8.4.1 General

This document describes a set of test conditions that shall be applied to verify that a given USAC decoder implementation complies with this standard. Test conditions are designed such that each tool can be tested isolated, thus setting the constraints for the corresponding conformance test sequences.

However, some tools show interactions and dependencies. To cover that fact, conformance test cases are defined that can be composed of one or more test conditions.

Every line in the electronic insert “Usac_Conformance_Tables.xlsx” (accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>) represents a conformance test case. For each conformance test case in the worksheet a set of conformance test sequences can also be found. Which tool or tool combination is tested by a given test sequence can be deduced from its filename, as it follows the nomenclature defined in Table 157. In most cases a conformance test sequence consists of an USAC encoded bitstream wrapped in the MP4 file format and the corresponding decoded wave file. Decoded wave files are always supplied with 24 bit resolution (RIFF (little-endian) data, WAVE audio, Microsoft PCM, 24 bit).

To claim conformance, every test sequence mandatory for a certain profile/level combination has to meet the conformance criteria specified for the given test. Bitstream restrictions depending on profile and level are described in 8.3.14.

For each conformance test case varying conformance criteria may apply. The output of the implementation under test has to be tested against the reference by applying the appropriate test procedure. Test procedures as well as constraints for each conformance test case are listed in the electronic insert “Usac_Conformance_Tables.xlsx” (accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>). All test procedures are defined in 8.3.2.

Some conformance test sequences that are defined in the USAC Conformance testing clause are not present on the conformance repository. Owing to the very unusual combination of tested parameters in certain conformance test conditions these files exhibit digital clipping and have therefore been excluded from the collection of conformance test sequences.

8.4.2 FD core mode tests

8.4.2.1 General

This subclause describes test conditions to test the transform based (FD: frequency domain) part of the decoder.

A full list of all FD core related test cases is shown in the attachment “Usac_Conformance_Tables.xlsx”: “FD core UsacSCE”, and “FD core UsacCPE”.

If not stated otherwise, the RMS test method shall be applied to all mandatory test cases. The RMS test method always includes the LSB test (RMS/LSB). The RMS/LSB measurement is defined in ISO/IEC 14496-26. The decoder under test shall satisfy the conformance criteria for at least 16 bit, if not stated otherwise in the attachment “Usac_Conformance_Tables.xlsx”.

If no test method is specified, a check of conformance using appropriate measurements, e.g., the LSB criterion or objective perceptual measurement systems, is not mandatory but highly recommended. This also applies to bitstreams with non-meaningful window sequences.

NOTE The MPEG-4 conformance tool ssnrcl can be used to apply the RMS/LSB test procedure. The tool is part of the MPEG-D USAC reference software.

If not stated otherwise the following constraints apply to all USAC FD core mode test cases:

- tests are carried out with coreSbrFrameLengthIndex 0 (768) and 1 (1024), respectively;
- the value of max_sfb is set to the maximum allowed value depending on the given sampling rate;
- sampling frequencies as defined in Table 166 are included in the tests;
- all test conditions apply to both UsacSingleChannelElement() and UsacChannelPairElement().

Table 166 — Subset of sampling rates under test (“SET”)

sampling rate / Hz	samplingFrequencyIndex
7350	0x0c
14400	0x19
22050	0x07
28800	0x14
44100	0x04
88200	0x01

The sampling frequencies in Table 166 are composed of a subset of values in Table 72 and were chosen to cover all available scale factor tables. This subset of sampling frequencies is also referred to as “SET” in this document and in the electronic insert “Usac_Conformance_Tables.xlsx” (accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>).

8.4.2.2 Basic FD test condition

8.4.2.2.1 General

The “basic FD test condition” represents a minimum setup of the FD core coder for both single channel and channel pair element.

8.4.2.2.2 Conformance test sequences

The test sequences cover the test of the basic functionalities of the USAC FD core coder. All compressed bitstreams are solely composed of long transform blocks (ONLY_LONG_SEQUENCE).

The tests are carried out at both coreSbrFrameLengthIndex 0 (768) and 1 (1024). For 1024 core coder frame length (coreSbrFrameLengthIndex == 1), additional sampling frequencies are included in the basic FD test case, as there are:

- All allowed values for the usacSamplingFrequencyIndex in Table 72 (ALL);
- The sampling frequencies 55425 Hz and 46008 Hz (arbitrary: ARB).

The sampling frequencies have to be mapped according to Table 84 to properly deduce all sampling frequency dependent tables.

For ARB sampling frequencies no `usacSamplingFrequencyIndex` is available. The sampling rate has to be transmitted by means of `usacSamplingFrequency` (24 bit, `UsacConfig()`).

The corresponding files can be identified by the names `Fd_[1|2]_c1_<uSFI>*`, where `uSFI` denotes the `usacSamplingFrequencyIndex`. If no index is available, `uSFI` is replaced by the given sampling frequency.

8.4.2.3 FD window switching test condition [Win]

8.4.2.3.1 General

This test condition shall be applied to verify the proper decoder behaviour in case a meaningful FD window sequence transition is triggered by a bitstream. Meaningful window sequence transitions are listed in Table 138. Furthermore, the test condition focuses on correct processing of all allowed short block groupings and window shapes.

8.4.2.3.2 Test sequences

Test sequences trigger window transitions as described in Table 167.

Table 167 — Window transitions

Frame	Window Sequence
1	ONLY_LONG_SEQUENCE
2	ONLY_LONG_SEQUENCE
3	LONG_START_SEQUENCE
4	EIGHT_SHORT_SEQUENCE
5	EIGHT_SHORT_SEQUENCE
6	LONG_STOP_SEQUENCE
7	ONLY_LONG_SEQUENCE
8	LONG_START_SEQUENCE
9	LONG_STOP_SEQUENCE
10	LONG_START_SEQUENCE
11	STOP_START_SEQUENCE
12	EIGHT_SHORT_SEQUENCE
13	STOP_START_SEQUENCE
14	STOP_START_SEQUENCE
15	LONG_STOP_SEQUENCE

For the FD window switching test condition [Win], the window sequences listed in Table 167 are run through twice using sine (`window_shape 0`) and KBD (`window_shape 1`). The next two frames are `window_sequence ONLY_LONG_SEQUENCE` and `LONG_START_SEQUENCE`, respectively. The next 128 frames have `window_sequence` of `EIGHT_SHORT_SEQUENCE` only and all possible combinations of `scale_factor_grouping` are transmitted. The values of `scale_factor_grouping` vary in the range from 0 to 127. The next frame has `window_sequence LONG_STOP_SEQUENCE`, after which the cycle repeats.

For test cases that combine the FD window switching test condition [Win] with other test conditions (e.g., `WinNf`), the window sequences listed in Table 167 are run through a first time using KBD (`window_shape 1`) and a second time using sine (`window_shape 0`). This set of window sequences and `window_shapes` is then repeated for the remainder of the bitstream.

8.4.2.4 Noise filling test condition [Nf]

8.4.2.4.1 General

This test condition shall be applied to verify the proper behaviour of the noise filling tool of USAC and the correct signalling of its parameters.

8.4.2.4.2 Test sequences

All bitstreams activate the noise filling tool in the UsacCoreConfig. The values of noise_level and noise_offset vary from frame to frame. All possible combinations of noise_filling and noise_offset are triggered at least once by the bitstream.

8.4.2.5 TNS test condition [Tns]

8.4.2.5.1 General

This test condition shall be applied to verify the proper behaviour of the temporal noise shaping (TNS) tool of USAC and the correct signalling of its parameters.

8.4.2.5.2 Test sequences

All bitstreams contain TNS data indicated by the bit tns_data_present. TNS parameters are applied as summarized in Table 168.

NOTE TNS short block combination is covered by the test case labelled "WinTns".

For both mono and stereo test sequences (channelConfigIndex 1 and 2) supplied bitstreams contain at least TNS values as indicated in Table 168.

Table 168 — Tns bitstream values

Bitstream element	Value
n_filt	1..3 (0, 1)
coef_res	0, 1
Length	1, maxSfb
Order	15 (7), 7 (3), 1
Direction	0, 1
coef_compress	0, 1
Coef	0, 15
NOTE The values in parenthesis are applied to short blocks.	

Table 169 shows TNS values only present in stereo test cases (channelConfigIndex 2).

Table 169 — Tns stereo bitstream values

Bitstream element	Value
tns_data_present[1]	0, 1
tns_on_lr	1
tns_present_both	0, 1
common_tns	0, 1

8.4.2.6 Varying max_sfb test condition [Sfb]

8.4.2.6.1 General

This test condition shall be applied to ensure the correct decoder behaviour in case varying values of max_sfb are signalled by the bitstream.

8.4.2.6.2 Test sequences

The value of max_sfb transmitted in ics_info() varies in the range from 0 to maximum. The upper bound is determined by the given sampling rate.

NOTE Varying max_sfb short block combinations is covered by the combined test case labelled "WinSfb".

Additional constraints apply to USAC channel pair element. Different values of max_sfb are transmitted for each channel in the channel pair element.

8.4.2.7 Handling of extensions test condition [Ex]

8.4.2.7.1 General

This test condition shall be applied to ensure the proper behaviour of the extension payload mechanism of the USAC decoder.

A USAC decoder shall at least be able to skip over all extensions – both configuration and payload – and decode the embedded USAC single channel element properly.

8.4.2.7.2 Test sequences

Bitstreams contain extensions to both configuration and payload. Extensions to the configuration are summarized in Table 170.

Table 170— Values of UsacConfigExtension

Bitstream element	Value			
numConfigExtensions	4			
usacConfigExtType	0	15	255	65805
usacConfigExtLength	1	1	1	1
tmp / fill_byte	165	49	50	51

Extensions to the payload are transmitted by means of an USAC extension element. For each extension element one configuration is embedded in the USAC decoder configuration. Table 171 shows the decoder configuration of the bitstream. The audio data is carried in element 2 (UsacSCE). The extension payload is transmitted via element 0, 1, 3 and 4 (UsacEXT). The test is only carried out for USAC single channel element.

Table 171— USAC decoder configuration

Element index	0	1	2	3	4
Element Type	UsacEXT	UsacEXT	UsacSCE	UsacEXT	UsacEXT
usacExtElementType	15	255	-	65805	0 (FILL)
usacExtElementConfigLength	4	4	-	4	0
usacExtElementDefaultLengthPresent	1	1	-	0	0
usacExtElementDefaultLength	8	65790	-	0	0
usacExtElementPayloadFrag	0	1	-	0	0
Tmp	"Ex_1"	"Ex_2"	-	"Ex_3"	-

The extension payload transmitted by means of and USAC extension element can vary from frame to frame. Table 172 shows the affected bitstream values.

Table 172— USAC extension payload

Element index	0	1	3	4
usacExtElementPresent	0, 1	0, 1	0, 1	0, 1
usacExtElementUseDefaultLength	0, 1	0	0	0, 1
usacExtElementPayloadLength	1..16	1..16	1..16	arbitrary
usacExtElementStart	-	0, 1	-	-
usacExtElementStop	-	0, 1	-	-

In case of fragmented extension payload (element 1), the payload is divided into 9 frames (distance between usacExtElementStart and corresponding usacExtElementStop flag). The payload transmitted for elements 0, 1 and 3 consists of the string “+++ USAC Conformance Test Extension Element [0,1,2] +++”.

Element 4 is used to write fill bytes (10100101) to into the bitstream if needed. The payload may only be present in a few frames at startup.

8.4.2.8 Context adaptive arithmetic coder test condition [Ac]

8.4.2.8.1 General

This test condition shall be applied to ensure the proper behaviour of the arithmetic decoder of USAC.

8.4.2.8.2 Test sequences

Bitstreams are designed such that:

- The window sequence repeatedly cycles through the following values: ONLY_LONG_SEQUENCE, LONG_START_SEQUENCE, EIGHT_SHORT_SEQUENCE, LONG_STOP_SEQUENCE;
- Window shape is always set to 0, i. e. sine window;
- The reset of the arithmetic decoder is triggered at least every 3 frames;
- The bitstream is divided into at least 4 sections, each 100 frames long. The first 4 sections repeat if the bitstream consists of more than 400 frames;
- In section 1 quantized MDCT values are set to zero. The value of max_sfb is increased frame by frame up to the maximum allowed value;
- In section 2 the amplitude of quantized MDCT values is limited to 3, only positive values are transmitted;
- In section 3 the value of the quantized coefficients is increased frame by frame. Spectral coefficients are coded both with and without STOP symbol;
- In section 4 the amplitude of quantized MDCT values is limited to 3 while the sign is altered;

Test sequences are provided for both 768 and 1024 transform length. The sampling rate is always 48 kHz.

8.4.2.9 Non-meaningful FD window switching test condition [Nmf]**8.4.2.9.1 General**

This test condition should be applied to monitor the decoder behaviour in case FD window sequence transitions not specified in Table 138 occur in a given bitstream.

8.4.2.9.2 Test sequences

All non-meaningful FD window transitions are triggered at least once by the bitstream. It should be ensured that the decoder does not crash during decoding. This test is not mandatory but highly recommended.

The decoder behaviour at non-meaningful FD window transitions is not covered by this document, hence no decoded waveforms are provided.

8.4.2.10 M/S stereo test condition [Ms]**8.4.2.10.1 General**

This test condition shall be applied to verify the proper behaviour of the M/S stereo tool of the USAC decoder.

8.4.2.10.2 Test sequences

Bitstreams make use of the M/S stereo tool. An overview of affected bitstream parameters is shown in Table 173.

Table 173— M/S stereo parameters

Bitstream element	Value	Description
ms_mask_present	0	M/S not active
	1	M/S active on some scale factor bands
	2	M/S active on all scale factor bands
ms_used	0, 1	Indicates the use of M/S stereo per scale factor band

All bitstreams activating the M/S stereo tool shall cover the values as described above.

8.4.2.11 Complex prediction stereo test condition [Cp]**8.4.2.11.1 General**

This test condition shall be applied to ensure the functionality of the complex prediction stereo tool of the USAC decoder.

8.4.2.11.2 Test sequences

Bitstreams activate the complex prediction stereo tool of USAC. The affected bitstream values are listed in Table 174.

Table 174— Complex prediction stereo parameters

Bitstream element	Value	Description
ms_mask_present	0	Complex prediction not active
	3	Complex prediction active
cplx_pred_used	0, 1	Indicates the use of complex prediction per prediction band
cplx_pred_all	0, 1	Complex prediction on all prediction bands
complex_coef	0, 1	Transmit complex coefficients (1) or real only coefficients (0)
delta_code_time	0, 1	Time differential coding (1) or frequency differential coding (0)
use_prev_frame	0, 1	Use only current frame (0) or use both current and previous frame (1) for MDST estimation
pred_dir	0, 1	Prediction from mid to side (0) or from side to mid (1)

All bitstreams activating the complex prediction stereo tool shall cover all values as described in Table 18.

8.4.3 LPD core mode tests

8.4.3.1 General

This subclause describes test cases that have to be applied to verify the behaviour of the USAC decoder when operated in LPD coding mode. A full list of all LPD core coding mode related test cases is shown in “Usac_Conformance_Tables.xlsx”: “LPD core UsacSCE”, and “LPD core UsacCPE”, accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>.

The decoded signals (reference and decoder-under-test) are always time-aligned, low-pass filtered and downsampled to twice the audio bandwidth of the LPD core before computing the conformance measure. The free resampling tool “ResampAudio” from the AFsp package, which is also required by the USAC reference software, can be used for this purpose. Unless specified otherwise, the audio bandwidth of the LPD core is equal to 6400 Hz when coreSbrFrameLengthIndex=1 (frame length equal to 1024 samples) and 4800 Hz when coreSbrFrameLengthIndex=0 (frame length equal to 768 samples).

The conformance measure depends on the test case. For the LPC coding test, the RMS log LPC spectral distance between the reference signal and the output of the decoder-under-test and the segmental SNR of the output of the decoder-under-test compared to the reference signal are used. For the other tests, the segmental SNR of the output of the decoder-under-test compared to the reference signal is used.

The computation of these measures is described in ISO/IEC 14496-26. Alternatively, an implementation of the RMS log LPC spectral distance can be found in the free “libtsp” TSP signal processing library (function called “SPpLSDist”), and the segmental SNR can be computed using the “CompAudio” tool from the AFsp package.

The tests are carried out for both 768 and 1024 core coder frame length (coreSbrFrameLengthIndex equal to 0 and 1).

For coreSbrFrameLengthIndex=1 (frame length equal to 1024 samples) three distinct test vectors are used to validate the operation of the USAC decoder under test at different internal sampling frequencies, namely 6000, 12800 and 24000 Hz. These are identified by the file names Lpd_c1_Lpd_<uSFI>*, where uSFI denotes the usacSamplingFrequencyIndex. The audio bandwidth of the LPD core is equal to half the internal sampling frequency.

8.4.3.2 LPC coding test condition [Lpc]

8.4.3.2.1 General

The test condition shall be applied to verify the functionality of the linear predictive coding (LPC) filter and the proper decoding of LPC parameters in the bitstream.

8.4.3.2.2 Test sequences

The test bitstream is designed such that:

- all frames are encoded using MDCT-based TCX;
- for each of the 4 LPC filters LPC1, LPC2, LPC3 and LPC4, every possible absolute and relative quantization mode from Table 148 is used at least once;
- each of the 256 entries in the first stage approximation codebook (see 7.13.6) is used at least once.

Furthermore, the test bitstream is designed to test the decoder on “extreme” LPC filters (in particular, exhibiting high resonances that cover well the entire audio spectrum).

8.4.3.2.3 Conformance criteria

The conformance criteria for the LPC coding test condition is based on the RMS log LPC spectral distance between the reference signal and the output of the decoder-under-test and on the segmental SNR of the output of the decoder under test compared to the reference signal.

The RMS log LPC spectral distance between the reference signal and the output of the decoder under test shall not exceed 0.6 dB. Also, the segmental SNR of the output of the decoder under test compared to the reference signal shall not be less than 40 dB.

8.4.3.3 ACELP core mode test condition [Ace]

8.4.3.3.1 General

This test condition shall be applied to verify the correct decoding of frames encoded with the ACELP coding scheme.

8.4.3.3.2 Test sequences

The test bitstream is designed such that:

- All frames are encoded using ACELP (no MDCT-based TCX);
- A complete and balanced coverage of the algebraic codebooks listed in 7.14.5.2.1 is ensured. Specifically, the usage of the algebraic codebooks is as follows:
 - 100 frames encoded using the 20-bit codebook, followed by;
 - 100 frames encoded using the 28-bit codebook, followed by;
 - 100 frames encoded using the 36-bit codebook, followed by;
 - 100 frames encoded using the 44-bit codebook, followed by;
 - 100 frames encoded using the 52-bit codebook, followed by;

100 frames encoded using the 64-bit codebook, followed by;

100 frames encoded using the 12-bit codebook, followed by;

100 frames encoded using the 16-bit codebook;

- Every possible value of the bitfields **mean_energy** (4 possibilities, see Table 152), **acb_index**[·] (512 or 64 possibilities, depending on the subframe position), **ltp_filtering_flag**[·] (two possibilities) and **gains**[·] (128 possibilities) is used at least once;
- The LPC filters exhibit weak resonances;
- The bass-post filter is always disabled (**bpf_control_info**=0).

8.4.3.3.3 Conformance criteria

The conformance criteria for the ACELP core mode test condition is based on the segmental SNR of the output of the decoder under test compared to the reference signal.

The length of the segments is equal to 256 samples.

The segmental SNR of the output of the decoder under test compared to the reference signal shall not be less than 50 dB.

8.4.3.4 TCX and noise filling test condition [Tcx]

8.4.3.4.1 General

This test condition shall be applied to verify the correct decoding of frames encoded with the TCX coding scheme. Furthermore, the TCX noise filling is covered.

8.4.3.4.2 Test sequences

The test bitstream is designed such that:

- All frames are encoded using MDCT-based TCX (no ACELP);
- A complete and balanced coverage of all possible MDCT window lengths is ensured;
- Moreover, a complete and balanced coverage of all possible intra-frame and inter-frame transitions between MDCT window lengths is ensured;
- Every possible value of the bitfields **noise_factor** (8 possibilities) and **global_gain** (128 possibilities) is used at least once as long as the values do not result in clipping. To avoid clipping the highest global gain values may not be tested as long as at least 90% of all values are used;
- The test bitstream contains LPC filters exhibiting weak resonances.

In order to guarantee a complete and balanced coverage of all MDCT window lengths and all transitions between these, the usage of the various MDCT window lengths is as follows:

[1 1 1 1] for 150 frames;

[2 2 2 2] for 150 frames;

[3 3 3 3] for 150 frames.

Then a repetition of the following pattern for a total of at least 150 frames:

[1 1 1 1][1 1 2 2][1 1 2 2][2 2 2 2][2 2 1 1][2 2 1 1][3 3 3 3][2 2 2 2][3 3 3 3][3 3 3 3]

where [...] represents the four LPD coding modes **mod[0..3]** for one frame and 1, 2 and 3 are the mode values that determine the MDCT window length as described in Table 97 (specifically, 1 for short TCX, 2 for medium TCX and 3 for long TCX).

8.4.3.4.3 Conformance criteria

The conformance criteria for the TCX and noise filling test condition is based on the segmental SNR of the output of the decoder under test compared to the reference signal.

The length of the segments is equal to 256 samples.

The segmental SNR of the output of the decoder under test compared to the reference signal shall not be less than 50 dB.

8.4.3.5 LPD mode coverage and FAC test condition [Lpd]

8.4.3.5.1 General

This test condition shall be applied to ensure the proper decoding of frames encoded in LPD mode. It also covers all allowed transitions between LPD coding schemes (ACELP/TCX).

8.4.3.5.2 Test sequences

The test bitstream is designed such that:

- Every possible combination of MDCT-based TCX and/or ACELP within a frame is used at least once;
- Moreover, a complete and balanced coverage of all possible intra-frame and inter-frame transitions between ACELP and the different MDCT window lengths is ensured;
- The test bitstream contains LPC filters exhibiting weak resonances;
- The bass-post filter is always disabled (**bpf_control_info**=0).

The first two conditions are guaranteed by using a repetition of the following mode pattern:

A sequence comprising the LPD coding modes corresponding to each of the 26 unreserved values of the bitfield **lpd_mode** from Table 94 followed by:

[0 0 1 1][0 0 1 1][1 1 0 0][1 1 0 0][0 0 2 2][0 0 2 2][2 2 0 0][2 2 0 0][3 3 3 3]

where [...] represents the four LPD coding modes **mod[0..3]** for one frame and 0, 1, 2 and 3 are the mode values as described in Table 97 (specifically, 0 for ACELP, 1 for short TCX, 2 for medium TCX and 3 for long TCX).

8.4.3.6 Conformance criteria

The conformance criteria for the LPD mode coverage and FAC test condition is based on the segmental SNR of the output of the decoder under test compared to the reference signal.

The length of the segments is equal to 256 samples.

The segmental SNR of the output of the decoder under test compared to the reference signal shall not be less than 50 dB.

8.4.3.7 Bass-post filter test condition [Bpf]

8.4.3.7.1 General

This test condition shall be applied to verify the behaviour of the bass-post filter of the USAC decoder in LPD coding mode.

8.4.3.7.2 Test sequences

The test bitstream is designed such that:

- The frames are encoded using alternately the MDCT-based TCX coding mode (5 consecutive frames) and the ACELP coding mode (25 consecutive frames);
- The bass-post filter is switched on (**bpf_control_info**=1) and off (**bpf_control_info**=0) every 5 ACELP frames;
- Every possible value of the **acb_index** parameter (512 or 64 possibilities, depending on the subframe position) is used at least once for the ACELP frames where the bass-post filter is enabled;
- The test bitstream contains LPC filters exhibiting weak resonances;
- For a USAC channel pair element both synchronous (Bpfs) and asynchronous (Bpfa) core coding modes are tested in combination with bass-post filter activity. The Bpfa case occurs when the two channels either use in a different core coding mode (ACELP/TCX) or, when both channels use the ACELP core coding mode but make a reversed use of the bass-post filter (active/inactive).

8.4.3.7.3 Conformance criteria

The conformance criteria for the bass-post filter test condition is based on the segmental SNR of the output of the decoder under test compared to the reference signal.

The length of the segments is equal to 256 samples.

The segmental SNR of the output of the decoder under test compared to the reference signal shall not be less than 50 dB.

8.4.3.8 AVQ test condition [Avq]

8.4.3.8.1 General

This test condition shall be applied to test the AVQ quantization tool of the USAC decoder.

8.4.3.8.2 Test sequences

The test bitstream is designed such that:

- All frames are encoded using alternately ACELP and short MDCT-based TCX (i.e., all frames are encoded using the LPD mode sequence [0 1 0 1]);
- As regards the quantization of the FAC information, every absolute leader from Table 146 is used at least once;
- The test bitstream contains LPC filters exhibiting weak resonances;
- The bass-post filter is always disabled (**bpf_control_info**=0).

8.4.3.8.3 Conformance criteria

The conformance criteria for the AVQ test condition is based on the segmental SNR of the output of the decoder under test compared to the reference signal.

The length of the segments is equal to 256 samples.

The segmental SNR of the output of the decoder under test compared to the reference signal shall not be less than 50 dB.

8.4.4 Combined core coding tests

8.4.4.1 General

This subclause describes test conditions to be applied to the USAC decoder in the case both FD and LPD coding mode are present in a bitstream.

If not stated otherwise, the conformance measure is calculated using the segmental SNR of the output of the decoder under test compared to the reference signal. The length of the segments is equal to 256 samples. The segmental SNR of the output of the decoder under test compared to the reference signal shall not be less than 50 dB. Also, the RMS test method shall be applied to all mandatory test cases. The RMS test method always includes the LSB test (RMS/LSB). The RMS/LSB measurement is defined in ISO/IEC 14496-26. The decoder under test shall additionally satisfy the conformance criteria for at least 7 bit.

8.4.4.2 FD-LPD transition and FAC test condition (synchronous/asynchronous) [Flt<a|s>]

8.4.4.2.1 General

This test condition shall be applied to ensure the proper decoder behaviour when a given bitstream activates both USAC core coding modes (FD/LPD).

8.4.4.2.2 Test sequences

Bitstreams trigger all allowed transitions between FD and LPD coding modes.

- Bitstreams shall trigger every allowed transition between FD and LPD coding modes as shown in Table 138 at least once;
- All allowed combinations of TCX modes and ACELP are triggered at least once;
- For USAC channel pair element both synchronous (Flts) and asynchronous (Flta) transitions are triggered. Asynchronous transitions occur when the two channels of the channel pair element use different coding modes (FD/LPD);
- No bass-post filter is used (bpf_contol_info == 0).

8.4.4.3 FD/TCX noise filling test condition [Cnf]

8.4.4.3.1 General

This test condition shall be applied to verify the interaction between the FD noise filling and the TCX noise filling functionality.

8.4.4.3.2 Test sequences

Bitstreams activate the noise filling tool in both FD and LPD path. The bitstreams are designed that:

- All allowed values of noise_level and noise_offset are transmitted at least once;
- All allowed values of noise_factor are transmitted at least once;
- All TCX modes are used at least once;
- No ACELP is used;
- All valid transitions between FD core mode and LPD core mode as shown in Table 138 are triggered at least once.

8.4.4.4 Bass-post filter test condition [Cbf]

8.4.4.4.1 General

This test condition shall be applied to ensure the correct behaviour of the bass-post filter at transitions between FD and LPD core mode.

8.4.4.4.2 Test sequences

Bitstreams are designed that:

- The bass-post filter is activated in every frame encoded using LPD coding mode;
- All valid transitions between FD core mode and LPD core mode as shown in Table 138 are triggered at least once;
- All allowed combinations of TCX modes and ACELP are triggered at least once.

8.4.4.5 Context adaptive arithmetic coder test condition [Cac]

8.4.4.5.1 General

This test condition shall be applied to test the arithmetic decoder of USAC when both FD and LPD coding modes are employed.

8.4.4.5.2 Test sequences

Bitstreams are designed such that:

- All valid transitions between FD core mode and LPD core mode as shown in Table 138 are triggered at least once;
- A reset of the arithmetic decoder is triggered in a frame consisting of only ACELP at least once.

Test sequences are provided for both 768 and 1024 transform length. Sampling rate is always 16 kHz.

8.4.5 eSBR tests

8.4.5.1 General

A full list of all eSBR related test cases is shown in “Usac_Conformance_Tables.xlsx” accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>.

8.4.5.2 eSBR Test procedure

If not stated otherwise, the RMS test method shall be applied to all eSBR test cases. The decoder under test shall satisfy the conformance criteria for at least 14 bit, if not stated otherwise in “Usac_Conformance_Tables.xlsx” accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>.

8.4.5.3 QMF accuracy test condition [Qma]

8.4.5.3.1 General

This test condition shall be applied to verify the implementation of the QMF filter bank.

8.4.5.3.2 Test sequences

The sequence consists of a linear sine sweep from 0 to 8000 Hz (eSbr cross over frequency).

8.4.5.4 Envelope adjuster accuracy and SBR preprocessing test condition [Eaa]

8.4.5.4.1 General

This test condition shall be applied to cover the test of the eSbr envelope adjuster as well as the eSbr preprocessing (pre-whitening) functionality.

8.4.5.4.2 Test sequences

Table 175 describes the variables in scope of this test condition.

Table 175 — Eaa bitstream values

Bitstream element	value
bs_sbr_preprocessing	0, 1
bs_data_noise	max. 31
bs_data_env	0..47
core_mode	0 (FD)
harmonicSBR	1
bs_add_harmonic_flag[0]	0
bs_interTes	0
bs_pvc	0
bs_xover_band	0
bs_frame_class	FIXFIX

8.4.5.5 Header and grid control test condition [Hgt]

8.4.5.5.1 General

This test condition has to be applied to verify the decoder behaviour at time-grid transitions. The test condition also covers changes of SBR header data triggered by a given bitstream.

8.4.5.5.2 Test sequences

Test sequences cover 8 envelopes in FIXFIX frames. Bitstream values affected by this test condition are listed in Table 176. All possible configurations are triggered in the bitstream as long as the combinations of parameters

result in a valid bitstream. If it is not possible to trigger all values in one bitstream as many as possible common combinations should be triggered.

Table 176 — Hgt bitstream values

Bitstream element	Value
bs_xover_band	0,...,6
bs_start_freq	0,...,14
bs_stop_freq	0,...,12
bs_noise_bands	0,...,3
bs_limiter_bands	0,...,3
bs_alter_scale	0,1
bs_interpol_freq	0,1
bs_smoothing_mode	0
bs_frame_class	FIXFIX
bs_num_env	8
core_mode	0 (FD)
harmonicSBR	0
bs_add_harmonic_flag[0]	0
bs_data_noise	max. 31
bs_interTes	0
bs_pvc	0

8.4.5.6 Inverse filtering test condition [Ift]

8.4.5.6.1 General

This test condition shall be applied to verify the SBR inverse filtering.

8.4.5.6.2 Test sequences

The inverse filter (*bs_invf_mode*) feature has 4 settings, described in ISO/IEC 14496-3:2019, 4.5.2.8.1, Table 4.124, which are triggered by the bitstream.

The test sequence cycles through the available inverse filter options changing every 50 frames.

Table 177 summarizes the bitstream values affected by the Ift test condition.

Table 177 — lft bitstream values

Bitstream element	Value
core_mode	0 (FD)
harmonicSBR	0
bs_add_harmonic_flag[0]	0
bs_data_noise	max. 31
bs_interTes	0
bs_pvc	0
noiseFilling	0
bs_xover_band	0
bs_frame_class	FIXFIX
bs_header_extra_2	1
bs_limiter_bands	3
bs_limiter_gains	0
bs_interpol_freq	1
bs_smoothing_mode	1

8.4.5.7 Additional sine test (missing harmonics) test condition [Ast]

8.4.5.7.1 General

This test condition shall be applied to verify the functionality of the missing harmonics insertion mechanism of the eSBR tool of the USAC decoder.

8.4.5.7.2 Test sequences

The encoder input consists of a mono music signal with strong harmonics. For each available scale factor band (nSfb) a sine tone is added (bs_add_harmonic == 1).

Table 178 summarizes the USAC features which have been disabled (or changed) in order to isolate the additional sine tones feature.

Table 178 — Ast bitstream values

Bitstream element	Value
core_mode	0 (FD)
harmonicSBR	0
bs_add_harmonic_flag[0]	1
bs_data_noise	max. 31
bs_interTes	0
bs_pvc	0
bs_xover_band	0
bs_frame_class	VARVAR
bs_num_env	2

8.4.5.8 Channel mode test condition [Cm]

8.4.5.8.1 General

This test condition shall be applied to verify proper decoding of various channel modes.

8.4.5.8.2 Test sequences

Test sequences are provided for both mono and stereo SBR channel mode. In stereo mode *bs_coupling* is toggled every 50 frames.

Table 179 summarizes the bitstream values affected by this test condition.

Table 179 — Cm bitstream values

Bitstream element	Value
core_mode	0 (FD)
bs_coupling	0, 1
sbrPatchingMode	0
harmonicSBR	1
bs_add_harmonic_flag[0]	0
bs_data_noise	max. 31
bs_interTes	0
bs_pvc	0

8.4.5.9 Inter-TES test condition [Tes]

8.4.5.9.1 General

This test condition shall be applied to verify the proper behaviour of the inter-TES tool of USAC.

8.4.5.9.2 Test sequences

Inter-TES is active (*bs_interTes*==1). In the bitstream inter-TES is switched on and off by *bs_temp_shape* in the *sbr_envelope()*. In the case of switching on inter-TES within a SBR envelope time segment, *bs_temp_shape_mode* is set to shape the temporal envelope of the HF signal. The bitstream covers all available values of *bs_temp_shape_mode*. Note that inter-TES is switched off when *bs_temp_shape*==1 and *bs_temp_shape_mode*==0.

Table 180 summarizes the USAC features which have been disabled or restricted in order to isolate the inter-TES feature.

Table 180 — Inter-TES bitstream values

Bitstream element	Value
core_mode	0 (FD)
harmonicSBR	0
bs_interTes	1
bs_pvc	0
bs_add_harmonic_flag[0]	0

8.4.5.10 PVC test condition [Pvc]

8.4.5.10.1 General

This test condition shall be applied to verify the correct behaviour of the USAC predictive vector coding tool (PVC).

8.4.5.10.2 Test sequences

All bitstreams contain PVC data indicated by the bit `bs_pvc`. PVC parameters in `Sbrinfo()`, `sbr_grid()`, `sbr_sinusoidal_coding()`, and `pvc_envelope()` are applied as summarized in Table 181.

Table 181 — PVC bitstream values

Bitstream element	Value
<code>bs_pvc_mode</code>	1, 2
<code>bs_noise_position</code>	0..15
<code>bs_var_len_hf</code>	0, 4, 5, 6
<code>bs_sinusoidal_position_flag</code>	0, 1
<code>bs_sinusoidal_position</code>	0..18, 31
<code>divMode</code>	0..7
<code>nsMode</code>	0, 1
<code>reuse_pvcID</code>	0, 1
<code>pvcID</code>	0..127
<code>length</code>	0..14
<code>grid_info</code>	0, 1

8.4.5.11 Harmonic transposition (QMF) test condition [Htq]

8.4.5.11.1 General

This test condition shall be applied to verify the proper behaviour of the QMF based harmonic transposer of USAC.

8.4.5.11.2 Test sequences

A test sequence is generated for each *sbrRatioIndex* described in Table 75.

The test sequence is generated from a mono music signal with strong harmonic content. The harmonic transposition QMF is triggered by setting *harmonicSBR* to 1 and *sbrPatchingMode[0]* to zero.

Table 182 summarizes the USAC bitstream values affected by the Htq test condition.

Table 182 — Htq bitstream values

Bitstream element	value
<code>core_mode</code>	0 (FD)
<code>sbrPatchingMode</code>	0
<code>harmonicSBR</code>	1
<code>bs_add_harmonic_flag[0]</code>	0
<code>bs_data_noise</code>	max. 31
<code>bs_interTes</code>	0
<code>bs_pvc</code>	0

8.4.5.12 Harmonic transposition (crossproducts) test condition [Xp]

8.4.5.12.1 General

This test condition shall be applied to verify the functionality of the crossproducts mechanism of the USAC decoder.

8.4.5.12.2 Test sequences

A test sequence is generated for each of the *sbrRatioIndex* values (except 0) described in Table 83.

The test sequences are generated from a mono music signal. Each of the three sequences uses the same crossproduct values but applies a different *sbrRatioIndex* value (2, 3 and 1). In each case crossproduct terms, which vary over the entire range [0 – 127], are triggered in the bitstream.

Table 183 summarizes the USAC bitstream values affected by this test condition.

Table 183 — Xp bitstream values

Bitstream element	value
core_mode	0 (FD)
sbrPatchingMode	0
harmonicSBR	1
bs_invf_mode[0]	0
bs_add_harmonic_flag[0]	0
bs_data_noise	max. 31
bs_interTes	0
bs_pvc	0
noiseFilling	0

8.4.5.13 Transposer toggle test condition [Ttt]

8.4.5.13.1 General

This test condition shall be applied to verify the decoder behaviour in case the transposer type is switched between copy-up and harmonic transposer by the bitstream.

8.4.5.13.2 Test sequences

Bitstreams contain all allowed transitions between different transposer types (copy-up and harmonic transposer).

A test sequence is generated for each *sbrRatioIndex* described in Table 75.

Test sequences are generated from a mono music signal. The transposer type is signalled by the flag *sbrPatchingMode*. The transposer type is toggled every 50 frames.

Table 184 summarizes the USAC bitstream values affected by this test condition.

Table 184 — Ttt bitstream values

Bitstream element	Value
core_mode	0 (FD)
harmonicSBR	1
sbrPatchingMode	0, 1
bs_invf_mode[0]	0
bs_add_harmonic_flag[0]	0
bs_data_noise	max. 31
bs_interTes	0
bs_pvc	0
bs_xover_band	0

Furthermore, test sequences are provided which combine the “Transposer toggle test condition” and the “Varying crossover frequency test condition”. Those sequences can be identified by the filename-tag _TttXo_. Bitstreams combine the restrictions of both test conditions, exceptions are listed below.

- LPD core mode is used (core_mode = 1);
- The transposer type is toggled every 100 frames (sbrPatchingMode: 0,1);
- The crossover frequency is varied through all available frequencies (bs_xover_band: 0..9).

8.4.5.14 Envelope shaping toggle (PVC on/off) test condition [Est]

8.4.5.14.1 General

This test condition shall be applied to ensure the proper decoder behaviour when the envelope shaping mode is switched between SBR and PVC.

8.4.5.14.2 Test sequences

All bitstreams contain PVC data indicated by the bit bs_pvc. PVC parameters in Sbrinfo(), sbr_grid(), and sbr_sinusoidal_coding() are applied as summarized in Table 185.

Table 185 — Est bitstream values

Bitstream element	value
bs_pvc_mode	0..2
bs_frame_class	0..3
bs_var_bord_1	0..3
bs_noise_position	0..15
bs_var_len_hf	0, 6
bs_sinusoidal_position_flag	0, 1
bs_sinusoidal_position	0..18, 31

8.4.5.15 Varying crossover frequency test condition [Xo]

8.4.5.15.1 General

The test condition shall be applied to verify the decoder behaviour in case the SBR crossover frequency is alternated by a given bitstream.

8.4.5.15.2 Test sequences

Bitstreams vary the SBR cross over frequency. Bitstreams cover at least extreme SBR cross over frequencies (maximum allowed, minimum allowed). The test covers increased range of crossover frequencies.

The test sequence is generated from a series of harmonically related sine tones. The test sequence triggers 10 allowed crossover frequencies which are applied in ascending order and changed every 40 frames.

Table 186 summarizes the USAC bitstream values affected by this test condition.

Table 186 — Xo bitstream values

Bitstream element	Value
core_mode	1 (LPD)
bs_xover_band	0..9
bs_invf_mode[0]	0
bs_add_harmonic_flag[0]	0
harmonicSBR	0
bs_data_noise	max. 31
bs_interTes	0
bs_pvc	0

8.4.5.16 stereoConfigIndex test condition [Mps]

8.4.5.16.1 General

The stereoConfigIndex test condition shall be applied to test the interaction of the eSBR and the MPS212 tool. All possible combination of both tools as described in Figure 23 through Figure 25 are covered by the test.

8.4.5.16.2 Test sequences

For each allowed value of stereoConfigIndex one bitstream is provided. The relation between stereoConfigIndex, bsStereoSbr and bsResidualCoding is shown in Table 77. Bitstreams have been generated from a stereo music signal.

Table 187 summarizes the USAC bitstream values affected by the Mps test condition.

Table 187 — Mps bitstream values

Bitstream element	value
core_mode	0 (FD)
coreSbrFrameLengthIndex	3
bs_invf_mode[0]	0
bs_add_harmonic_flag[0]	0
bs_data_noise	max. 31
bs_harmonicSBR	0
bs_interTes	0
bs_pvc	0

8.4.6 MPEG Surround 212 tests

8.4.6.1 Parameter bands test condition [fr<X>]

8.4.6.1.1 General

This test condition shall be applied to verify the decoder behaviour for different number of MPS parameter bands.

8.4.6.1.2 Test sequences

7 different test sequences are provided each of which employs a different integer value of *bsFreqRes* in the interval [1..7].

8.4.6.2 TSD test condition [Tsd]

8.4.6.2.1 General

This test condition shall be applied to verify the performance of the transient steering decorrelator (TSD) tool of the USAC decoder.

8.4.6.2.2 Test sequences

Bitstreams contain *bsTempShapeConfig* set to 3 in order to activate the TSD tool. Test sequences cover all allowed values for *TsdSepData* and *bsTsdTrPhaseData*.

8.4.6.3 Rate mode test condition [Rm]

8.4.6.3.1 General

This test condition shall be applied to test the high rate mode of MPEG Surround 212.

8.4.6.3.2 Test sequences

Test sequences are provided for each allowed value of *stereoConfigIndex* (except for 0). To enable the high rate mode the *bsHighRateMode* flag is set to 1.

8.4.6.4 Phase coding test condition [Pc]

8.4.6.4.1 General

This test condition shall be applied to verify the performance of the phase coding tool of the USAC decoder.

8.4.6.4.2 Test sequences

Bitstreams have *bsPhaseCoding* set to 1 in order to activate the phase coding tool. Phase coding and OPDSmoothingMode can be switched on and off on a frame basis by setting *bsPhaseMode* and *bsOPDSmoothingMode* accordingly. All test sequences toggle *bsPhaseMode* and *bsOPDSmoothingMode* at least once.

8.4.6.5 Decorrelator configuration test condition [Dc]

8.4.6.5.1 General

This test condition shall be applied to test different decorrelator configurations in MPEG Surround 212.

8.4.6.5.2 Test sequences

Two test sequences are provided. Bitstreams enable *bsDecorrConfig* = 1 and *bsDecorrConfig* = 2, respectively.

8.4.6.6 Bands phase test condition [Bp<X>]**8.4.6.6.1 General**

This test condition shall be applied to verify the decoder behaviour for different number of MPS parameter bands employing phase parameters.

8.4.6.6.2 Test sequences

Bitstreams contain values for *bsOttBandsPhase* that differ from the default values listed in Table 109. Bitstreams contain *bsOttBandsPhasePresent* set to 1 to indicate the number of IPD parameter bands explicitly. Multiple test sequences are provided covering all allowed values of *bsOttBandsPhase* in the range of 0 to numBands.

For *stereoConfigIndex* equal to 2 and 3 the number of residual bands is fixed to 0.

8.4.6.7 DMX gain test condition [Dm]**8.4.6.7.1 General**

This test condition shall be applied to verify the decoder behaviour for all allowed values of *bsFixedGainDMX*.

8.4.6.7.2 Test sequences

8 different test sequences are provided each of which employs a different integer value of *bsFixedGainDMX* in the interval [0..7].

8.4.6.8 Pseudo lr test condition [Plr]**8.4.6.8.1 General**

This test condition shall be applied to test the pseudo lr mechanism of the USAC decoder.

8.4.6.8.2 Test sequences

Test sequence are available for both *stereoConfigIndex* = 2 and 3.

All bitstreams contain *bsPseudoLr* set to 1.

8.4.6.9 Residual bands test condition [Rb<X>]**8.4.6.9.1 General**

This test condition shall be applied to verify the decoder behaviour for different number of MPS parameter bands employing residual coding.

8.4.6.9.2 Test sequences

Test sequence are available for both *stereoConfigIndex* = 2 and 3.

Multiple bitstreams are provided to cover all allowed values of *bsResidualBands*.

8.4.6.10 Temporal shaping enabling test condition [Tse<X>]

8.4.6.10.1 General

This test condition shall be applied to verify the temporal shaping tools of the USAC decoder and the ability to switch them on and off.

8.4.6.10.2 Test sequences

To test all temporal shaping tools the value `bsTempShapeConfig` shall be set to [1..3]. In case of `bsTempShapeConfig` is set to 1 (STP) or 2 (GES), the temporal shaping tools can be switched on and off on a frame basis by setting `bsTempShapeEnable` and `bsTempShapeEnableChannel[ch]`. These test sequences toggle `bsTempShapeEnable` at least once. To handle as many conditions as possible all combinations of `bsTempShapeEnableChannel[ch]` related to the channels shall be triggered at least once. In case of `bsTempShapeConfig` is set to 3 (TSD), the temporal shaping tool can be switched on and off on a frame basis by setting `bsTsdEnable`. These test sequences toggle `bsTsdEnable` at least once.

8.4.6.11 Smoothing mode test condition [Smg]

8.4.6.11.1 General

This test condition shall be applied to verify the decoder behaviour for the smoothing mode.

8.4.6.11.2 Test sequences

Bitstreams have `bsHighRateMode` set to 1 in order to activate the smoothing. The smoothing can be switched on and off on a frame basis by the `bsSmoothMode[ps]`. Every mode shall be triggered at least once. Additional to test the mode “keep previous smoothing parameters unchanged” there shall be a transition from every mode to mode 1 at least once.

To test all conditions all values in Table 188 shall be triggered at least once.

Table 188 — Smg bitstream values

Bitstream element	Value
<code>bsSmoothTime</code>	0..3
<code>bsFreqResStrideSmg</code>	0..3
<code>bsSmgData</code>	0..1

8.4.7 Bitstream extensions

8.4.7.1 General

This subclause describes test conditions to test the USAC configuration extensions as contained within the bitstream structure `UsacConfigExtension()` as well as USAC bitstream payload extensions as declared and contained within the bitstream structures `UsacExtElementConfig()` and `UsacExtElement()` respectively.

A full list of all extension related test cases is shown in “Usac_Conformance_Tables.xlsx”: “Extensions” accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>.

If not stated otherwise, the RMS test method shall be applied to all mandatory test cases. The RMS test method always includes the LSB test (RMS/LSB). The RMS/LSB measurement is defined in ISO/IEC 14496-26:2010. The decoder under test shall satisfy the conformance criteria for at least 14 bit, if not stated otherwise in “Usac_Conformance_Tables.xlsx”.

8.4.7.2 AudioPreRoll() and streamID condition, immediate play-out frame (IPF)

8.4.7.2.1 General

The audio pre-roll extension enables the creation of bitstreams which produce valid audio signal output starting from the very first decoded audio frame. The test conditions in this subclause aim at covering the conceivable and practical use cases of employing this functionality. For the sake of testing the AudioPreRoll() in various constellations, this test condition defines subtypes whose characteristics are laid out in the subclauses below.

8.4.7.2.2 IPF frequency of occurrence [I-foo-<x>]

8.4.7.2.2.1 General

This test condition shall be applied to verify the correct decoding behaviour upon (re-) initialization of a decoder when AudioPreRoll() extension payload is present in the compressed bitstream and when decoding streams which carry regularly occurring stream access points in the form of immediate play-out frames (IPF).

8.4.7.2.2.2 Test sequences

Conformance test bitstreams shall comply to the following constraints. The streams:

- shall contain one configuration extension of type ID_CONFIG_EXT_STREAM_ID, and one extension payload of type ID_EXT_ELE_AUDIOPREROLL;
- shall start with an access unit with AudioPreRoll() present (usacExtElementPresent==1);
- shall contain, in the AudioPreRoll() payload, a non-empty and correct config() (configLen>0, config() == usacConfig());
- shall contain, in the AudioPreRoll() payload, at least one pre-roll frame (numPreRollFrames>0);
- shall contain access units with AudioPreRoll() present (usacExtElementPresent==1) in a regular frequency of occurrence of once per <x> audio frames. If <x> == 0, then only the first frame shall be an access unit with AudioPreRoll() present;
- shall be encapsulated in ISO Base Media file format in accordance with Annex H.

8.4.7.3 Dynamic range and loudness control

8.4.7.3.1 General

The following test conditions shall be applied to verify the proper integration and behaviour of the MPEG-D DRC decoder as part of the USAC decoder. In addition to the test conditions in this subclause, the isolated MPEG-D DRC decoder shall fulfil conformance according to ISO/IEC 23003-4.

The MPEG-D DRC decoder is too complex to define only one conformance test condition for USAC. For this reason, there are several conformance test conditions. In case no dynamic range and/or loudness control related conformance test conditions are active (respectively no conformance test condition is active, which is defined in the current subclause 8.4.7.3), no config extension payload of type ID_CONFIG_EXT_LOUDNESS_INFO and no extension payload of type ID_EXT_ELE_UNI_DRC shall be written.

The audio content shall be chosen such that the application of dynamic range and loudness metadata results in a measurable and preferably perceptually noticeable difference when compared to the result if the MPEG-D DRC decoder is in bypass mode.

8.4.7.3.2 Loudness normalization test condition [Ln]

8.4.7.3.2.1 General

This test condition shall be applied to verify the transmission and application of loudness metadata for normalization of the USAC decoder output. It shall also verify the proper integration of the loudness normalization module.

8.4.7.3.2.2 Test sequences

This test condition shall fulfil following conditions:

- UsacConfigExtension() shall include at least one extension of type ID_CONFIG_EXT_LOUDNESS_INFO.
- UsacExtElementConfig() shall include an extension of type ID_EXT_ELE_UNI_DRC if the definition of **downmixId** values is required for a test sequence.
- loudnessInfoSet() shall define a loudnessInfo() structure with **drcSetId**=0 and **downmixId**=0 which shall at least include one measure with **methodDefinition** set to 1 or 2. Additional loudnessInfo() structures and loudness parameters may be present.

8.4.7.3.2.3 Default behaviour

If this test condition is not active, UsacConfigExtension shall not include an extension of type ID_CONFIG_EXT_LOUDNESS_INFO.

8.4.7.3.3 Dynamic range control test condition [Drc<x>]

8.4.7.3.3.1 General

This test condition shall be applied to verify the transmission and application of DRC metadata for dynamic range control of the USAC decoder output. It shall also verify the proper integration of the DRC modules.

8.4.7.3.3.2 Test sequences

This test condition shall fulfil following conditions:

- UsacExtElementConfig() shall at least include one extension of type ID_EXT_ELE_UNI_DRC.
- uniDrcConfig() shall be configured depending on the parameter <x> as defined in Table 189.

Table 189 — Configuration of uniDrcConfig() depending on <x>

<x>	Requirement
1	One or several DRC sets with downmixId =0
2	One or several DRC sets with downmixId =127
3	One or several DRC sets with downmixId !=0 & downmixId !=127

8.4.7.3.3.3 Default behaviour

If this test condition is not active, UsacExtElementConfig() shall not include an extension of type ID_EXT_ELE_UNI_DRC.

8.5 Decoder settings

8.5.1 General

The decoder settings describes some additional input configurations for the decoder. If they are needed, these abbreviations are only added to the reference wav files. The corresponding compressed mp4 test file has the same file name up to (but without) the double underline characters, which separate the conformance test cases from the decoder settings. The filenames do not contain any other double underline characters at a different place.

8.5.2 Target loudness [Lou-<x>]

8.5.2.1 General

This test condition shall be applied to verify the application of different target loudness values by the USAC decoder. This condition shall verify the proper behaviour of the loudness normalization module.

8.5.2.2 Decoder settings description

The decoder shall be set up such that it normalizes the output to a given target loudness as specified in ISO/IEC 23003-4. The target loudness shall be given as an integer number <x> in LKFS that should not be larger than -10 LKFS. Note that the requested target loudness may be passed via the `uniDrcInterface()` structure if available.

8.5.2.3 Default behaviour

If this test condition is not active, no target loudness value shall be specified through a decoder interface and the loudness normalization module shall be disabled.

8.5.3 DRC effect type request [Eff-<x>]

8.5.3.1 General

This test condition shall be applied to verify the application of different DRC effect type requests by the USAC decoder. This condition shall verify the proper behaviour of DRC modules.

8.5.3.2 Decoder settings description

The decoder shall be set up such that a DRC effect type request is passed to the MPEG-D DRC decoder as specified in ISO/IEC 23003-4. The DRC effect type request shall be given as an integer number <x> and should be mapped to a fall-back DRC effect type sequence as recommended in ISO/IEC 23003-4:2015, Annex E.2.2. Note that the requested DRC effect type sequence may be passed via the `uniDrcInterface()` structure if available.

8.5.3.3 Default behaviour

If this test condition is not active, no DRC effect type request shall be passed to the internal MPEG-D DRC decoder.

8.6 Decoding of MPEG-4 file format parameters to support exact time alignment in file-to-file coding

Conformant USAC decoders shall be able to decode MPEG-4 files having one edit list with one entry that specifies the decoded waveform segment that the USAC decoder and associated MPEG-4 systems support shall reproduce. It is strongly encouraged that, whenever appropriate, USAC coded content stored in an MPEG-4 File have such an edit list.

If present, the edit list shall be specified using the MPEG-4 file format `EditListBox` as follows:

```
version = 0
entry_count = 1
segment_duration = <N1>
media_time = <N2>
media_rate_integer = 1
media_rate_function = 0
```

where:

- <N1> is an integer that specifies the duration of the desired audio segment, measured in MovieHeader timescale units;
- <N2> is an integer that specifies time of first sample in the desired audio segment, measured in MediaHeader timescale units.

The timescale values in the MPEG-4 file format MediaHeaderBox shall be set to the audio signal sampling rate, in units of Hz. If possible, the timescale values in the MPEG-4 File Format MovieHeaderBox shall be set to the audio signal sampling rate, in units of Hz, otherwise the timescale values shall be set to the appropriate media timescale value, e.g., 60 for video at 60 frames per second.

9 Reference software

9.1 Reference software structure

9.1.1 General

This clause contains simulation software for MPEG-D USAC as defined in this document. This software has been derived from reference models used in the process of developing this document.

Reference software is normative in the sense that it correctly implements the USAC decoding processes described in this document. Complying implementations are not expected to follow the algorithms or the programming techniques used by the reference software. Although the decoding software is considered normative, it cannot add anything to the textual technical description of USAC included in this document.

The software contained in this clause and in Annex G is divided into several categories:

- a) **Bitstream decoding software** is catalogued in 9.2. This software accepts bitstreams encoded according to the normative specification in this document and decodes the streams into the audio signals associated with each bitstream. While this software appears in the normative part of this document, attention is drawn to the fact that the implementation techniques used in this software are not considered normative – several different implementations could produce the same result – but the software is considered normative in that it correctly implements the USAC decoding processes described in this document.
- b) **Bitstream encoding software** is catalogued in H.1. The software creates compressed bitstreams from associated audio signals. The techniques used for encoding are not specified by this document. Two encoder software implementations are provided as an electronic attachment accessible at <https://standards.iso.org/iso-iec/23003/-3/ed-2/en>.
- c) **Utility software** is catalogued in G.2. This software was found useful by the developers of this document, but may not conform to the normative specifications it contains.

9.1.2 Copyright disclaimer for software modules

Each source code module in this specification contains copyright disclaimer which shall not be removed from the source code module.

The generic version of this disclaimer is provided below:

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This software module was originally developed by <FN1> <LN1> (<CN1>) and edited by <FN2> <LN2> (<CN2>), <FN3> <LN3> (<CN3>), in the course of development of the <standard> for reference purposes and its performance may not have been optimized. This software module is an implementation of one or more tools as specified by the <standard>.

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- In the text <standard> should be replaced with the appropriate International Standard, e.g., ISO/IEC 23003-3.
- <FN> = First Name, <LN> = Last name, <CN> = Company Name.
- Sentences in *italics* are not required in the statement if the original developer does not wish to be identified.
- Sentences in **bold** are not required in the statement if the original developer allows unrestricted use of this software.
- Sentences underlined should be removed when the <standard> is published.
- Reference to "ITU Recommendation" may be omitted when the module is deemed not to be relevant for ITU Recommendations.

9.2 Bitstream decoding software

9.2.1 General

The provided bitstream decoding software is a normative reference implementation of the respective specification.

9.2.2 USAC decoding software

Location	Content
mpegD_usac\usacEncDec\	Unified Speech and Audio Decoder
mpegD_usac\mp4spatialdec\	MPEG Surround 2-1-2 Decoding Module

STANDARDSISO.COM : Click to view the full PDF of ISO/IEC 23003-3:2020

Annex A (normative)

Tables

A.1 Tables for frequency domain coding

Table A.1 — Frequency domain coding table references

Table	Please see
Scalefactor Huffman codebook	ISO/IEC 14496-3:2019, 4.A.1, Table 4.A.1
Differential scalefactor to index tables	ISO/IEC 14496-3:2019, 4.A.3, Table 4.A.17 and Table 4.A.18

A.2 SBR tables

Please refer to ISO/IEC 14496-3:2019, 4.A.6, Table 4.A.78 to Table 4.A.89 and Table 4.A.91.

A.3 MPEG Surround IPD tables

Table A.2 — hcodFirstBand_IPD

Index	length	codeword (hexadecimal)	Index	length	codeword (hexadecimal)
0	1	0x00	4	5	0x1d
1	3	0x06	5	6	0x3f
2	5	0x1c	6	5	0x1e
3	6	0x3e	7	2	0x02

Table A.3 — hcod1D_IPD_YY

Index	DF		DT	
	length	codeword	length	codeword
0	1	0x0000	1	0x0000
1	3	0x0006	2	0x0002
2	5	0x001e	4	0x000e
3	6	0x003a	6	0x003e
4	6	0x003b	7	0x007e
5	5	0x001c	7	0x007f
6	5	0x001f	5	0x001e
7	2	0x0002	3	0x0006

Table A.4 — hcod2D_IPD_YY_ZZ_LL_escape

LL	DF/FP		DF/TP		DT/FP		DT/TP	
	length	codeword	length	codeword	length	codeword	length	codeword
01	3	0x00007	3	0x00007	3	0x00007	3	0x00007
03	8	0x000ff	8	0x000ff	8	0x000bf	8	0x000bf
05	9	0x001bf	9	0x001bf	11	0x005ff	11	0x005ff
07	11	0x0057f	11	0x0057f	13	0x01fbf	13	0x01fbf

Table A.5 — hcod2D_IPD_YY_ZZ_01

Idx0	Idx1	DF/FP		DF/TP		DT/FP		DT/TP	
		length	codeword	length	codeword	length	codeword	length	codeword
0	0	1	0x0	1	0x0	1	0x0	1	0x0
0	1	3	0x7	3	0x7	3	0x7	3	0x7
1	0	3	0x6	3	0x6	3	0x6	3	0x6
1	1	2	0x2	2	0x2	2	0x2	2	0x2

Table A.6 — hcod2D_IPD_YY_ZZ_03

Idx0	Idx1	DF/FP		DF/TP		DT/FP		DT/TP	
		length	codeword	length	codeword	length	codeword	length	codeword
0	0	1	0x000	1	0x000	1	0x000	1	0x000
0	1	8	0x0ff	8	0x0ff	8	0x0bf	8	0x0bf
0	2	8	0x0ff	8	0x0ff	8	0x0bf	8	0x0bf
0	3	8	0x0ff	8	0x0ff	8	0x0bf	8	0x0bf
1	0	8	0x0ff	8	0x0ff	5	0x016	5	0x016
1	1	3	0x006	3	0x006	3	0x006	3	0x006
1	2	8	0x0ff	8	0x0ff	8	0x0bf	8	0x0bf
1	3	8	0x0fe	8	0x0fe	7	0x05e	7	0x05e
2	0	7	0x07c	7	0x07c	6	0x02e	6	0x02e
2	1	7	0x07e	7	0x07e	4	0x00e	4	0x00e
2	2	4	0x00e	4	0x00e	4	0x00a	4	0x00a
2	3	2	0x002	2	0x002	4	0x00f	4	0x00f
3	0	7	0x07d	7	0x07d	8	0x0be	8	0x0be
3	1	8	0x0ff	8	0x0ff	8	0x0bf	8	0x0bf
3	2	8	0x0ff	8	0x0ff	8	0x0bf	8	0x0bf
3	3	5	0x01e	5	0x01e	3	0x004	3	0x004