AC-3 and DTS

Prof. Dr.-Ing G. Schuller
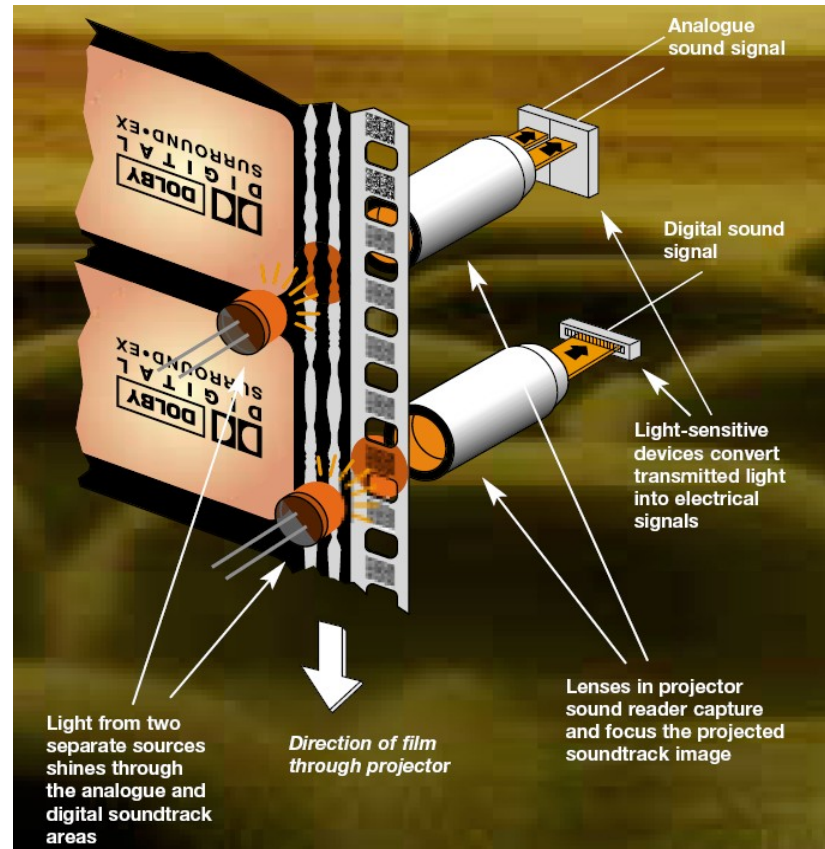
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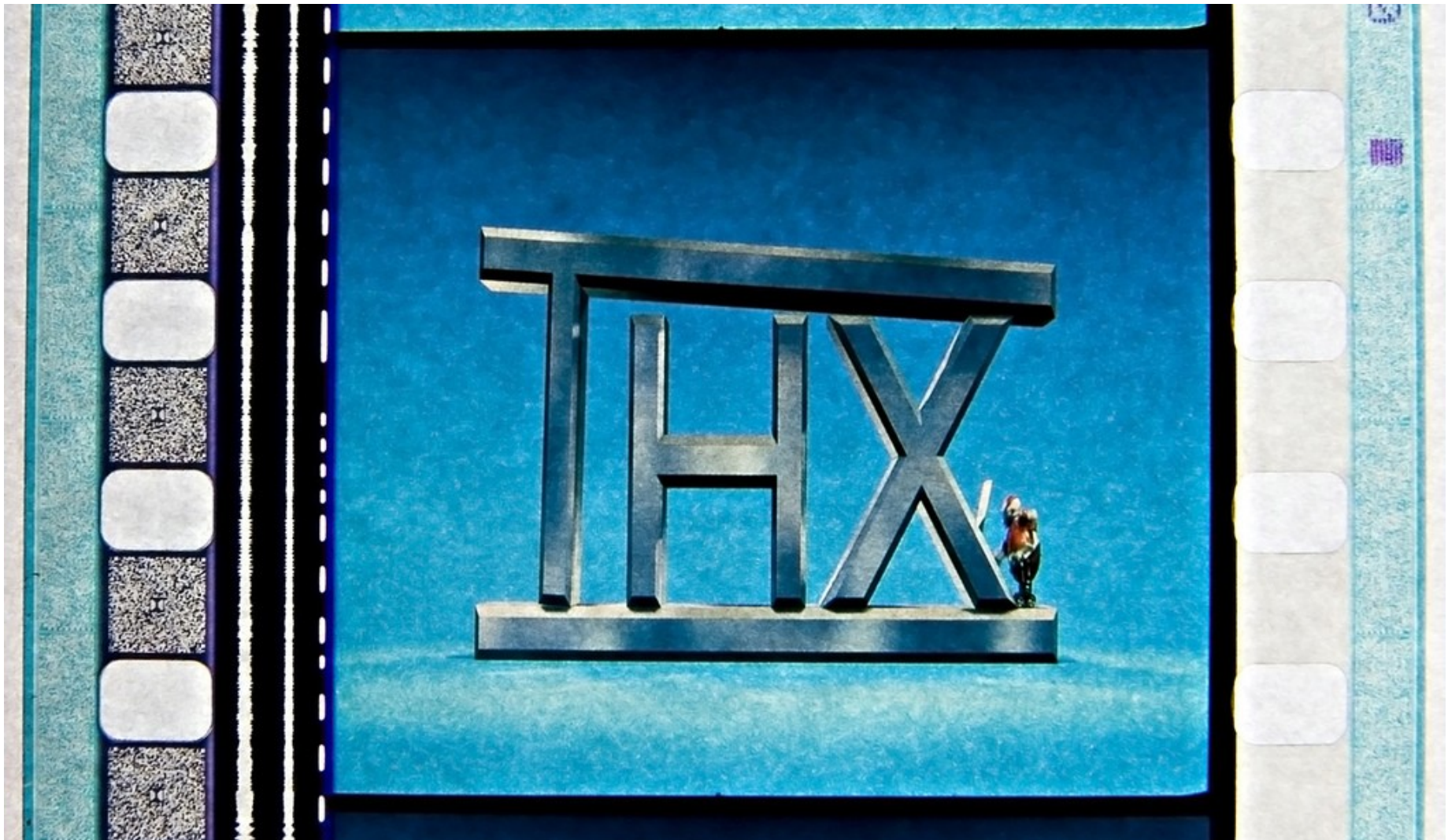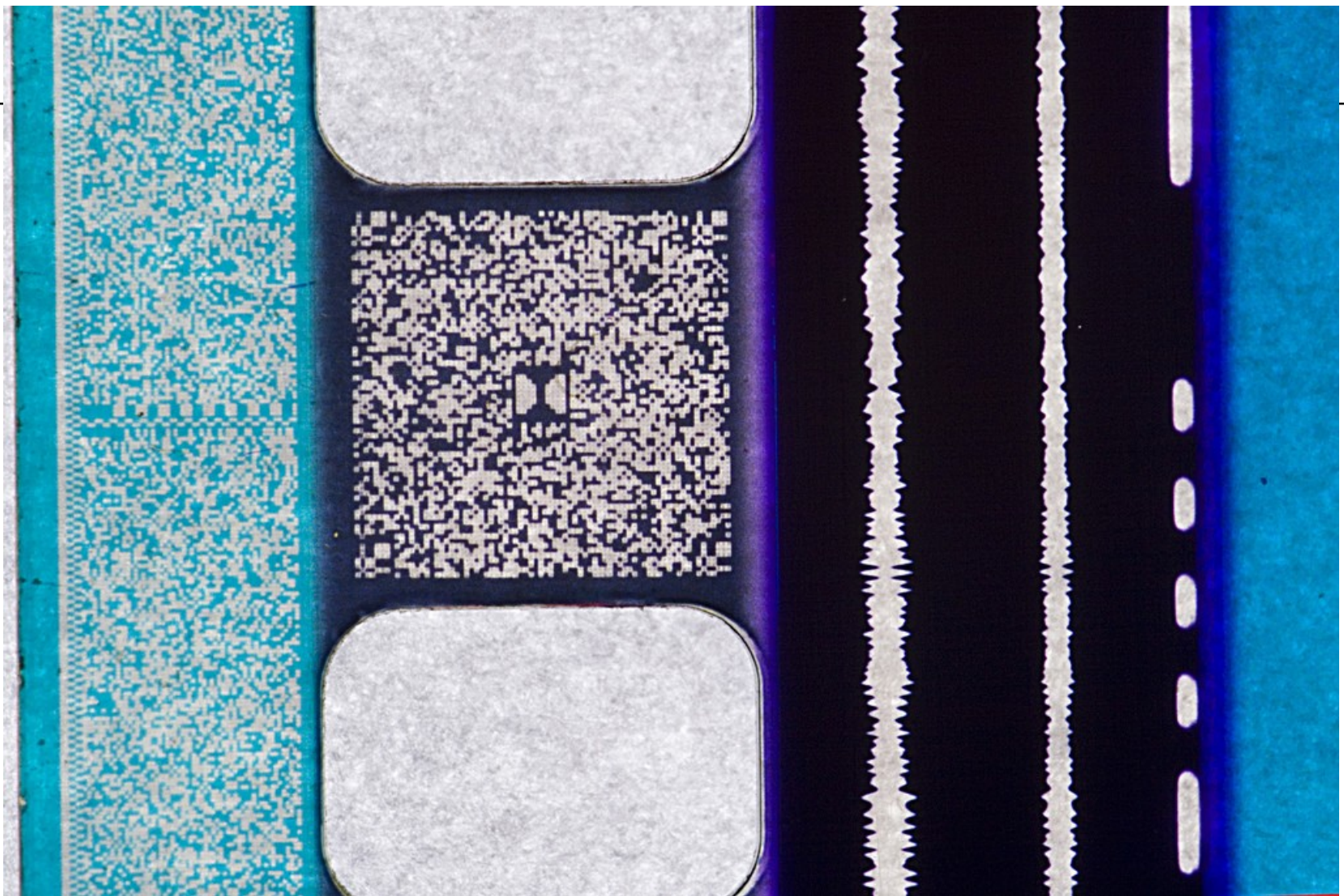ILMENAU

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Dolby Digital

- Dolby Digital (AC-3) was first commercially used in 1992
- Multi-channel digital audio for 35mm movie film material alongside the (optical) analog audio channel
- Perceptual coding with block length of 256 samples
- Additionally it is used in:
  - Laser Disc
  - ATSC High Definition Digital Television (HDTV)
  - DVB/ATSC Standard Definition Digital Television (SDTV)
  - DVD-Video/Audio
  - Internet-, Cable-, Satellite broadcasting
- For 5.1-channel audio, the bit stream is packed in the AES-EBU transmission format.
- Bit stream defined in ATSC "Digital Audio Compression Standard, Revision B": Doc. A/52B from June 2005; also E-AC3 included

Source: Dolby Labs, Internet

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Dolby Digital embedded in a piece of film

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Dolby AC-3 (1)

- Predecessors:
  - Dolby AC-1: low-cost, based on delta modulation
  - Dolby AC-2: transform based codec
- Lossy coder that uses psychoacoustics
- Special Features:
  - Use of a Variable Frequency Resolution Spectral Envelope
  - Hybrid Backward/Forward Adaptive Bit Allocation
- Primarily developed for multi-channel format for HDTV
- Based on ITU-R BS.775 that showed that 5 + 1 channels are enough for new digital audio system of movies (based on an analog Split-Surround-Format from 1979)
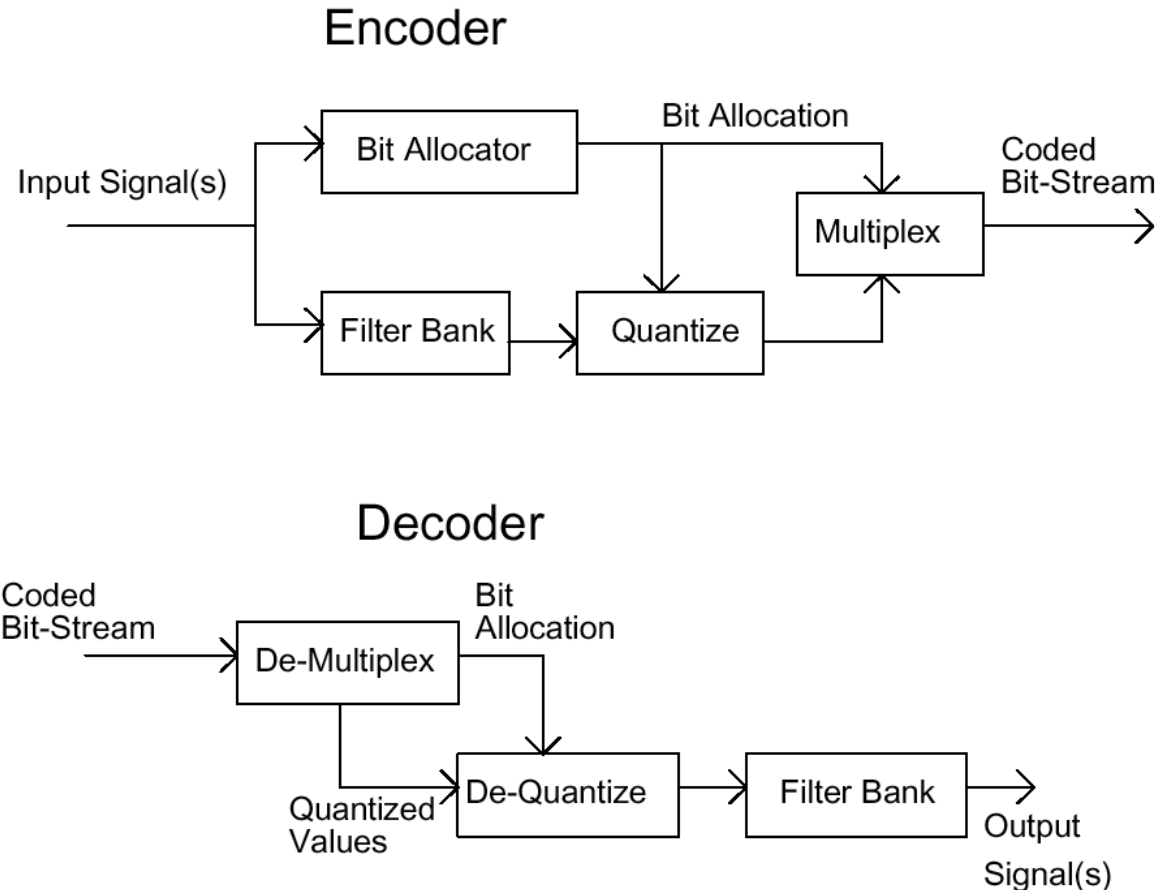
Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage

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Dolby AC-3 (2)

- There is an useable data rate of 320kbps on 35mm movie film such that:
    - Audio compression must be used for 5.1 channel audio
    - The peak bit rate can not surpass 320kbps
- First film with AC-3: Star Trek VI (Dec. 1991)
- Transform:
    - Fielder windowing (aka KBD-Window)
    - Window length 512 Samples (10.66ms@48kHz) with 50% overlap: 256 Spectral values
    - Oddly Stacked Time-Domain Alias-Cancellation Filter Bank from Princen and Bradley
    - With signal transients (attacks) block switching is used to half the block length.
    - Frequency resolution: 93,75 Hz
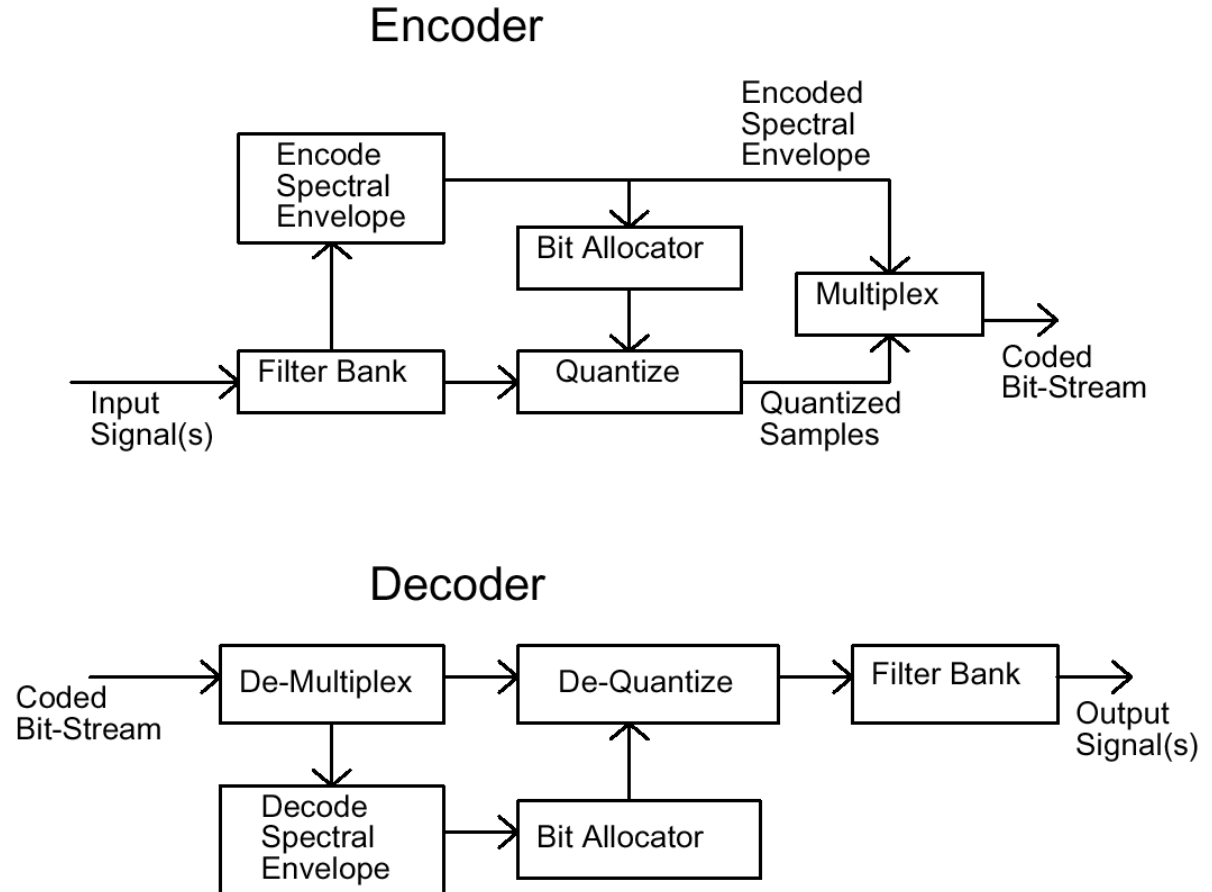   - No „Critical Bands" like in MP3

Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage

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Dolby AC-3: Forward Adaptive Bit Allocation

Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage

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Dolby AC-3: Backward Adaptive Bit Allocation

Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage

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Dolby AC-3: Hybrid Backward/Forward ABA
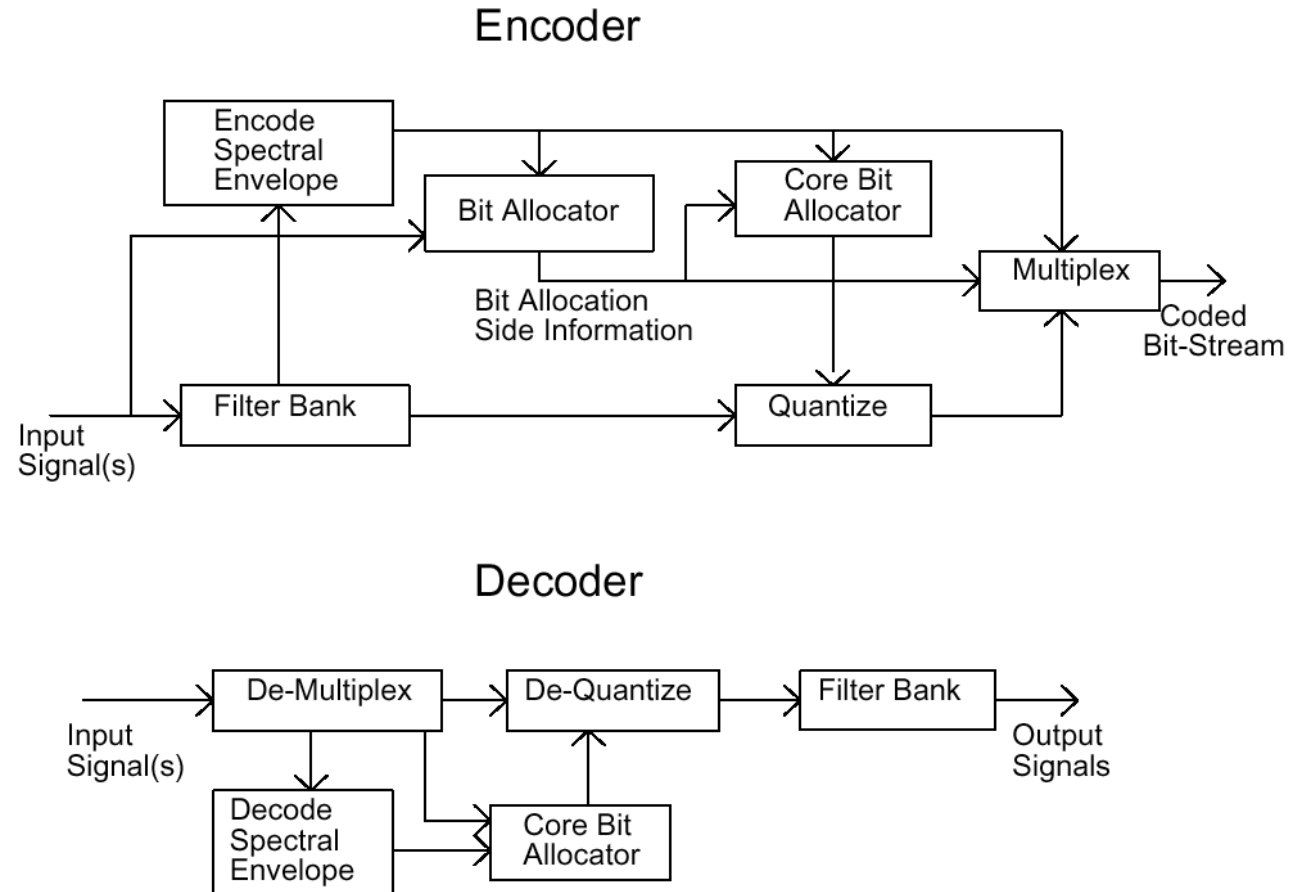
Encoder

Decoder

Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage

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Dolby AC-3: Encoder

Source: Advanced Television Systems Committee: „Digital Audio Compression Standard (AC-3)", Nov. 94

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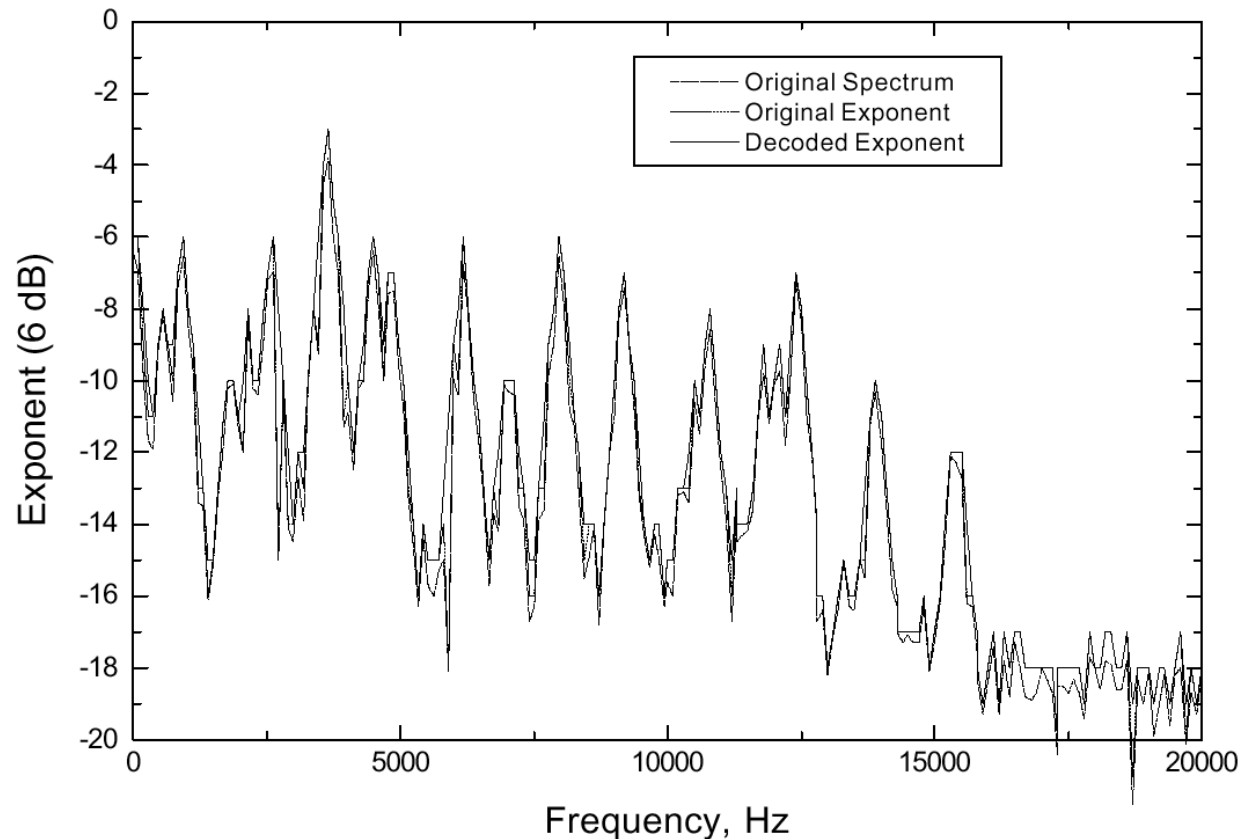
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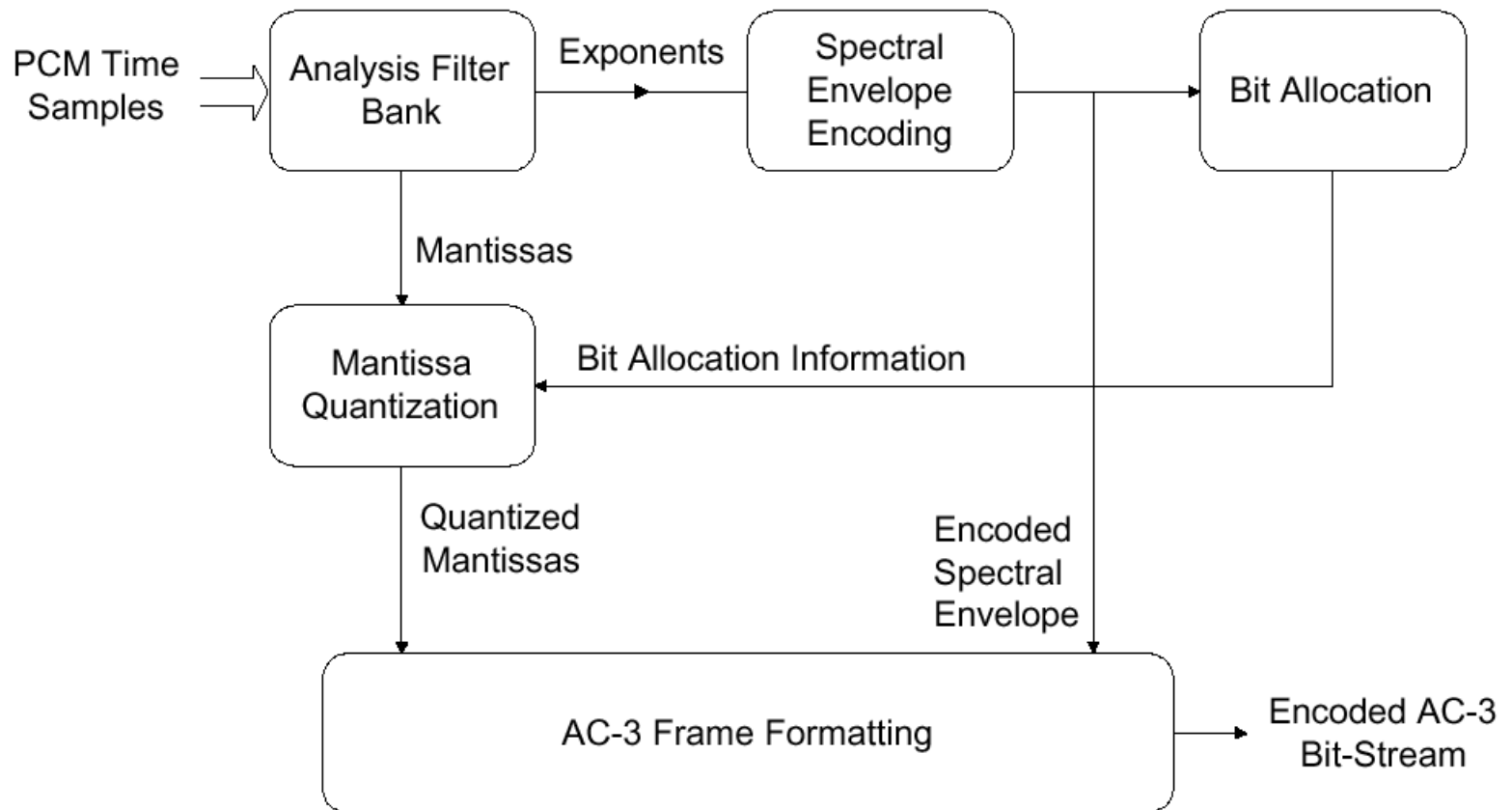
Dolby AC-3: Decoder

Source: Advanced Television Systems Committee: „Digital Audio Compression Standard (AC-3)", Nov. 94

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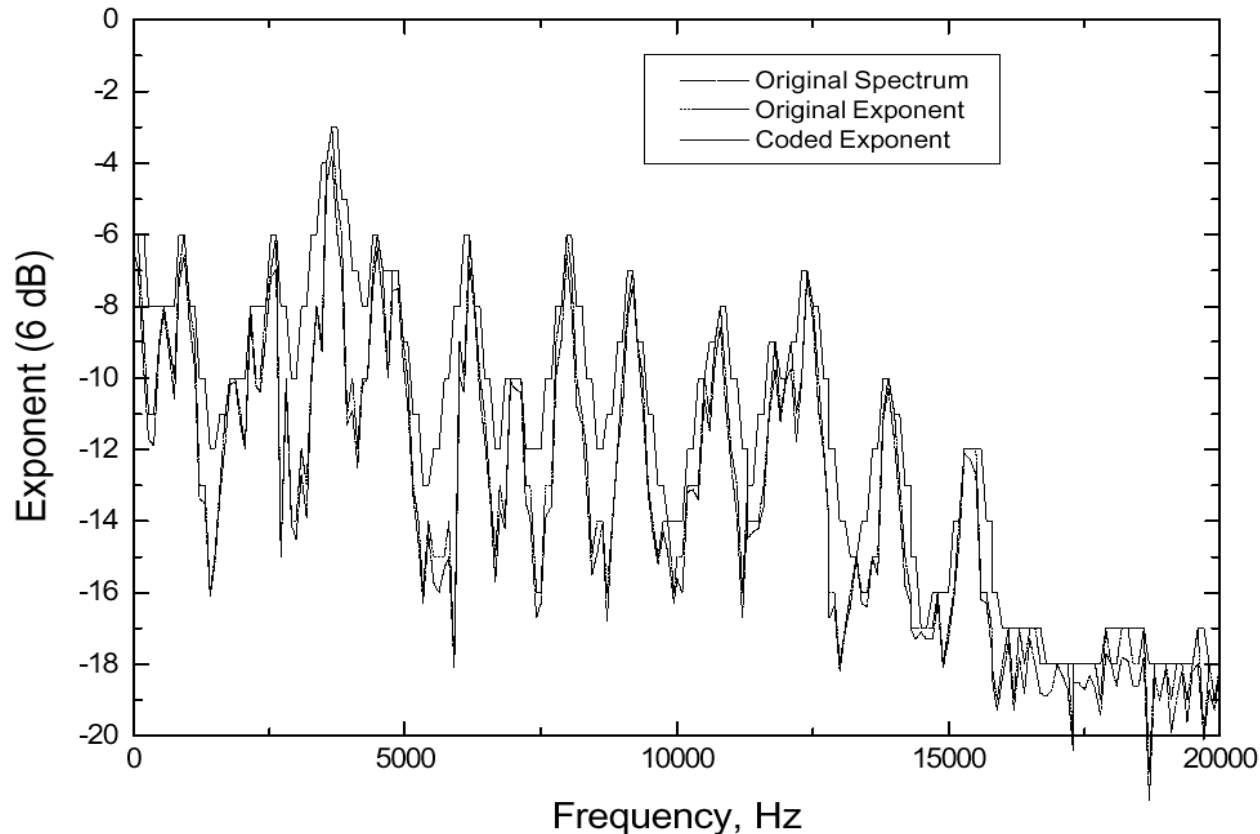ILMENAU

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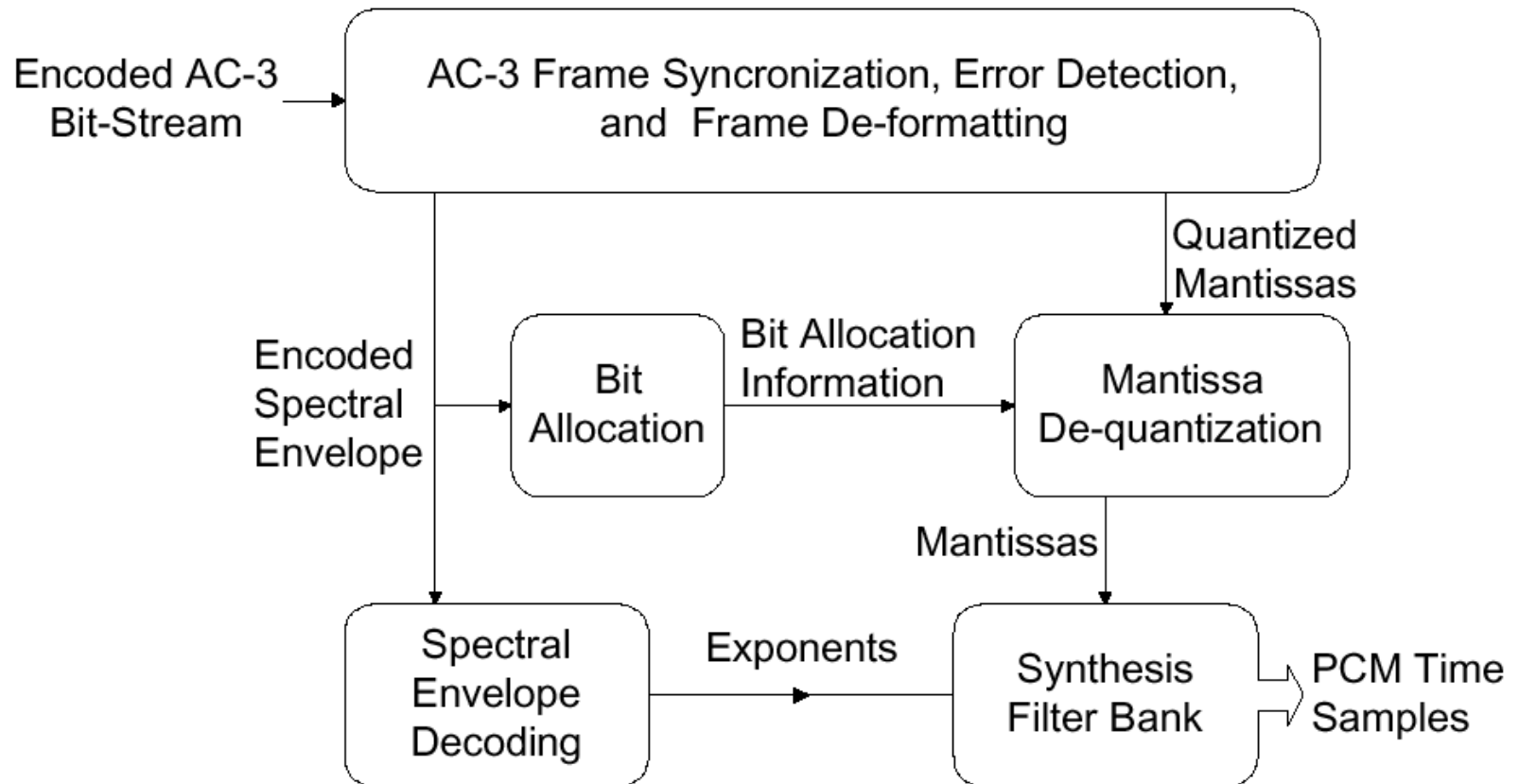
Dolby AC-3: Spectral Envelope (1)

Spectral Envelope Coding, D15 Mode, Triangle Signal

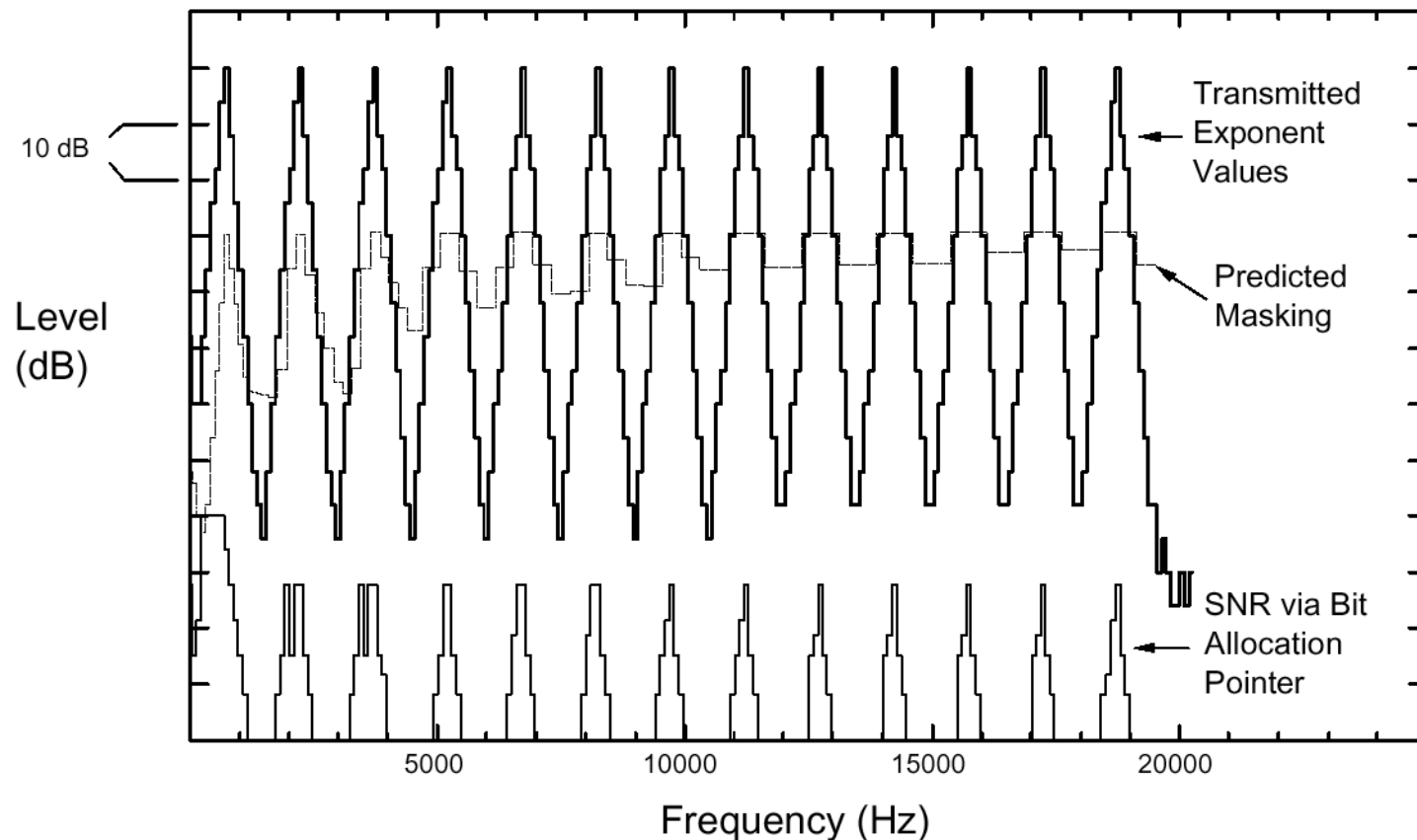Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage"

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Dolby AC-3: Spectral Envelope (2)

Spectral Envelope Coding, D25 Mode, Triangle Signal

Legend:
- Original Spectrum
- Original Exponent
- Coded Exponent

Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage"

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Dolby AC-3: Bit Allocation

Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage"

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Dolby Digital Setup

Source: Dolby Labs, Internet

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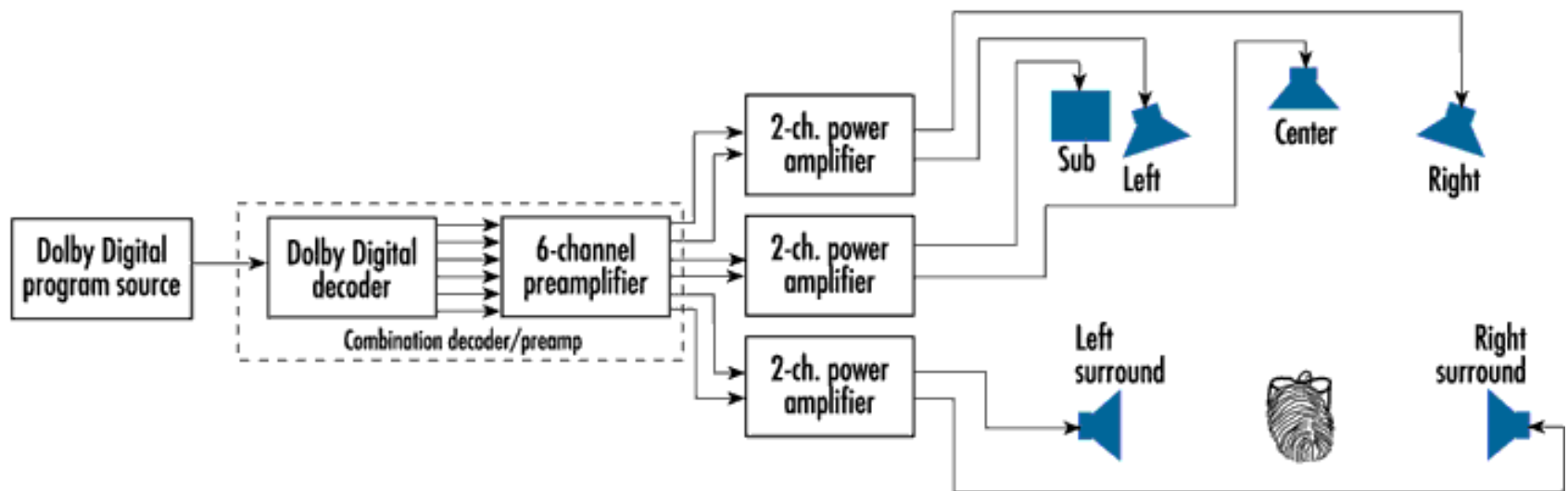
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Dolby Digital Enhancement for 6.1-channel audio

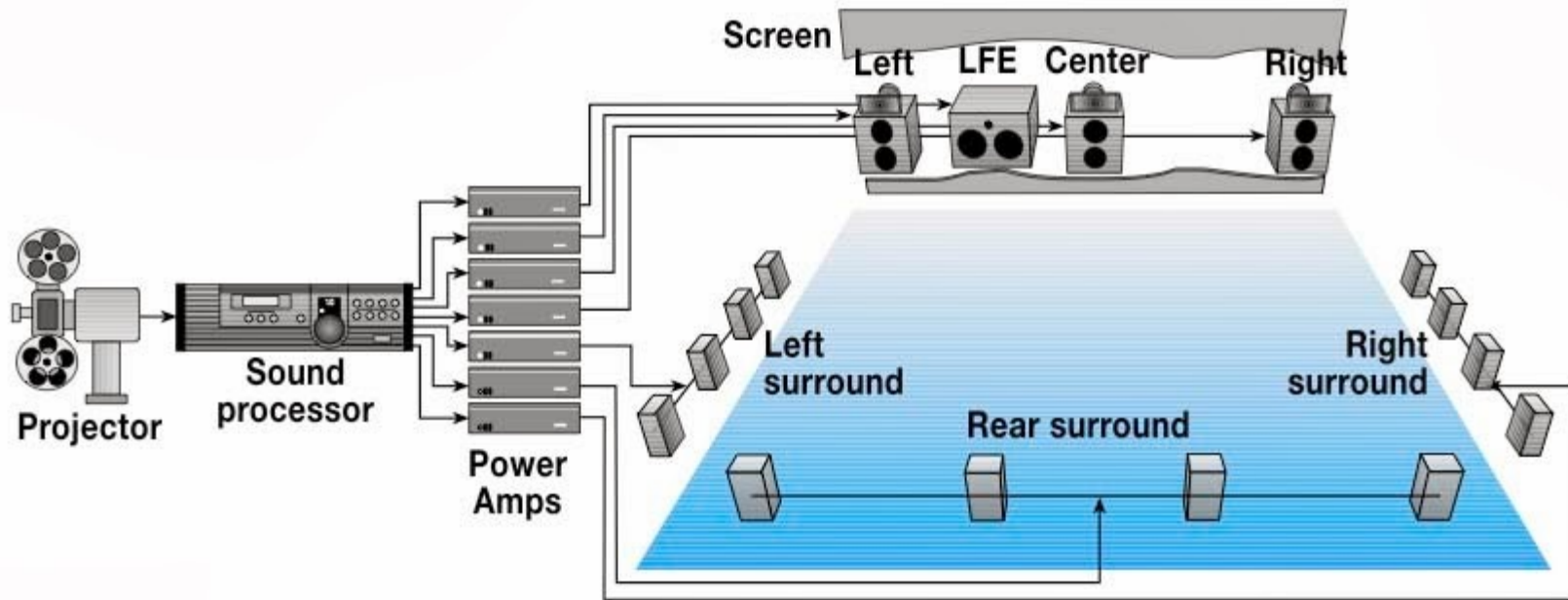

Figure 6: Dolby Digital Surround EX playback

Source: Dolby Labs, „AC-3: Flexible Perceptual Coding for Audio Transmission and Storage"

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Dolby Digital Plus (E-AC-3, Enhanced AC-3): Main features

- greater range of data rates: 32kbps – 6.144 Mbps, fine-grain data rate resolution
- 13.1 channel support
- High resolution hybrid filter bank (AC-3 filter combined with 2nd stage DCT -> 1536 coeffs or subbands)
- New quantization tools
- Improved channel coupling (similar to BCC)
- Spectral extension tool (similar to SBR)
- Transient pre-noise processing
- Based on AC-3: low-loss and low-complexity conversion from E-AC-3 to AC-3

Source: L.D. Fielder et al., "Introduction to Dolby Digital Plus, an Enhancemnet to the Dolby Digital Coding System", 117th AES Convention

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E-AC-3: Decoder setup example
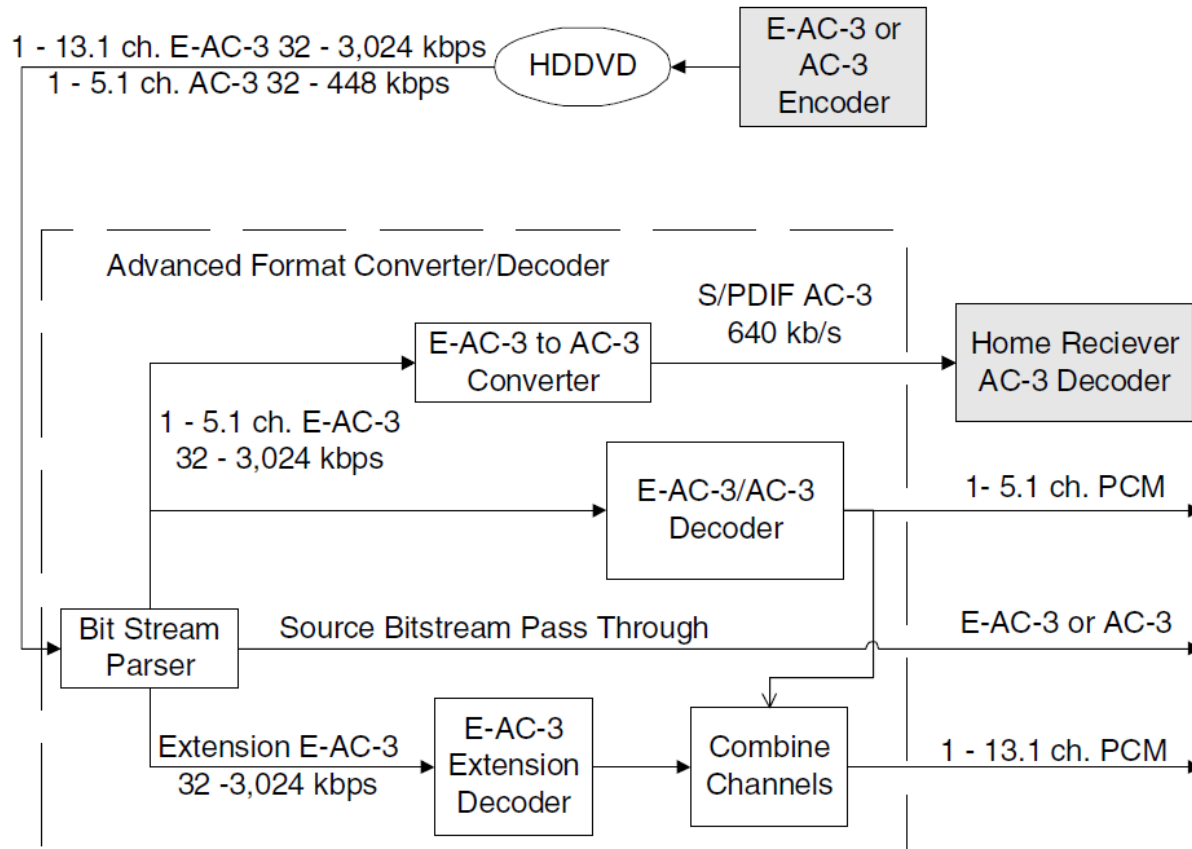
Source: L.D. Fielder et al., "Introduction to Dolby Digital Plus, an Enhancemnet to the Dolby Digital Coding System", 117th AES Convention

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E-AC-3: Adaptive Hybrid Transform (AHT)

- Based on AC-3 MDCT (256 coeffs or subbands, KBD window with alpha factor 5.0) for easy interoperability, filter length N=512

- 2nd stage DCT Type 2 with M=6 subbands, resulting in 1536 coeffs or subbands

→ higher frequency resolution for stationary signals

MDCT:
$$X(k,m)=\sum_{n=0}^{N-1} x(n+m\frac{N}{2})\cdot w(n)\cos\left(\frac{2\pi(k+\frac{1}{2})\cdot(n+\frac{N}{4}+\frac{1}{2})}{N}\right)$$

k... MDCT frequency index → k = 0,..., N/2 -1

n... MDCT sample index

m... MDCT blockindex → m = 0,..., L-1 ; L: total number of Blocks

DCT-2:
$$X^{AHT}(kM+l)=\frac{\sqrt{2}}{M} C_l \sum_{m=0}^{M-1} X(k,m)\cdot\cos\left(\frac{(2m+1)l\pi}{2M}\right)$$

l... DCT-II frequency index → l = 0,..., M-1

m... DCT-II sample index

$$C_l=\begin{cases} 1/\sqrt{2} & l=0 \\ 1 & l\neq 0 \end{cases}$$

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E-AC-3: Spectral Extension Tool

- Parametric description of high frequency region of the high frequency subband coeffs, which then are transmitted as this parametric description

- Spectral extension bands approx. match Critical Bands

- For each band an energy ratio and a noise blending parameter is calculated

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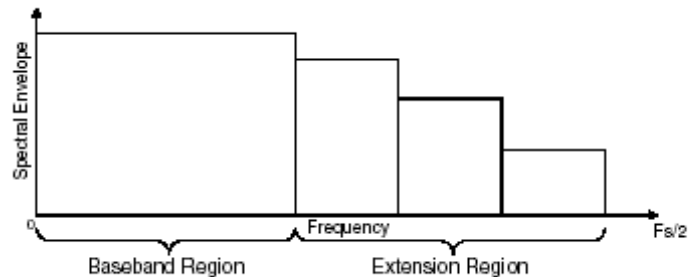IDMT

E-AC-3: Spectral Extension (1)
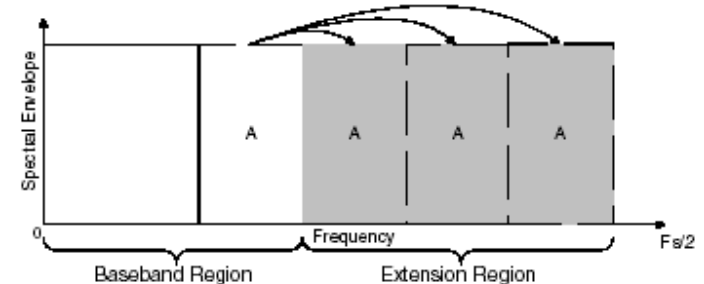

Fig 1: Original Spectrum

Fig 2: Decoder: Translation
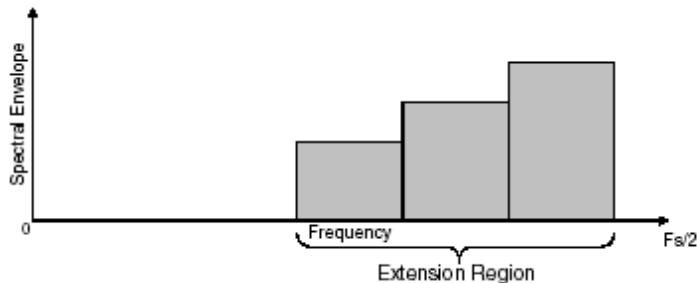
Fig 3: Decoder: Noise spectrum multiplied by blending function
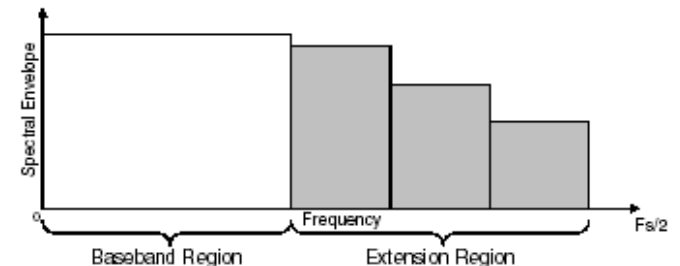
Fig 4: Decoder: Translated spectrum, multiplied by inverse blending function

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E-AC-3: Spectral Extension (2)
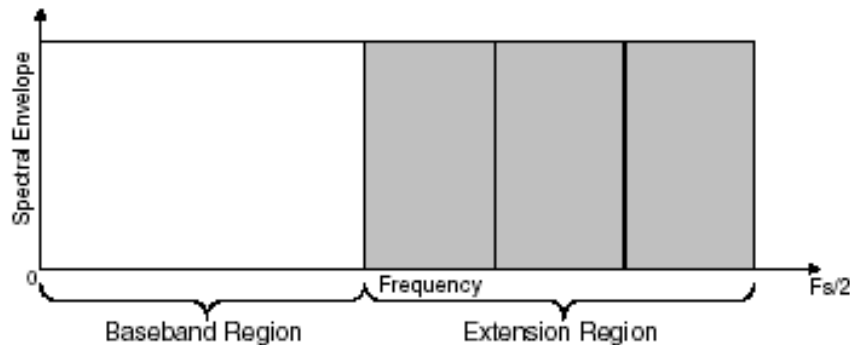
Fig 5: Decoder: Blended spectrum (blending of noise and translated spectrum)
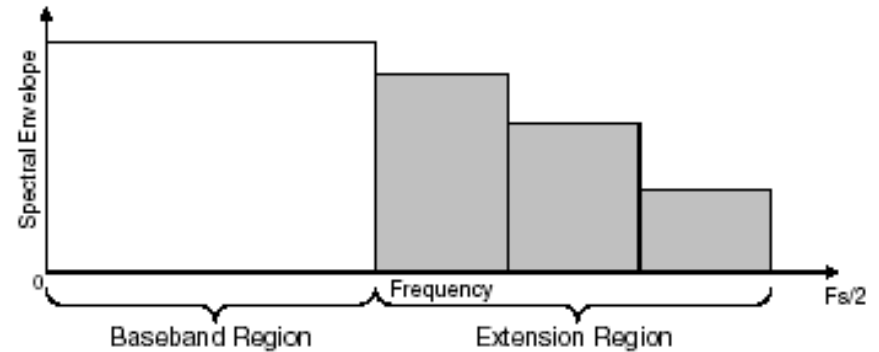
Fig 6: Decoder: Final spectrum, multiplication by transmitted energy ratios
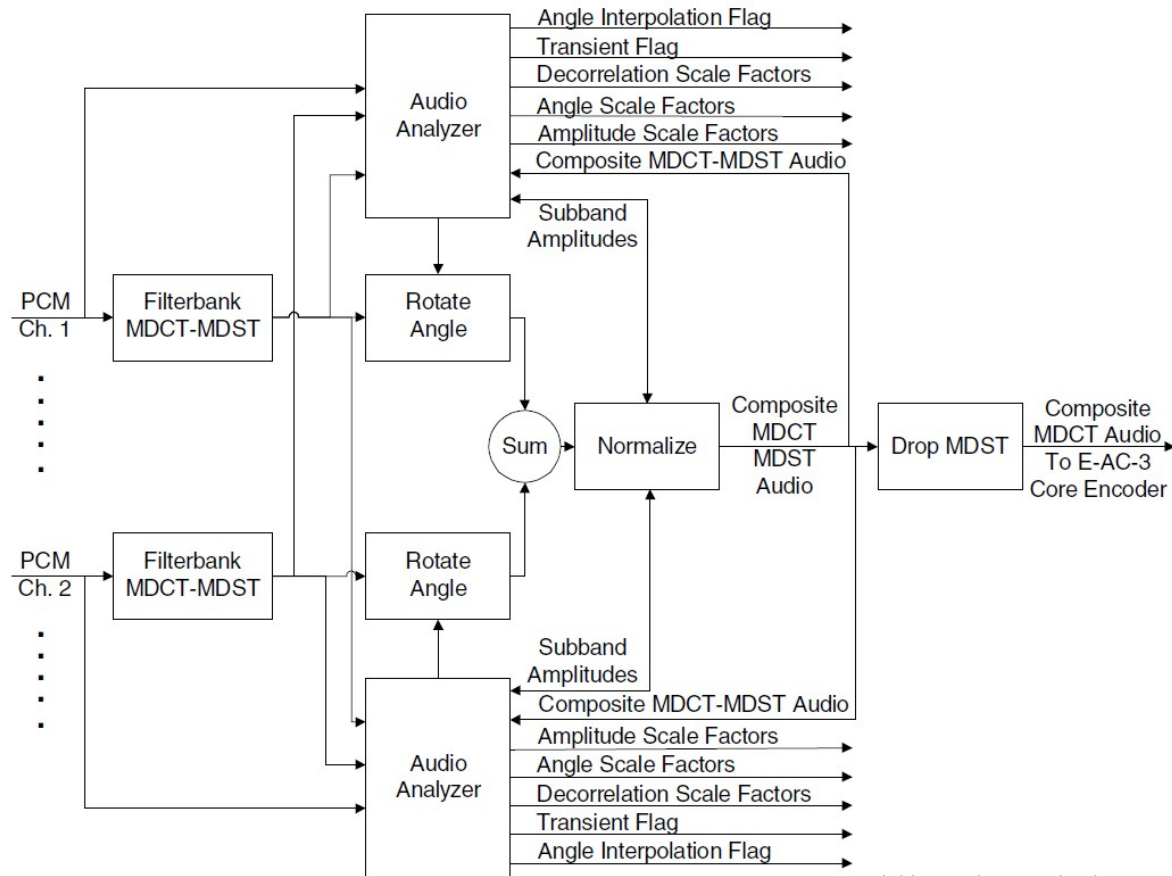
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E-AC-3: Enhanced Coupling

Source: L.D. Fielder et al., "Introduction to Dolby Digital Plus, an Enhancemnet to the Dolby Digital Coding System", 117th AES Convention

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E-AC-3: Transient Pre-Noise Processing

- reduces pre-echo artifacts with a time-domain strategy
- a time-scaled part of the signal substitutes quantization noise just before a transient
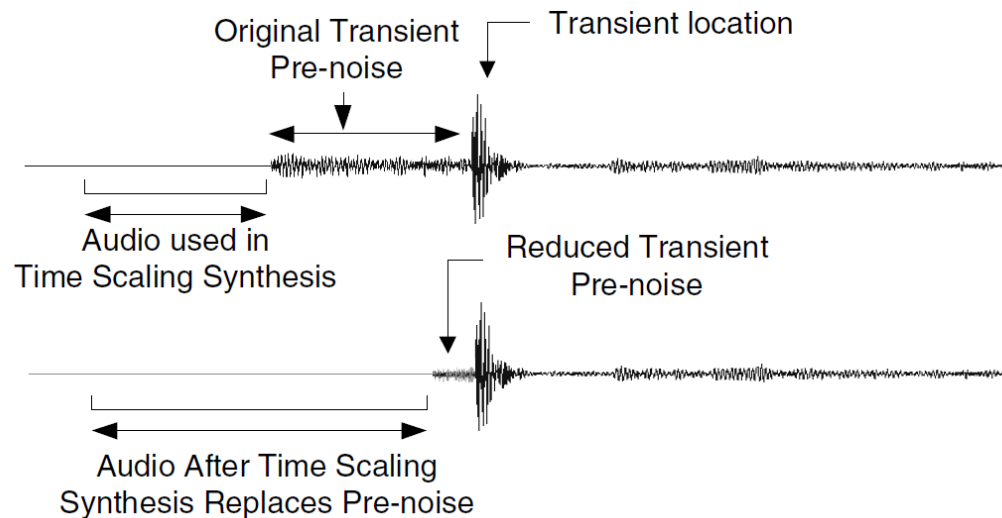
Source: L.D. Fielder et al., "Introduction to Dolby Digital Plus, an Enhancemnet to the Dolby Digital Coding System", 117th AES Convention

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DTS

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DTS: Coherent Acoustics coding or Digital Surround®

- Intended for entertainment and professional use

- Optional coding scheme for DVD

- Part of the Blue Ray audio standard

- Audio data rates from 8 to 512 kbit/s/channel

- Sampling rates up to 192 kHz / 24 bit

- 5.1 core coder with up to 1536 kbit/s

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DTS: Encoder overview

- Two main stages: polyphase filtering and subband-ADPCM

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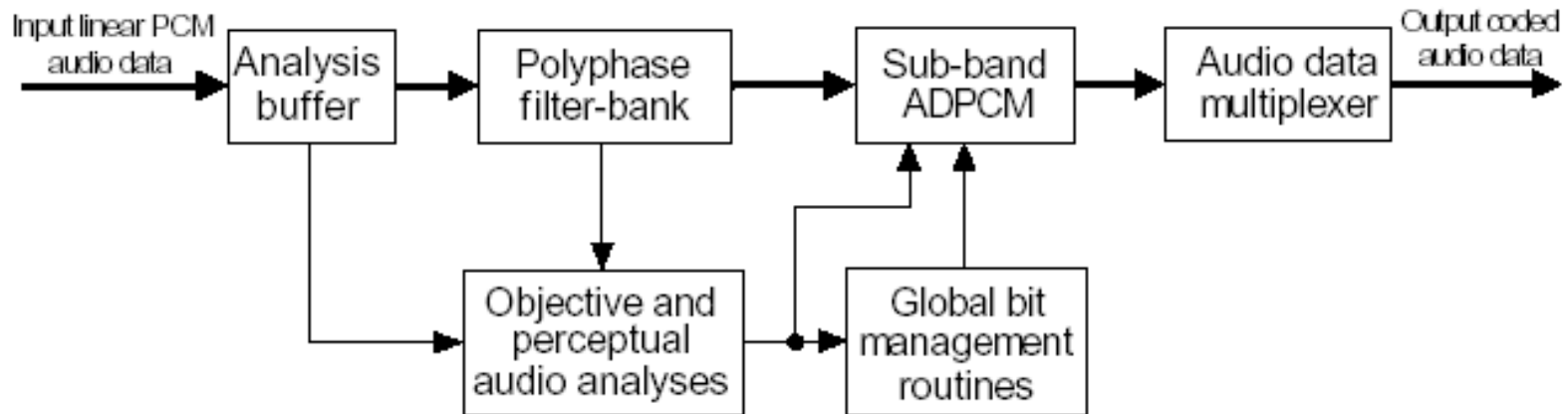
DTS: Polyphase Filter Bank

- 32 subbands
- Frames of 256, 512, 1024, 2048 or 4096 samples
- Long frames mainly used for low bit rates (coding efficiency)
- Two filter banks: perfect reconstruction (high bit rates) and near-perfect reconstruction (lower bit rates)

Type	Taps	Transitional bandwidth [Hz]	Stop-band rejection [dB]	Ultimate Rejection [dB]	Reconstruction resolution [dB]
NPR	512	300	110	120	90
PR	512	350	85	90	145

Example: Polyphase filter banks at 48 kHz

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DTS: Subband Adaptive DPCM

- Reduce sample-to-sample correlation within each subband

- Disengageable within each subband, if simple PCM renders better results

- Forward prediction based on LPC analysis

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DTS: Subband Adaptive PCM (block diagram)

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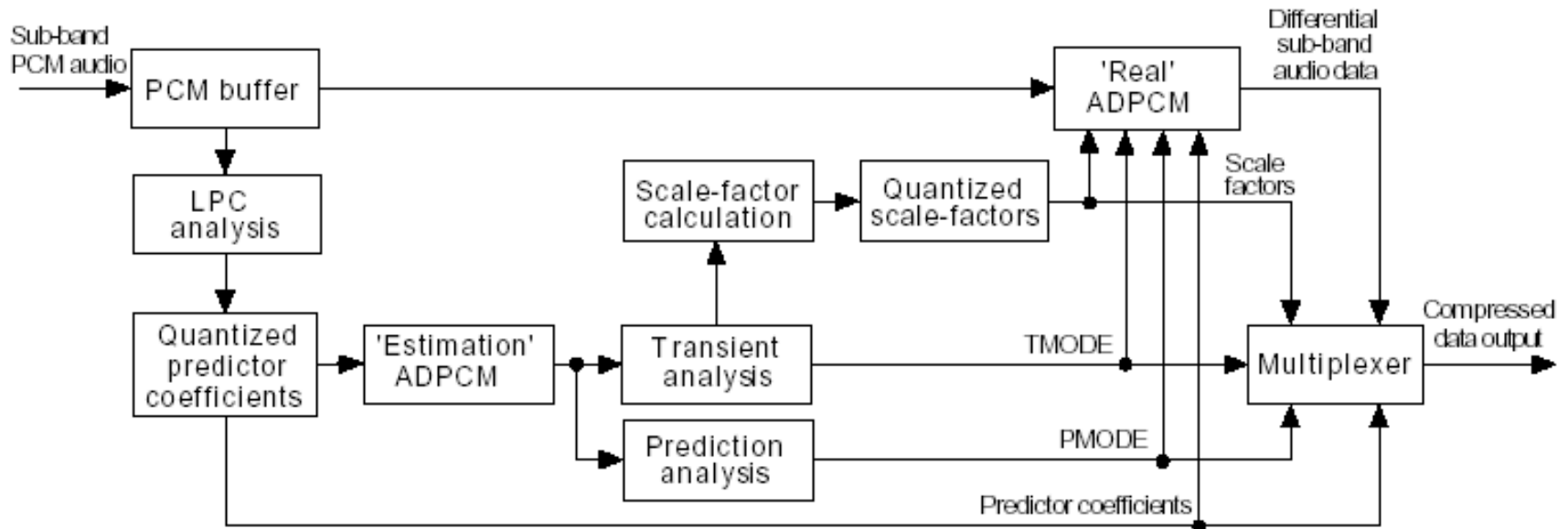
DTS: Quantization and Bit Allocation

- 28 different mid-tread quantizers up to 16,777,216 levels
- Psychoacoustically controlled
- Optional table-based entropy coding at low bit rates

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DTS: Quantization and Bit Allocation (block diagram)

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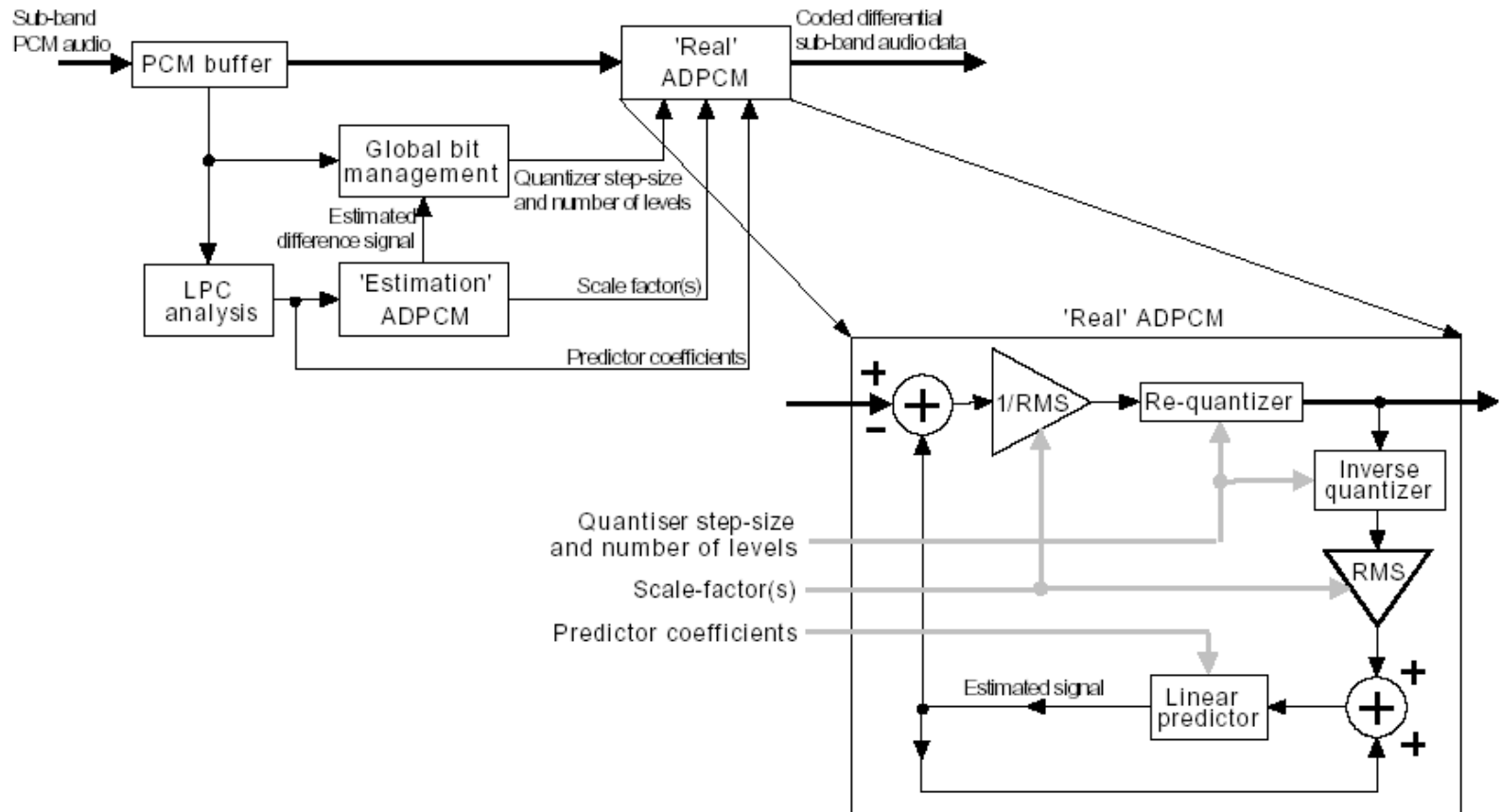
DTS: Example for the use of the extension audio data

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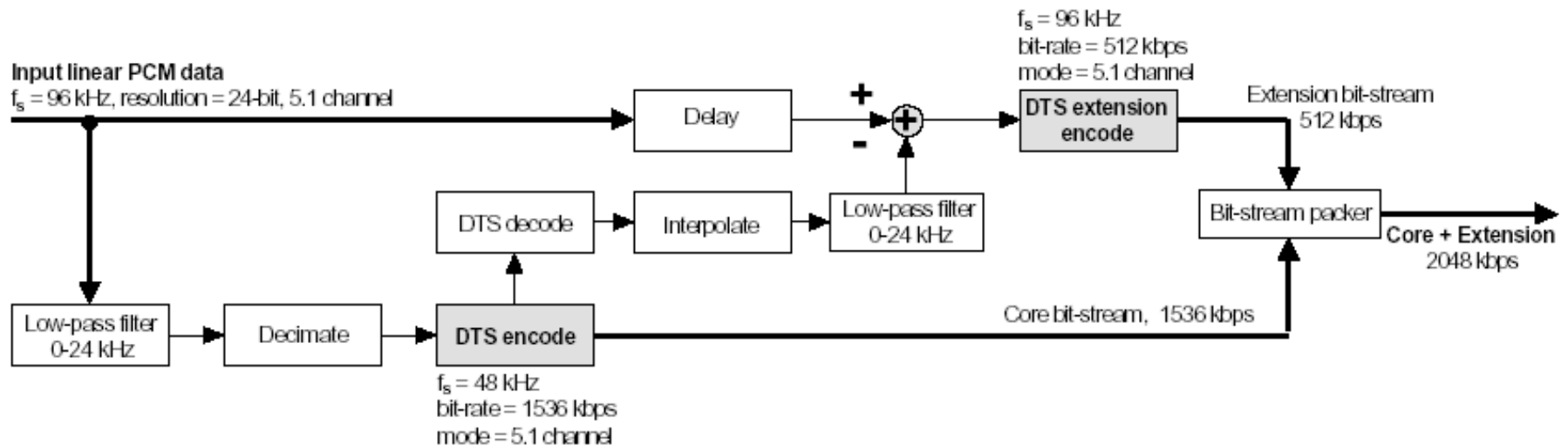
DTS-ES: discrete 6.1 multi channel coding

- 5.1 channel DTS core + additional Center Surround channel
- Additional channel is transmitted using Extension Audio Data
- Backwards compatible to 5.1 DTS core coder
- Three possible decoder setups possible:
  - 5.1 decoding with phantom source
  - Matrix decoding of Center Surround Channel
  - Discrete 6.1 decoding by evaluating Extension Audio Data

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DTS-ES: Encoder block diagram and Bit Stream

DTS-ES
Encoder

DTS-ES Bit
Stream

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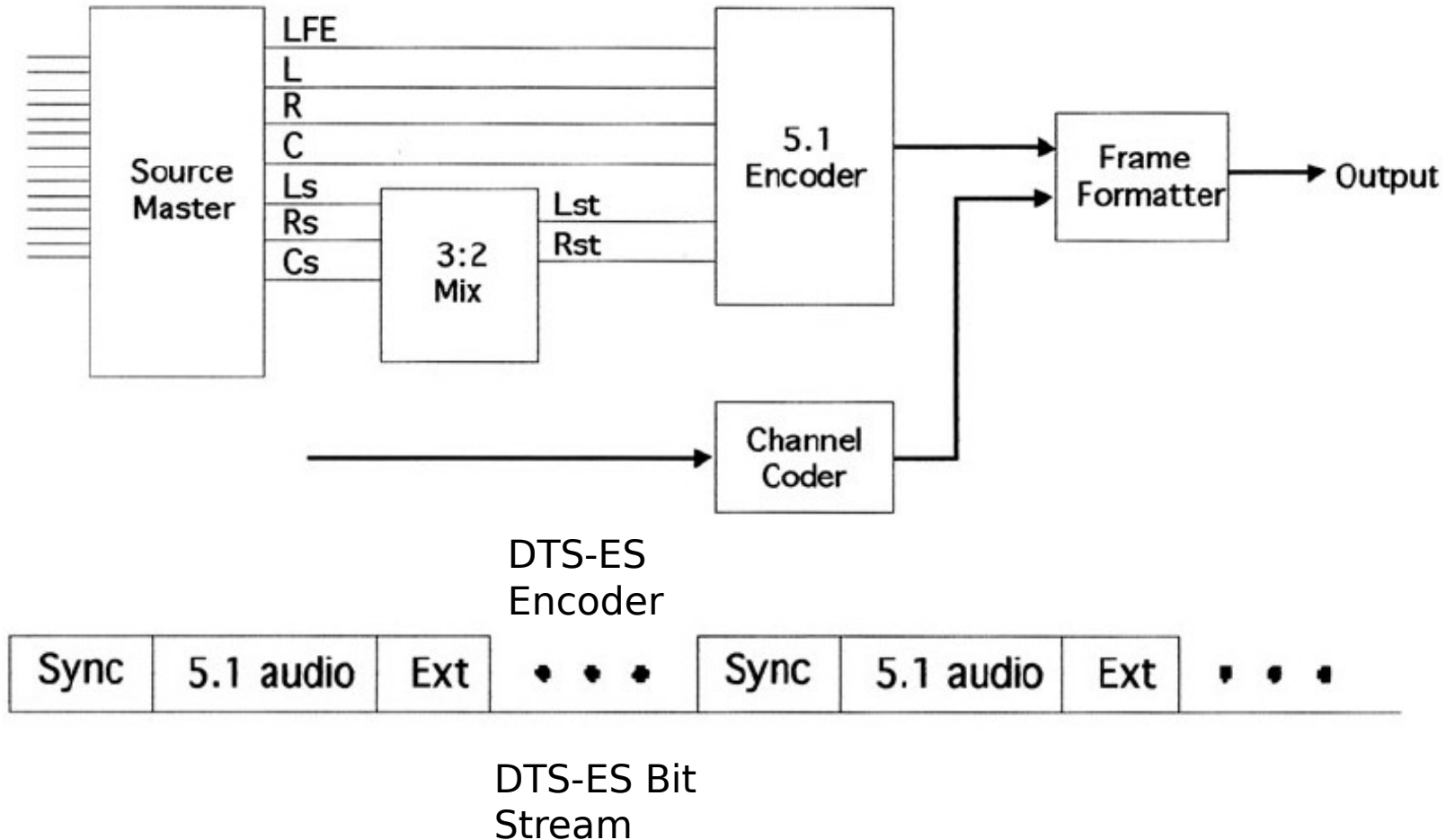
DTS-HD

- DTS Digital Surround (DTS 5.1 core) mandatory for HD-DVD and Blu-Ray

- DTS-HD is optional for (HD-DVD outdated) Blu-Ray

- DTS-HD is a set of extensions to DTS core, encompassing DTS core, DTS-ES, Neo:6 and DTS 96/24

- Lossless audio coding possible

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Ogg Vorbis

- Ogg project started 1993 to provide a license-fee free audio coder/decoder
- Ogg: file transport protocol
- Vorbis: audio coder
  - Psycho-acoustically controlled forward adaptive monolithic codec based on MDCT
  - Inherently variable bit rate coder
  - Provides no framing, synchronization or error protection by itself (therefore use Ogg for file transport, RTP for multicast)
  - Low-complexity decoder, but high memory usage due to non-static probability models
  - Huffman and VQ codebooks are transmitted within bit stream header

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Windows Media Audio (WMA)

- Proprietary Audio Coder developed by Microsoft
- Collection of profiles for different applications:
  - WMA 9: most scenarios, backwards compatible to WMA 8, about 20% lower data rate, VBR possible
  - WMA 9 professional: 24 bit/96 kHz audio, 7.1 channels, 128-768 kbps, stereo downmix available
  - WMA 9 voice: speech content at low bit rates (<20 kbps)
  - WMA 9 lossless: compression depending on input audio, used for high-quality archiving purposes

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WMA: main features

- MDCT (or MLT) based
- Multiple numbers of frequency lines (128, 256, 512, 1024, 2048)
- Sinusoidal shaped windows, transition windows and "bridge" windows ("soft" transition between long and short blocks)
- Uniform quantization within scale factor bands
- M/S coding frame-by-frame instead of scale-factor-band-wise
- Bit reservoir available (1-pass and 2-pass coding)

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MPEG Spatial Audio Object Coding (SAOC)

Overview

- Concept

- MPEG Surround integration

- Advantages of SAOC

- Applications

- Conclusion

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Concept: From MPEG Surround to SAOC (1)

Current Spatial Audio Coding: **_Channel_**-oriented (MPEG Surround)

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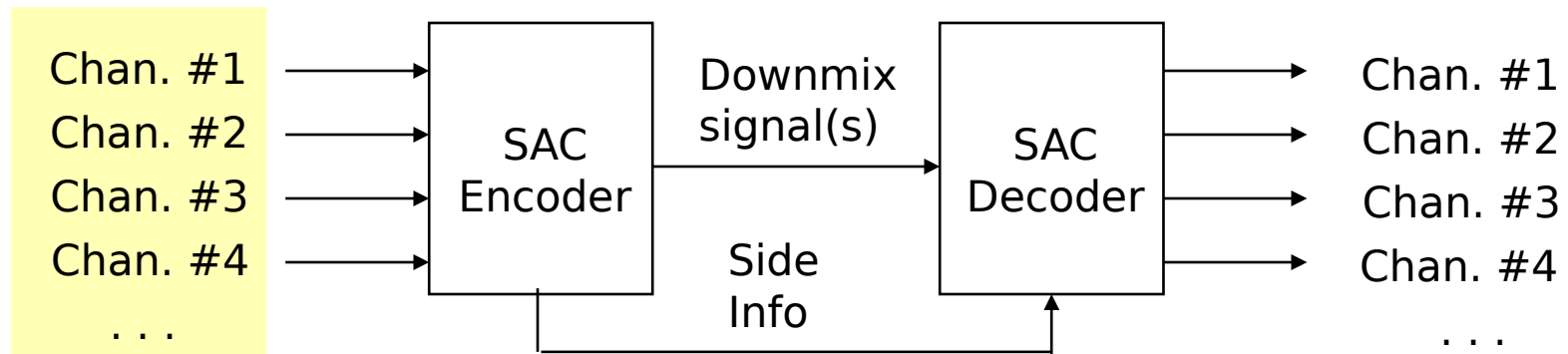
Concept: From MPEG Surround to SAOC (2)

Object-oriented Spatial Audio Coding
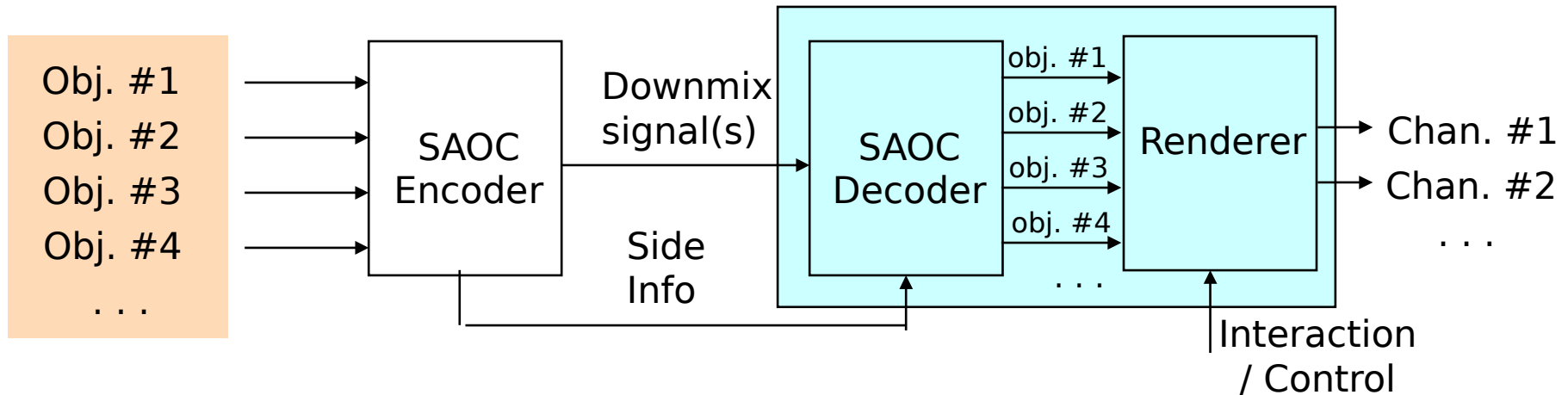
- Processes **object signals** instead of **channel signals**
- Side Info: few kbit/s per audio object
- Mono or stereo downmix
- "Mixing"/rendering parameters vary according to user interaction

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MPEG Surround integration/extension
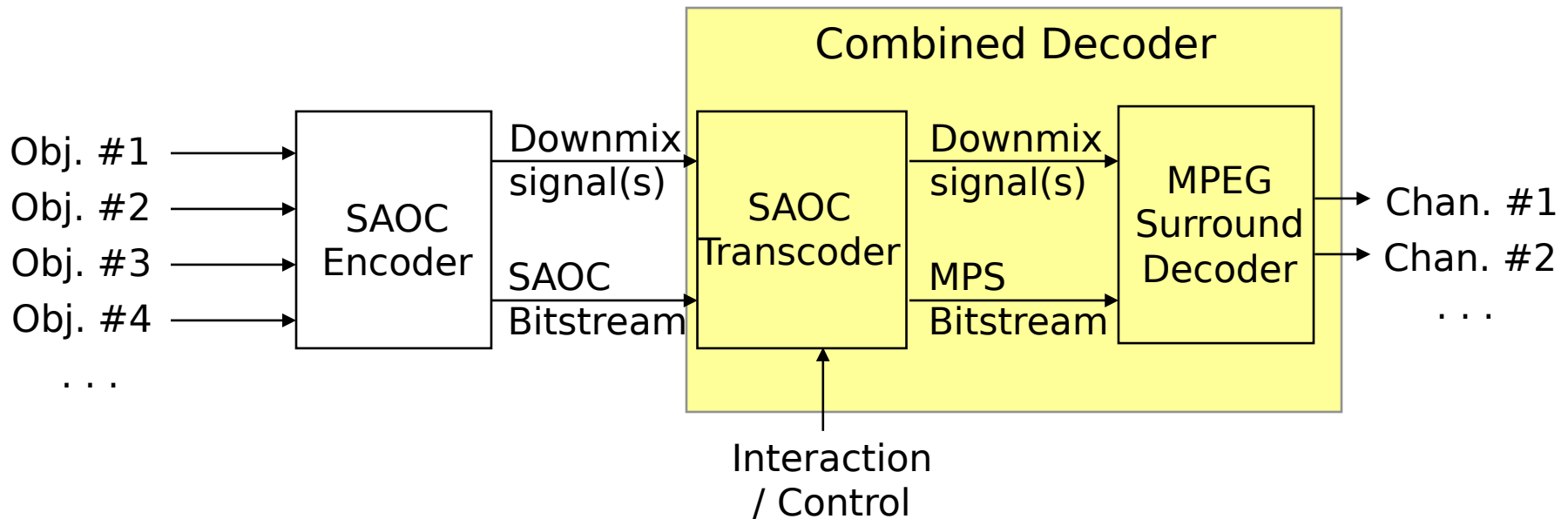
- MPEG SAOC decoder = MPEG SAOC Transcoder + MPEG Surround decoder

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Advantages using MPEG SAOC (1)

Key features

- Highly *efficient* storage/transport of individual audio objects ..

- .. in a *backwards compatible* downmix

- User *interactive rendering* of the audio objects (e.g. move or amplify objects)

- *Flexible rendering* configurations (e.g. 2.0, 5.1, binaural, ..)

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Advantages using MPEG SAOC (2)

Other features

- Low complexity decoding/rendering for a large number of objects compared with individually encoded and rendered objects

- Compatible with any core codec (for the downmix)

- Powerful rendering engine (= MPEG Surround) integrated, no additional solution required

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Applications (1)

Examples

- **Interactive Remix / Karaoke**
    - Suppress / attenuate instruments or vocals (Karaoke)
    - Modify the original track to reflect current preference (e.g. "more drums & less strings" for a dance party)
    - Choose between different vocal tracks ("female lead vocal vs. male lead vocal")
    - Control the dialog/speech level in movies/news broadcasts for better speech intelligibility.

Main feature

- Backwards compatibility

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Applications (2)

Examples

- **Gaming / Rich Media**
  - Efficient and flexible audio transport in multi-player games or applications (e.g. Second Life)
  - Efficient storage together with flexible rendering of audio in small interactive games

Main feature

- Storage/ Bitrate Efficiency

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Applications (3)

Examples

- **Teleconferencing**
  - Mobile conference over headphones: Virtual 3D-audio line-up of communication partners all around the listener
  - Conference setup with 2 or more loudspeakers: Spatial distribution of communication partners

Main feature

- Quality Improvement:
  - Increased speech intelligibility
  - Increased listening comfort

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Conclusions SAOC

- Highly efficient transport/storage of audio objects **and** flexible/interactive audio scene rendering

- Backwards compatible downmix for reproduction on legacy devices

- Flexible rendering configurations

- Under standardization within MPEG

- Very interesting applications, e.g.:
  - Remixing/Karaoke
  - Gaming
  - Teleconferencing

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