Performance analysis and low power VLSI implementation of DVB-T receiver

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http://www.ele.kth.se/~imed/%7Eimed/PCC/ofdm2.pdf

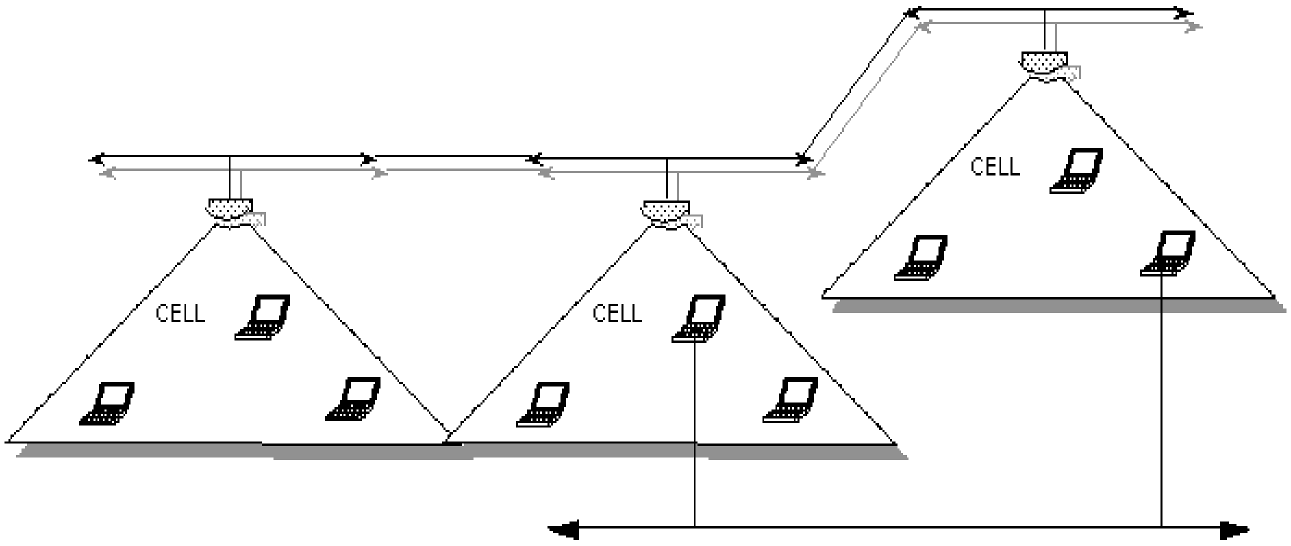
Presentation outline

- Introduction to WLAN
- Relation Between WLAN and OSI
- 802.11 MAC and Physical Layer:Current status
- Future Challenges for designing high-data rate WLAN in the ISM band (5GHZ)
- High Data Rate WLAN in the ISM band: ESDLAB vision
- Overview of OFDM
- Efficient signalling techniques over dispersive channels
- Characteristics of the OFDM for DVB-T
- ESDLab proposal for WLAN PHY layer.
- How to achieve longer-battery life for WLAN high data-rate?

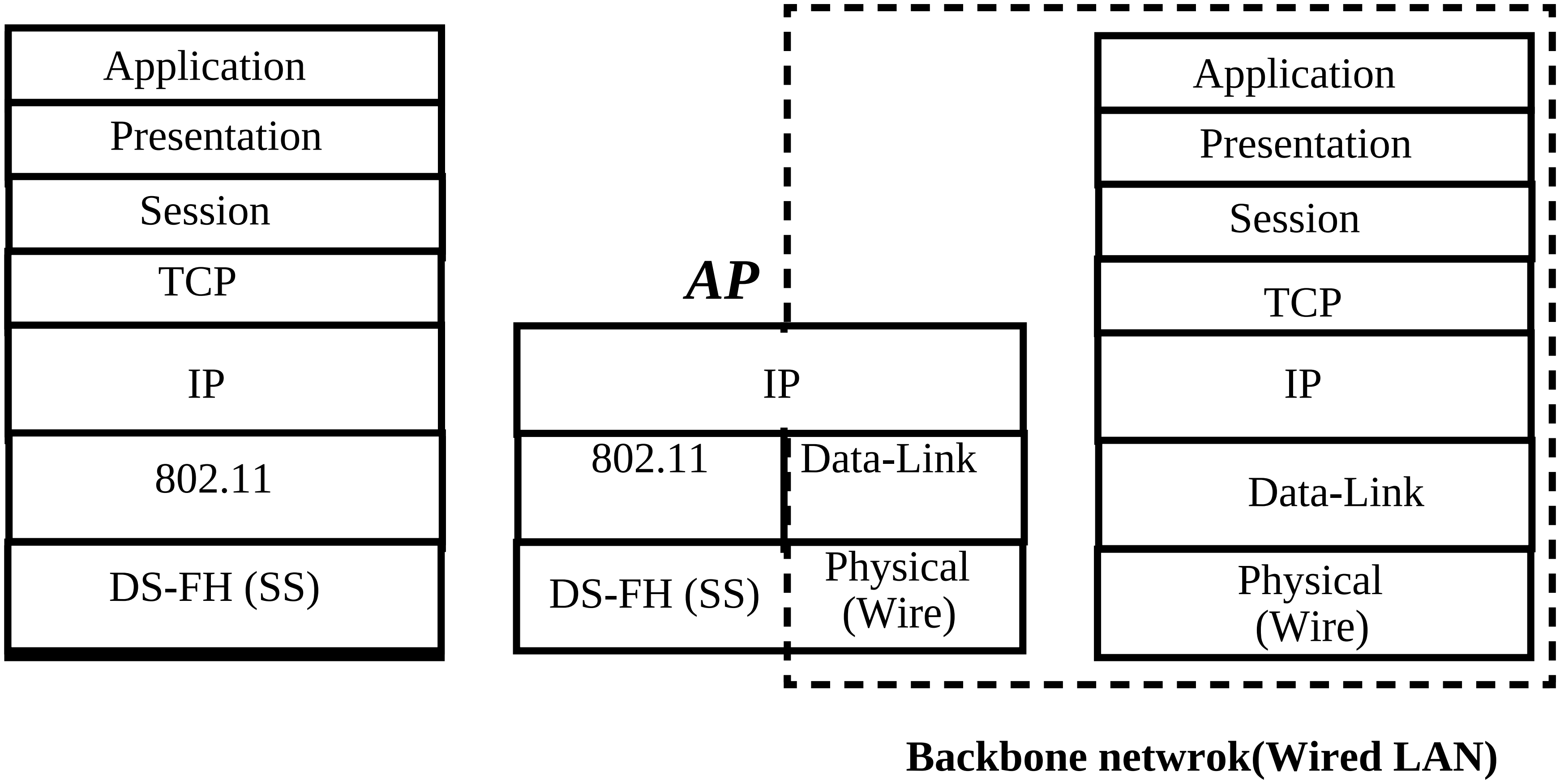
Presentation outline (part 2)

- DVB-T system description
- DVB-T transmitter overview
- DVB-T receiver overview
- Design Flow
- Improving the initial design in terms of area and power consumption.
- Hardware implementations:
- Demapper
- Symbol / Bit deinterleaver
- Depuncturer
- VLSI implementation and performance analysis

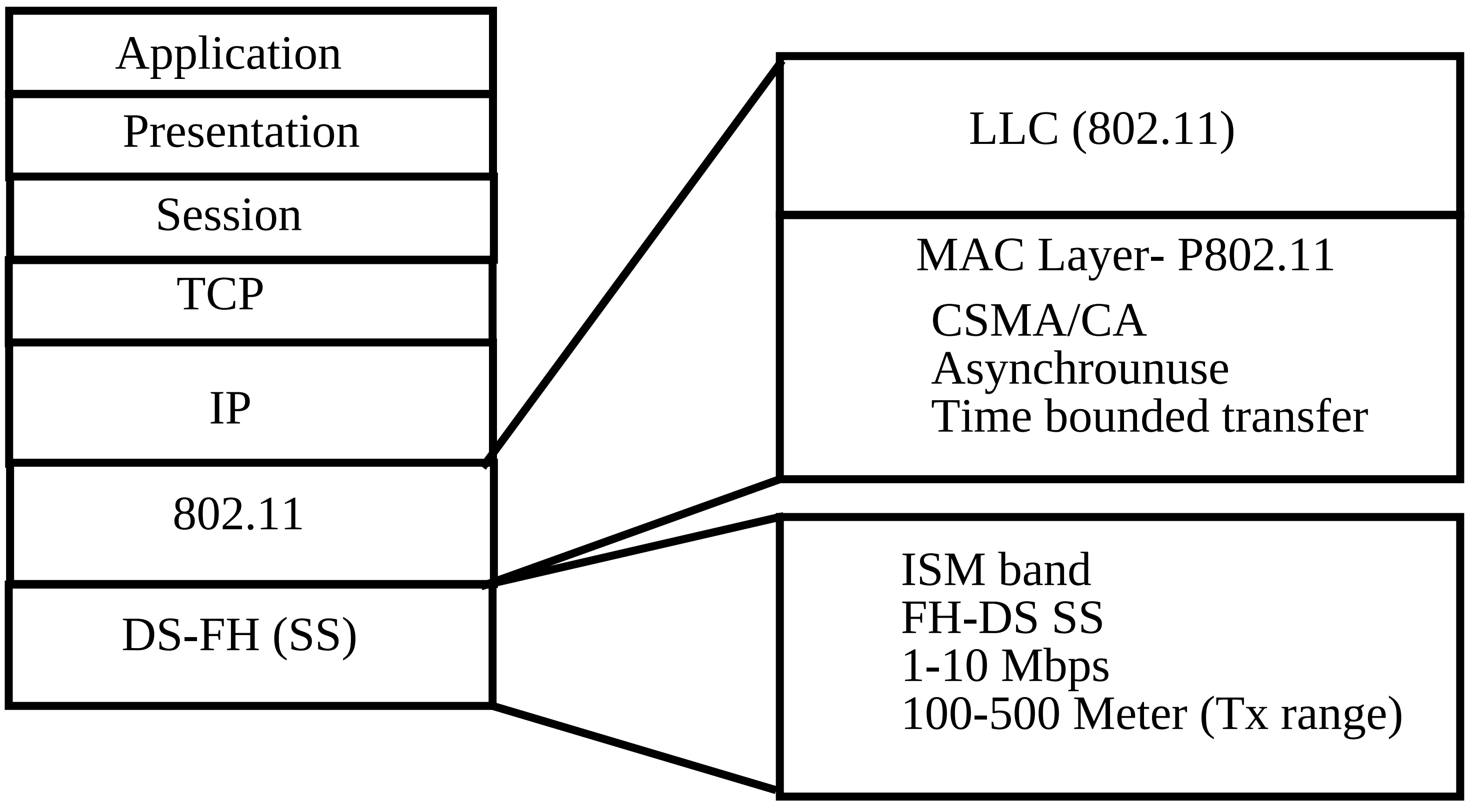
Introduction to WLAN



Wirless Local Area Network
Client Server Architecture



Relation Between WLAN and OSI (Open System Interconnect)

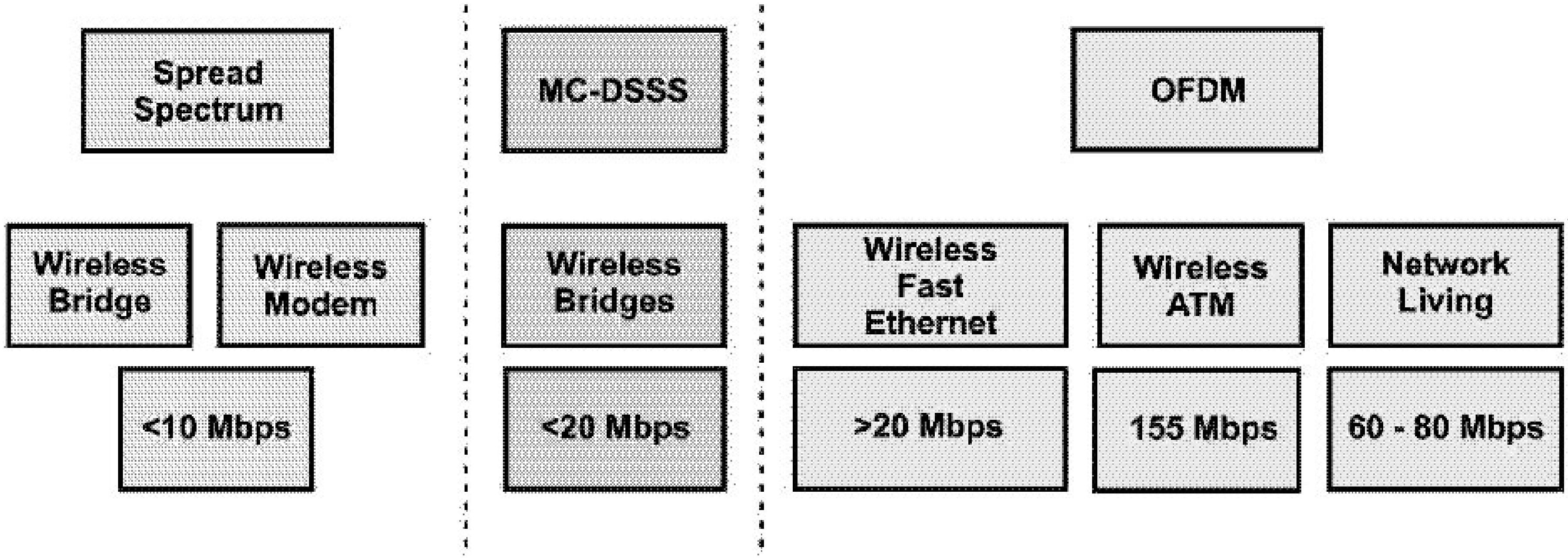


802.11 MAC and Physical Layer (Current status)

- Study expert group 802.11 was formed under the IEEE project 802.11
- Its mission to recommend an international standard for WLANs
- The standard supports both ad-hoc and client-server architecture
- The first ratified standard was proposed in June 1996,
  - Frequency hoppoing and Direct sequence spread spectrum is used at the PHY-level
  - The IEEE standard supports DSSS for use with Differential Binary Phase Shift Keying (DBPSK) with data rate of 1Mbps, or Differential Quadrature Phase Shift Keying (DQPSK) 2 Mbps data rate.
  - FHSS is supported under 802.11 with GFSK modulation and two hopping patterns with data rates of 1 Mbps and 2 Mbps.
- The second draft of the standard, July 1998, the digital modulation at the PHY-level is :Direct Sequence/Pulse Position Modulation (DS/PPM) proposed by *Lucent*^{TM}[1]
- The MAC layer specification for 802.11 is similar to the Ethernet standard 802.3.

1. http://www.lucent.com/press/0497/970422.bla.html

Future Challenges for designing high-data rate WLAN in the ISM band (5GHZ)



High Data Rate WLAN in the ISM band: ESDLAB vision

- For WLAN with data rate>100 Mbps, OFDM is a very good candidate:

1. High-spectral efficiency,
2. Robust against multi-path fading: Typical problem for WLAN communication channel,
3. In the ISM band, it is possible to design a single WLAN receiver for 80.11: DSSS, FHSS and DS/PPM,
4. OFDM is being proposed as PHY-level by the ETSI/BRAN (the Project for Broadband Radio Access Networks European Telecommunications Standards Institute)
5. The draft of 802.11a standard supports OFDM as PHY-layer[1]

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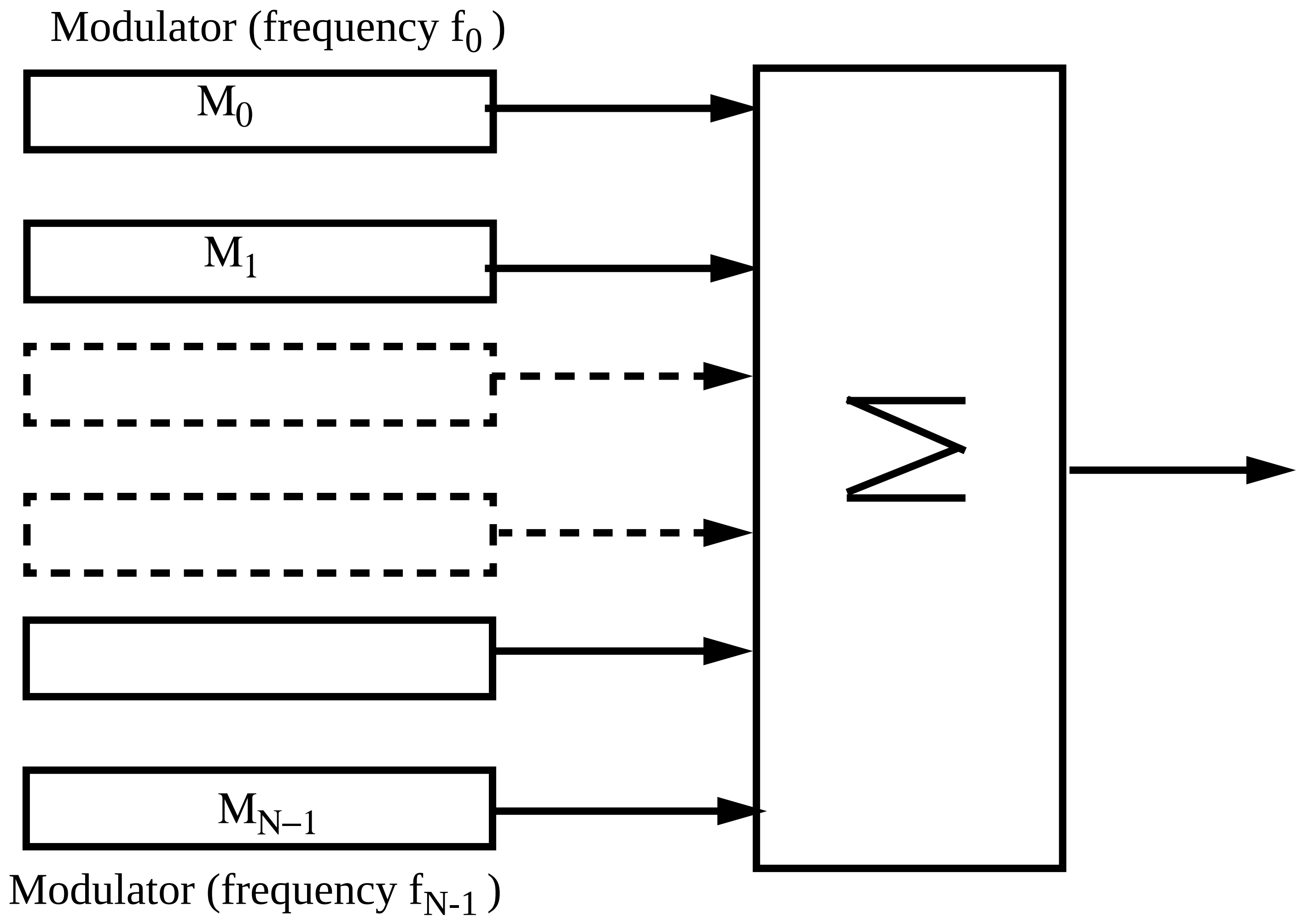
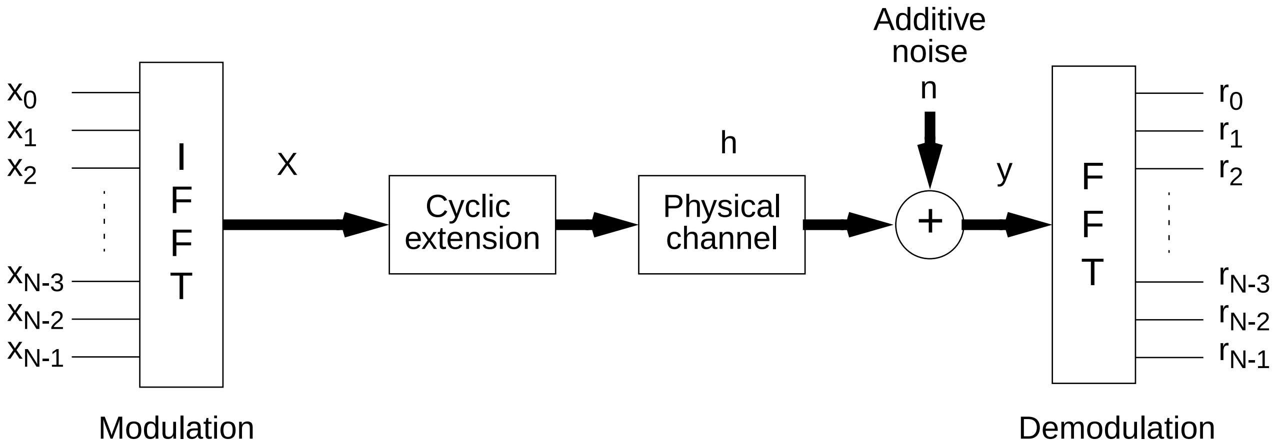
1. http://grouper.ieee.org/groups/802/11/Reports/Summary-report-99January-meeting.html

Overview of OFDM (Orthogonal-Frequency Division Multiplexing



Digital OFDM (IFFT/IDFT)



$r_k = H_k \cdot x_k + n_k$ where

r_k = received symbol
H_k = frequency response of the physical channel
x_k = transmitted symbol
n_k = additive noise

$$r = FFT(y+n) = FFT(h \otimes X+n) = FFT(h \otimes IFFT(x)+n) = FFT(h) \cdot x+FFT(n) = H \cdot x+\tilde{n}$$

What are the problems when using OFDM digital modulation?

- ICI (Inter-channel Interference): Also called: Cross-talk, meaning: interference between symbol in adjacent frequencies.
- ISI sometimes called IFI (Inter-frame Interference), caused by the interference of successive OFDM frames.
- Highly vulnerable to synchronization errors and frequency offsets
- Highly vulnerable to the non-linearity of the PAs (in the RF analog front end).

Efficient signalling techniques over dispersive channels

- Spacing between adjacent sub-carriers is ensured by 1/T. T is the duration of the OFDM frame,
- Use pulse shaping signals in time domain to preserve orthogonality.

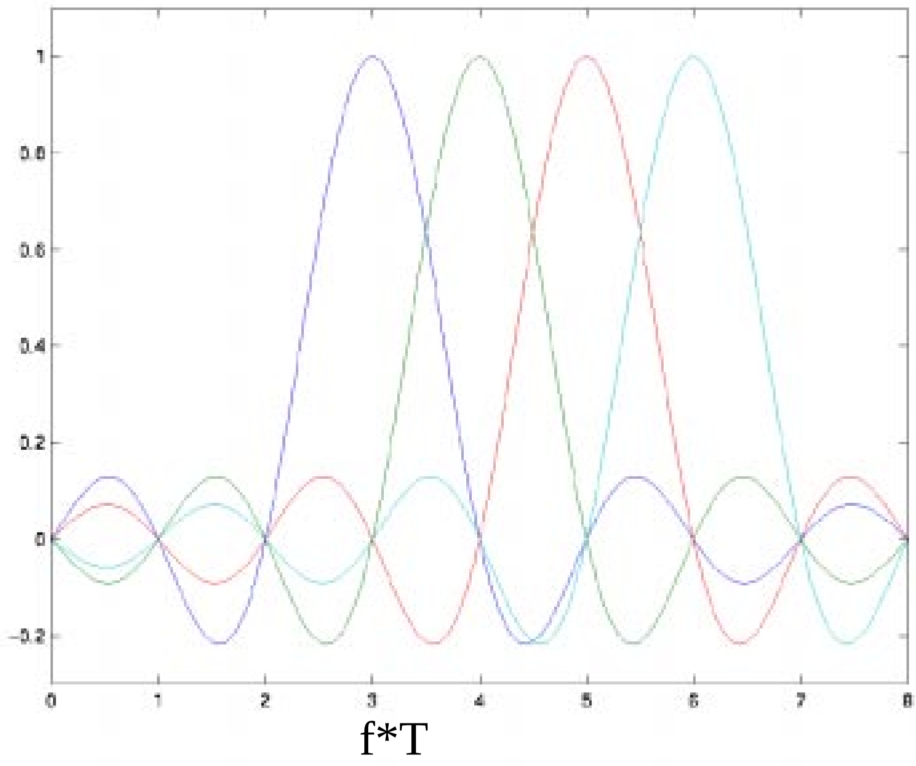


Fig.1 Spacing between adjacent subcarriers.

Reducing spectral overlap by designing efficient signalling techniques.

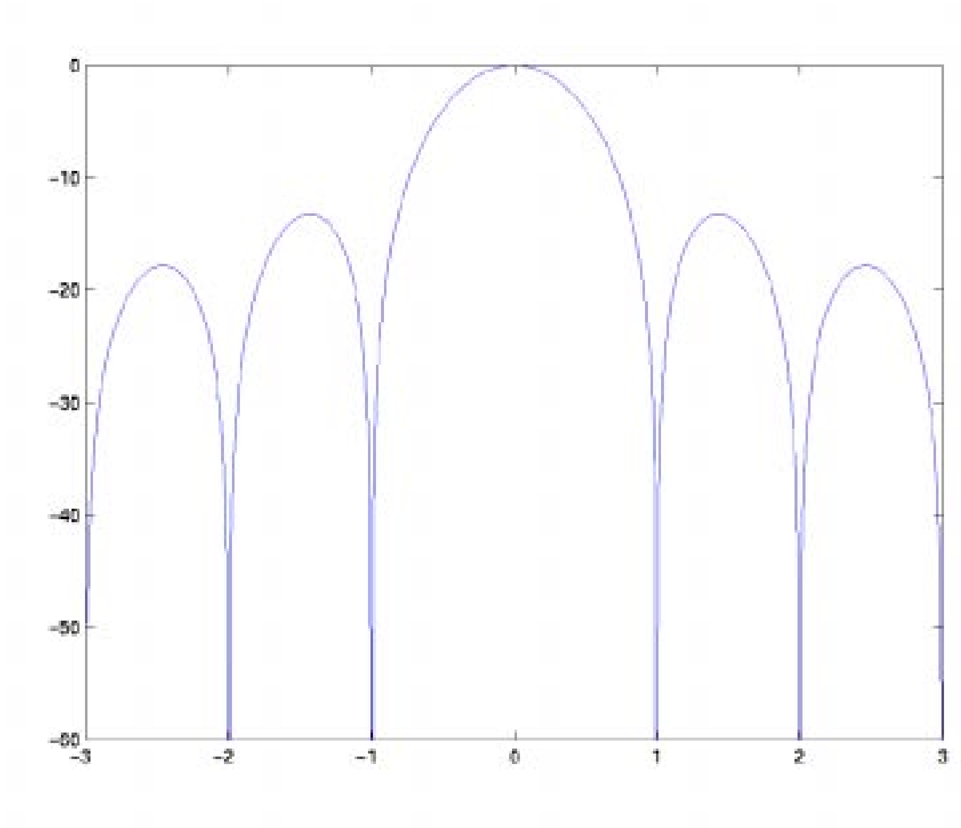


Fig2: Sidelobes when using rectangular pulse shaping

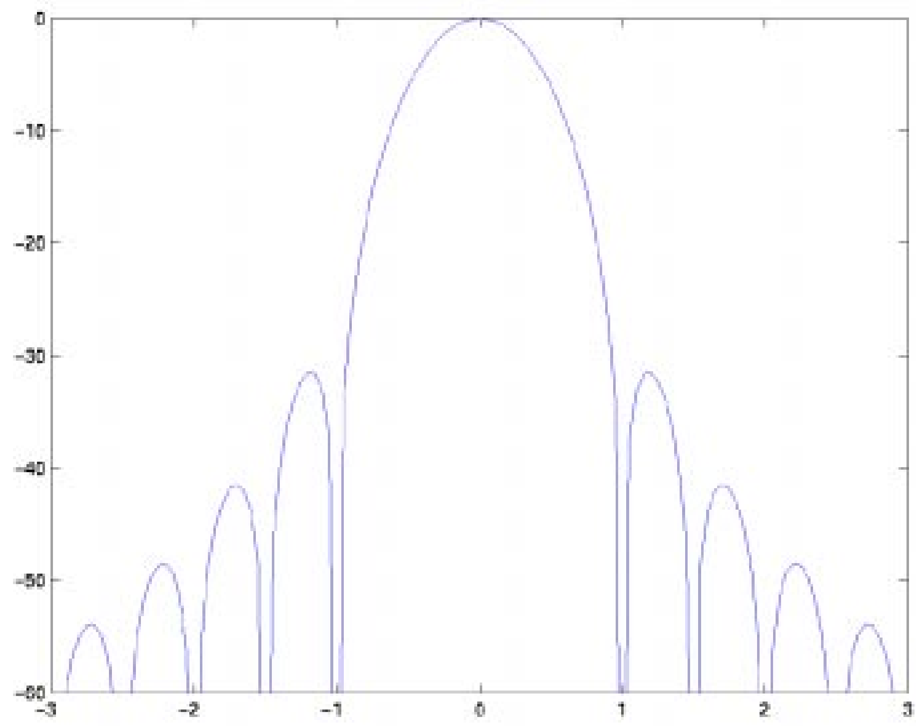


Fig3: Sidelobes when using RC filter with RF 0.5

How about M-band wavelet?

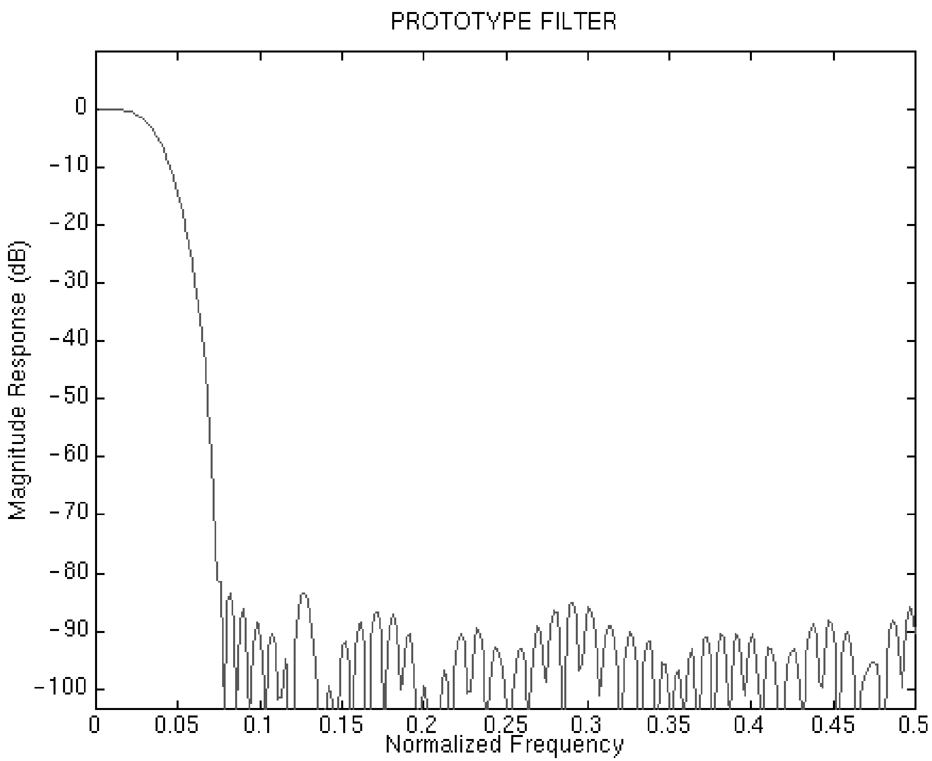


Fig4: MCFB, low-pass filter

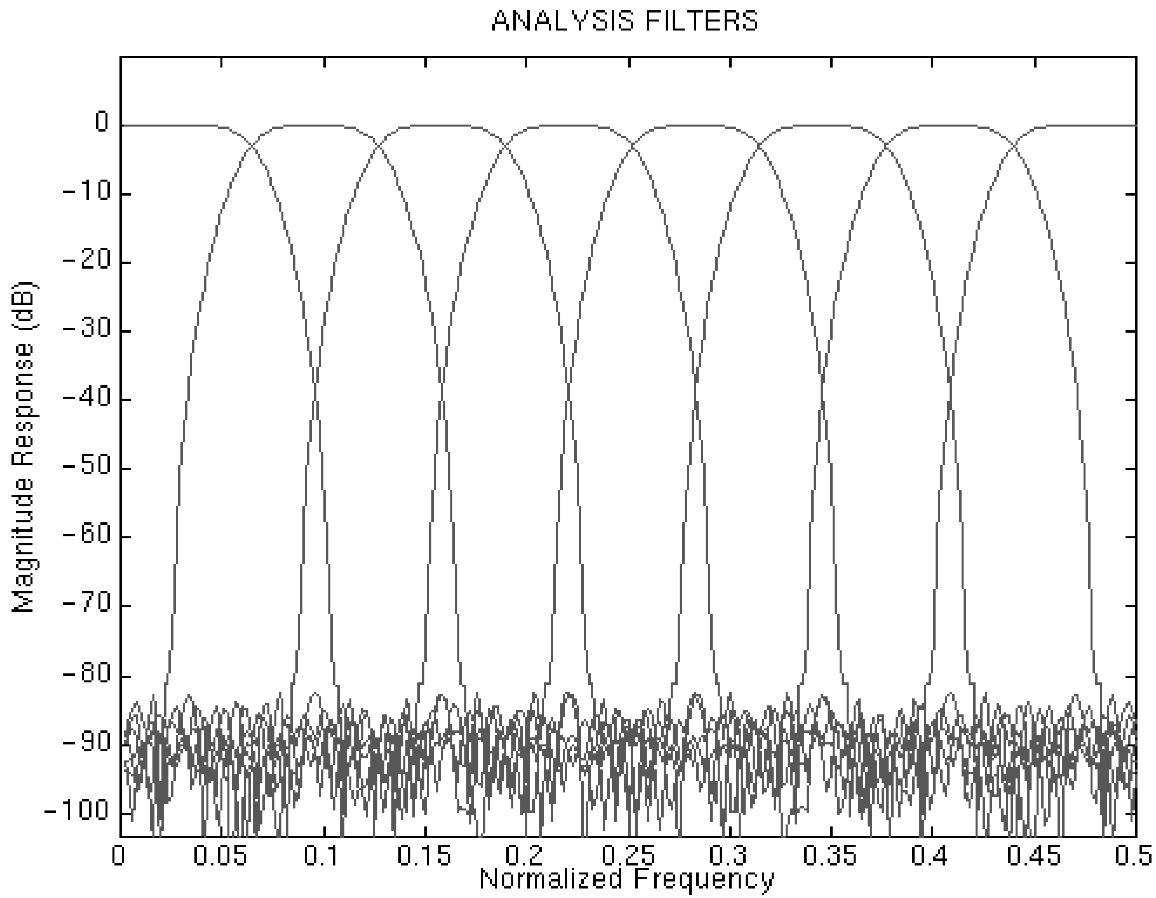


Fig 5: 8-band CMBF (Analysis part)

Characteristics of the OFDM for DVB-T

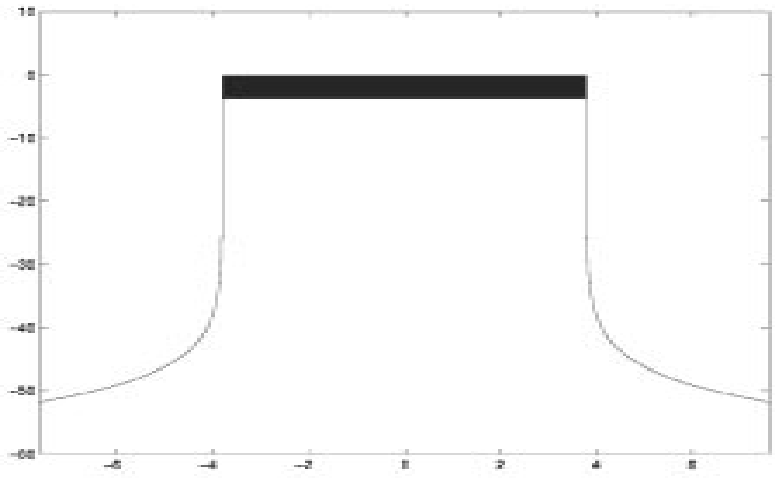


Fig6: 2K mode, Tg=Tu/4.

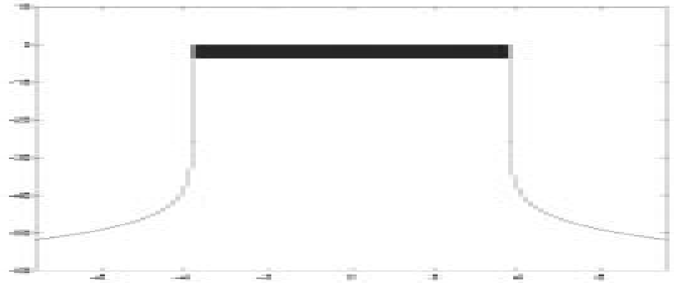


Fig7: 8k mode, Tg=Tu/4.

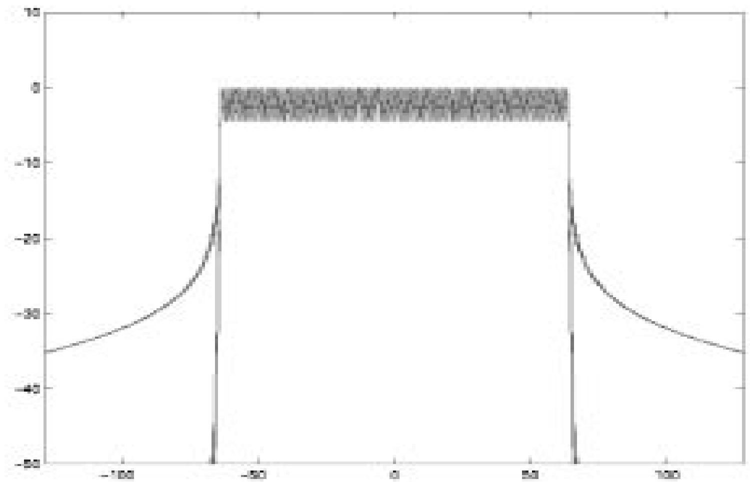
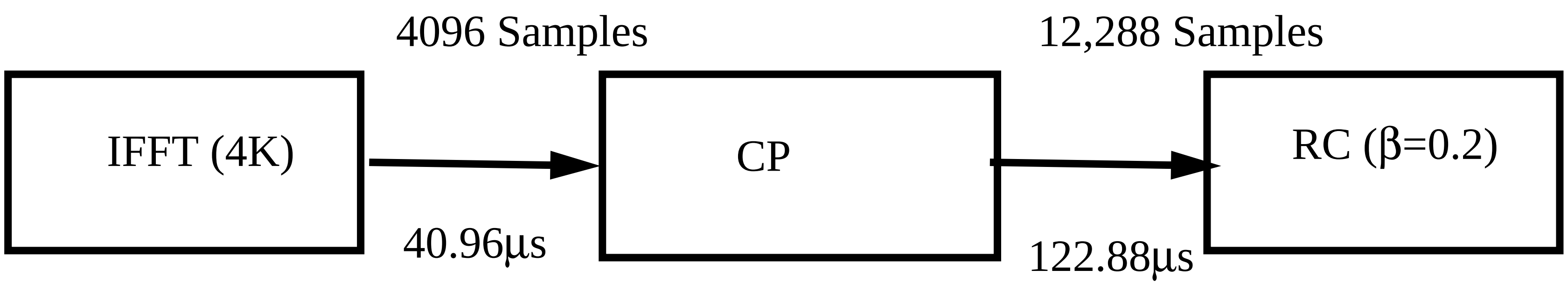


Fig8: Comparison between RC filter and rectangular Pulse shaping, 2K mode.

Parameters for efficient signalling of the DVB-T.

Parameter	2k mode	8k mode
Block length N	2048	8192
Number of carriers K	1705	6817
Symbol duration Ts	109,375 ns	109,375 ns
Duration $Tu = NTs$	224 µs	896 µs
Duration of guard interval Tg	$T_u/4$ = 56 µs	$T_u/4$ = 224 µs
Block duration $T_{block} = Tu+Tg$	280 µs	1,12 ms
Carrier spacing $1/Tu$	4,464 kHz	1,116 kHz
Bandwidth $W = K/Tu$	7,611607 MHz	7,608259 MHz

Proposed OFDM for WLAN (US Patent)[1]



1. US. Patent, Jan. 25, 1994. # 5,282,222

ESDLab proposal (not yet finalized!)[1]

- **Mband wavelet with 128 at 5GHZ, data-rate: 150 Mbit/sec, using array processor at the PHY-level. Pico cells of range 50m. Supports both ad-hoc and client-server network.**

1. Proposed by: Ben Dhaou Imed, e-mail: imed@ele.kth.se, http://www.ele.kth.se/~imed

How to achieve longer-battery life for WLAN high data-rate?

- Low-power cellular planning (trade-off: Coverage, BER, data-rate): up to 30% power saving
- Energy efficient protocols:from 10-70% power saving
- Low-complex, high-performance algorithms: 10-70% power saving,
- Low-power VLSI/ULSI design: up to 60% of power saving

Ways and methods for low-power VLSI/ULSI design.

System Level (system integration)

Partitioning, Power saving, high level of integration, low system clocks

Algorithm

Complexity, Concurrency, Regularity, minimizing number of operations

Architecture

Parallelism, Pipelining, Data encoding, Power management, Memory partitioning,
Minimizing number of global busses, Minimizing number of instructions, uses of caches.

Circuit/Logic

Logic optimization, Multi V_T logic circuits, Reducing V_{DD} in noncritical path

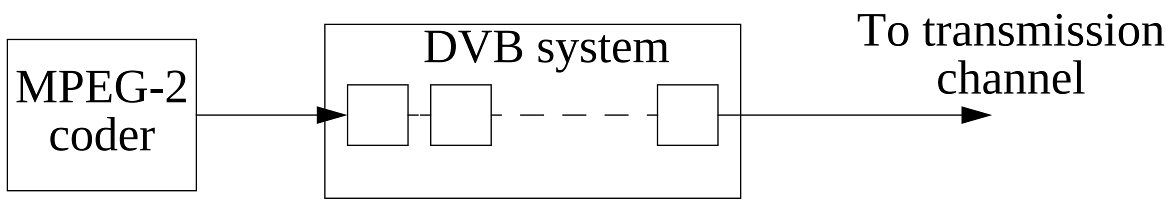
Device level

High density of integration, Reducing junction capacitance,
Improved device characteristics for low voltage operation.

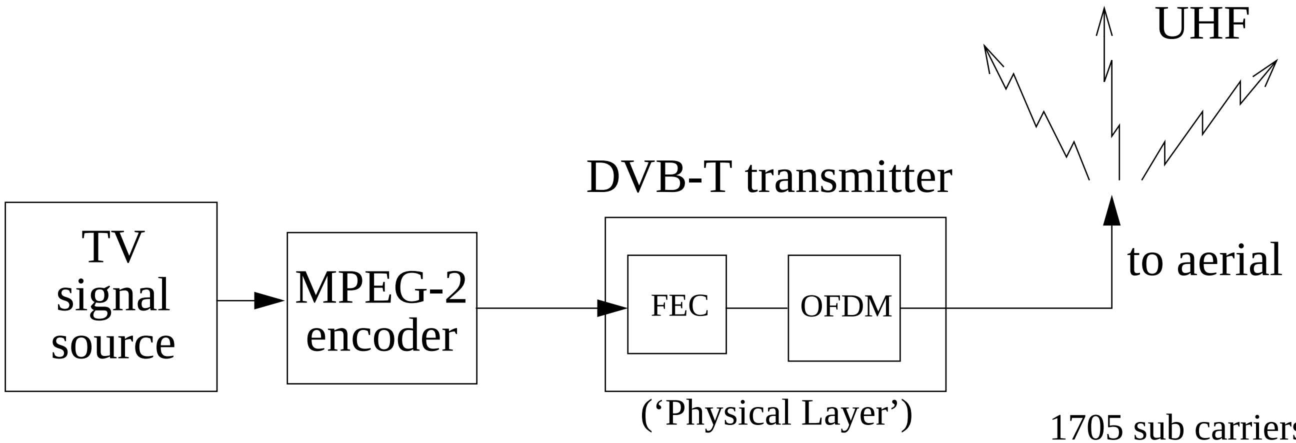
DVB-T system description

- DVB-T: Digital Video Broadcasting Terrestrial Version [EN 300 744]
- The standard was ratified in March 1997 by ETSI (European Telecommunications Standards Institute)
- The standard specifies the digitally modulated signal:
  - Modulator side: Detailed description of signal processing.
  - Receiver side: Left open for different implementation solutions.

- DVB-C [EN 300 429]: Cable system specifications.
- DVB-S [EN 300 421]: Satellite system specifications.



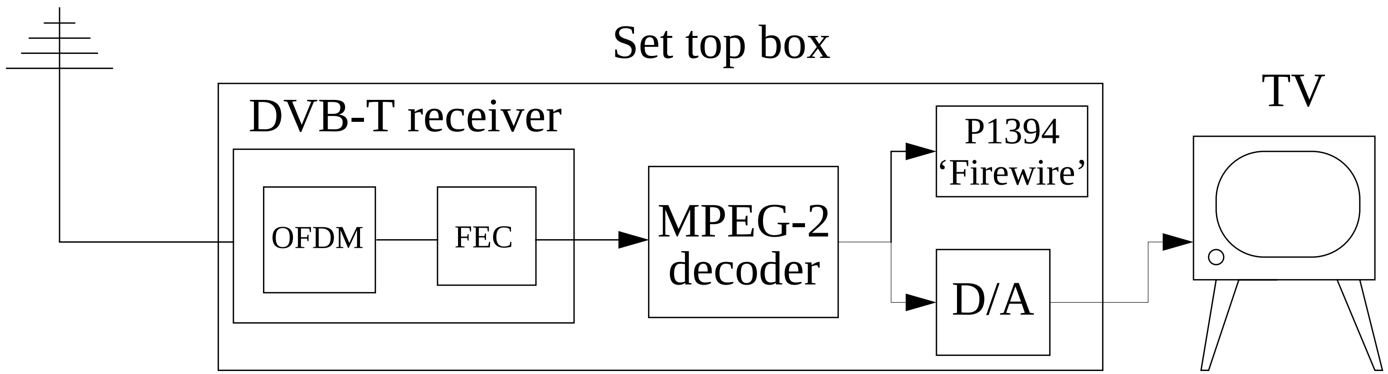
DVB-T / Digital Video Broadcasting for terrestrial television



1 DVB channel
~ 8 MHz

1705 sub carriers (spacing: 4464 HZ) - 2k mode

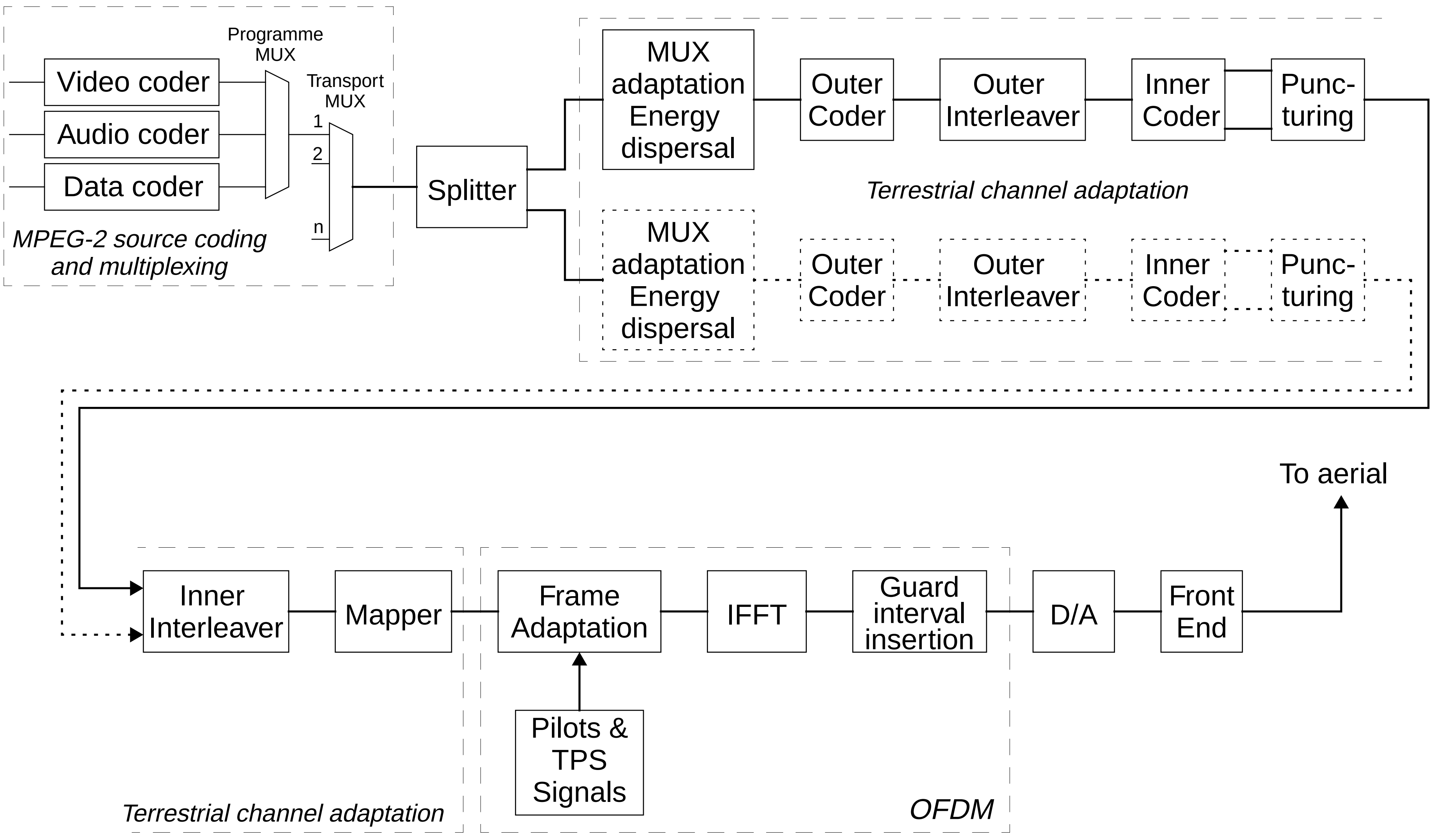
6817 sub carriers (spacing: 1116 HZ) - 8k mode



DVB-T system description

- The system will have to operate within the existing UHF spectrum allocated for analogue transmissions which means that its required to have:
  - Sufficient protection against high levels of Co-channel interference (CCI)
  - Sufficient protection against Adjacent-Channel Interference (ACI): Interference caused when two or more channels are placed in frequency bands that are too close together on the spectrum.
- Also the system is required to use the UHF-bands with maximum spectral efficiency, this can be achieved by utilizing Single Frequency Network (SFN) operation. (In Single Frequency Networks transmitters may use identical frequencies if they transmit absolutely identical data containers.)
- To achieve these requirements an OFDM system with concatenated error correcting coding is used for transmission (COFDM).

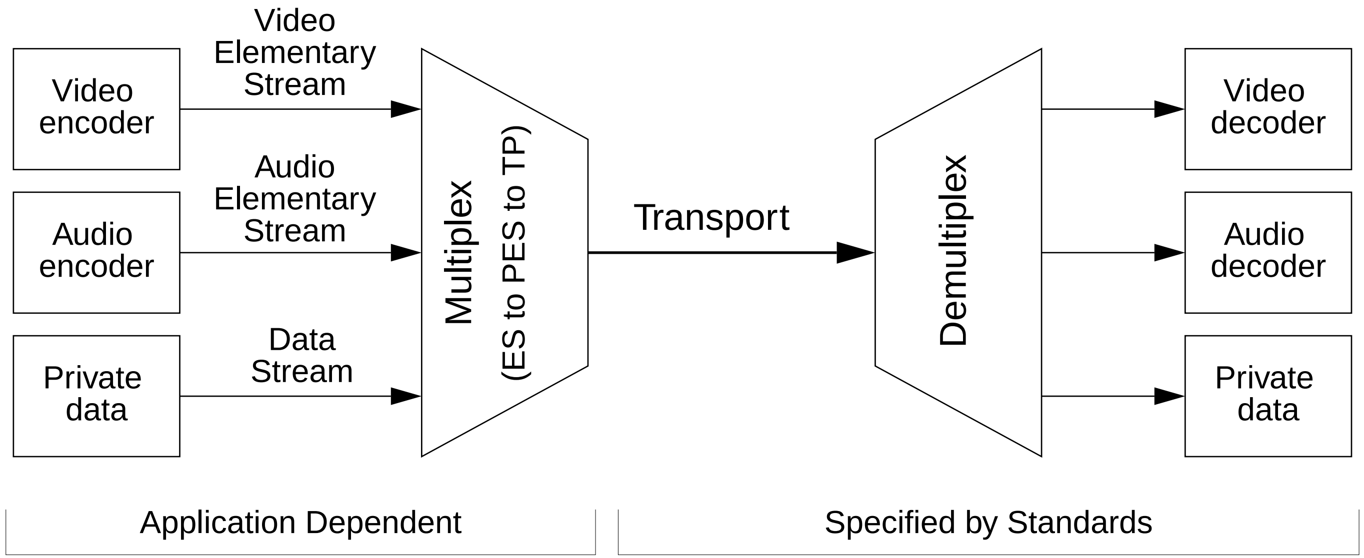
DVB-T Transmitter overview



MPEG-2

- MPEG - Moving Picture Experts Group - the name given to the group of experts that developed the standards MPEG-1 and MPEG-2 and MPEG-4, currently working on MPEG-7. Established in 1988, the MPEG working group is part of JTC1, the Joint ISO/IEC Technical Committee on Information Technology.
- MPEG-2 is an encoding standard that convert analog video and audio input signals into compressed digital form.
- MPEG-2 also describes a decoding (reconstruction) process where the coded bits are mapped from the compact representation into the original image sequence.
- Common bit rate: 15 Mbits/s (Main profile, main level)
- Critical programmes (live broadcasts) require 6 Mbits/s. Non-critical 4-4.5 Mbits/s.

MPEG-2 Elementary and Transport streams

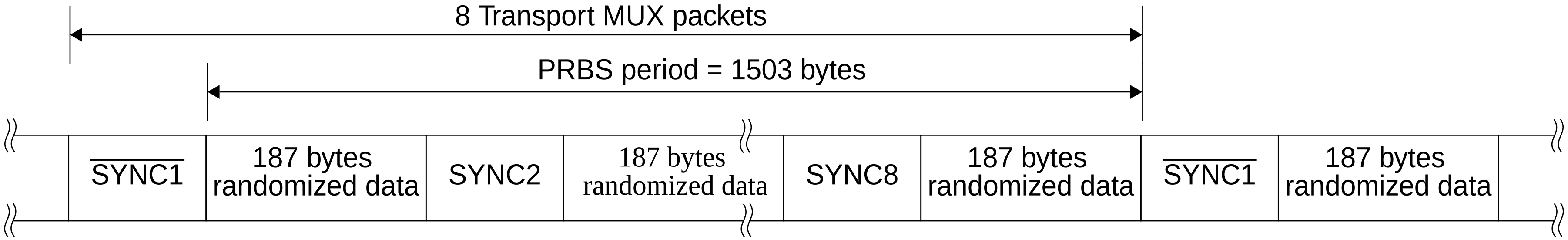


- Audio and video are compressed to form ES (elementary streams).
- The ES are then used to form PES (packetized elementary streams)
- which are further packetized to form TS (transport streams).

1. Randomization for energy dispersal (scrambling) & transport multiplex adaptation

SYNC 1 byte	MPEG-2 transport multiplex data 187 bytes

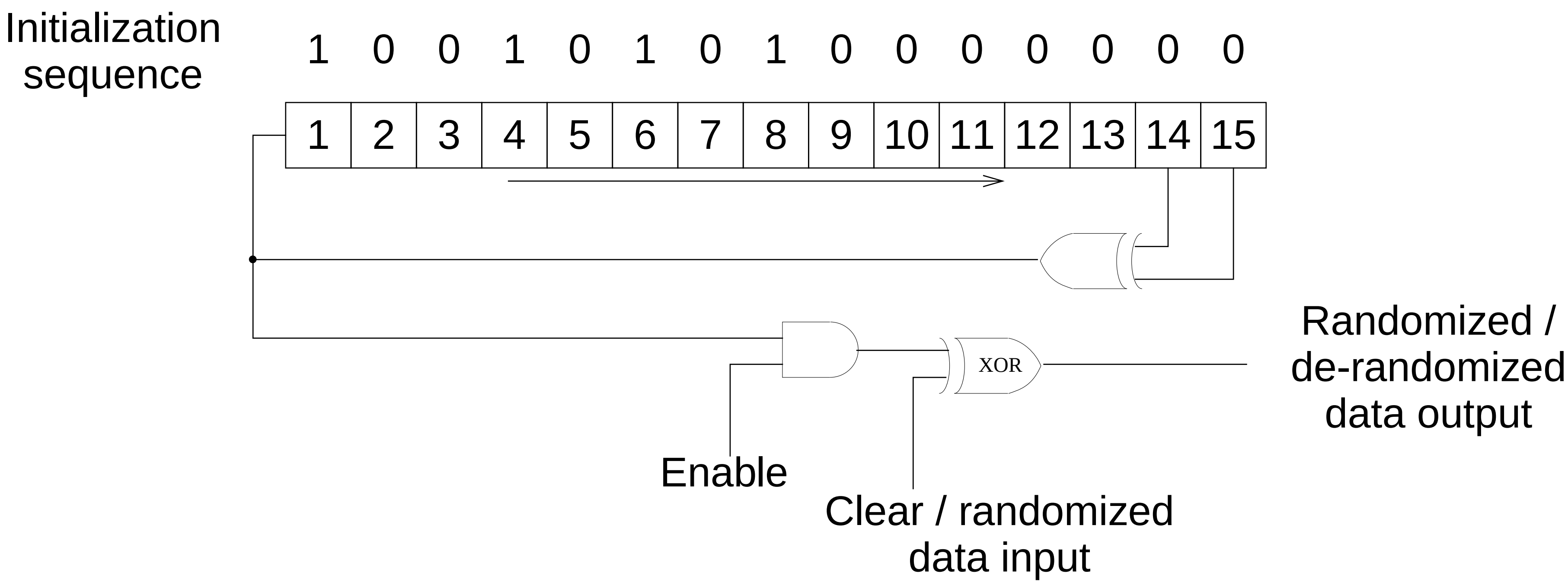
a) MPEG-2 transport multiplex packet



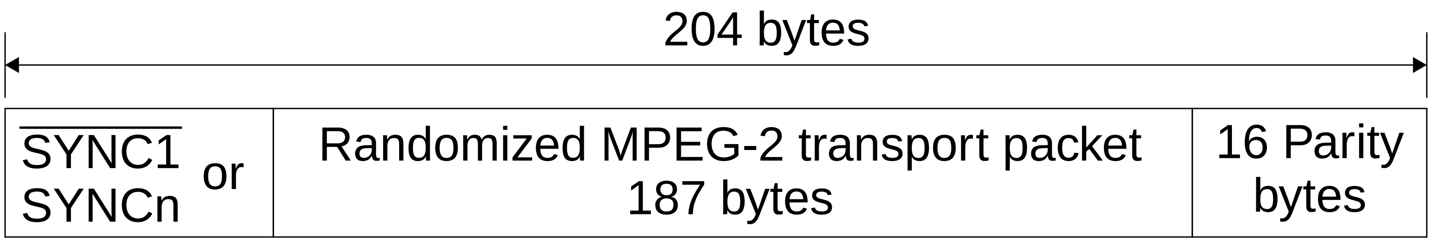
b) Data structure after scrambling and transport multiplex adaptation

- A pseudo-random bit stream (PRBS) is added modulo-2 to the transport packet stream. (but not to the SYNC bytes)
- Transport multiplex adaptation: Inverted SYNC byte provides synchronisation.

Scrambler / descrambler



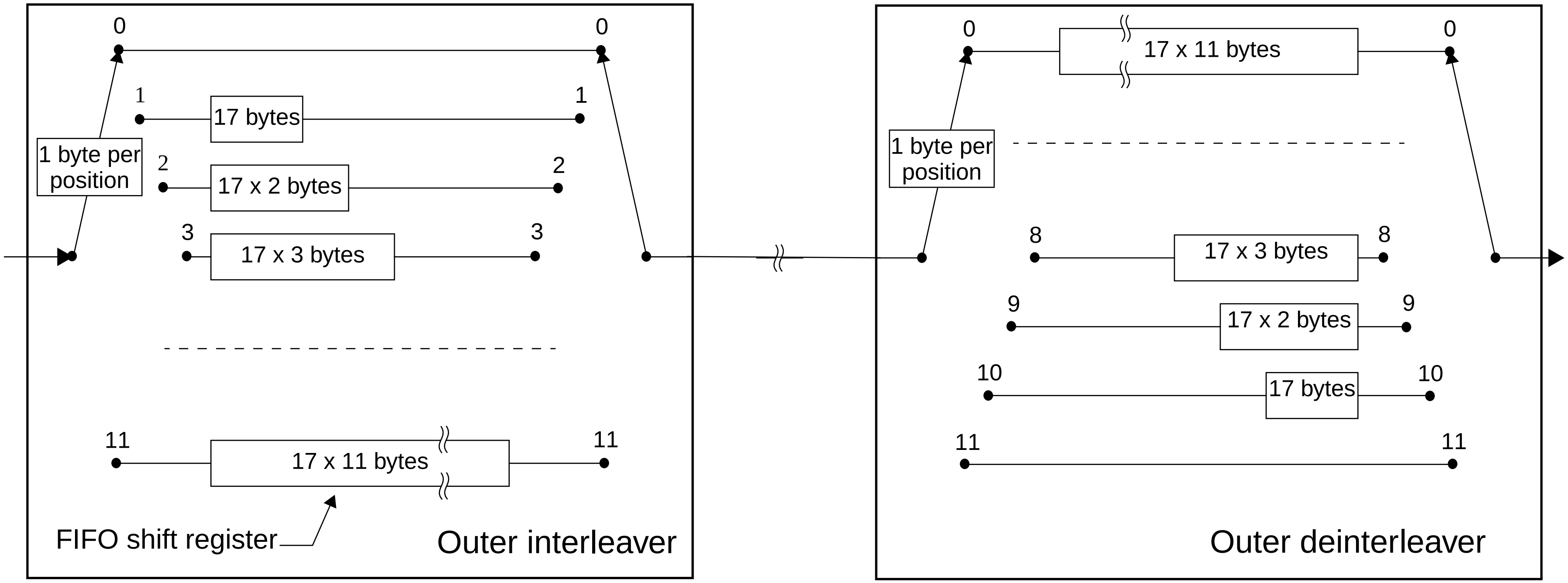
2. Outer coding



c) Reed Solomon RS(204, 188, t=8) error protected packets

- Provides protection against byte errors.
- Detectable errors: r = N - k = 204-188 = 16
- Correctable errors: t = r/2 = 8

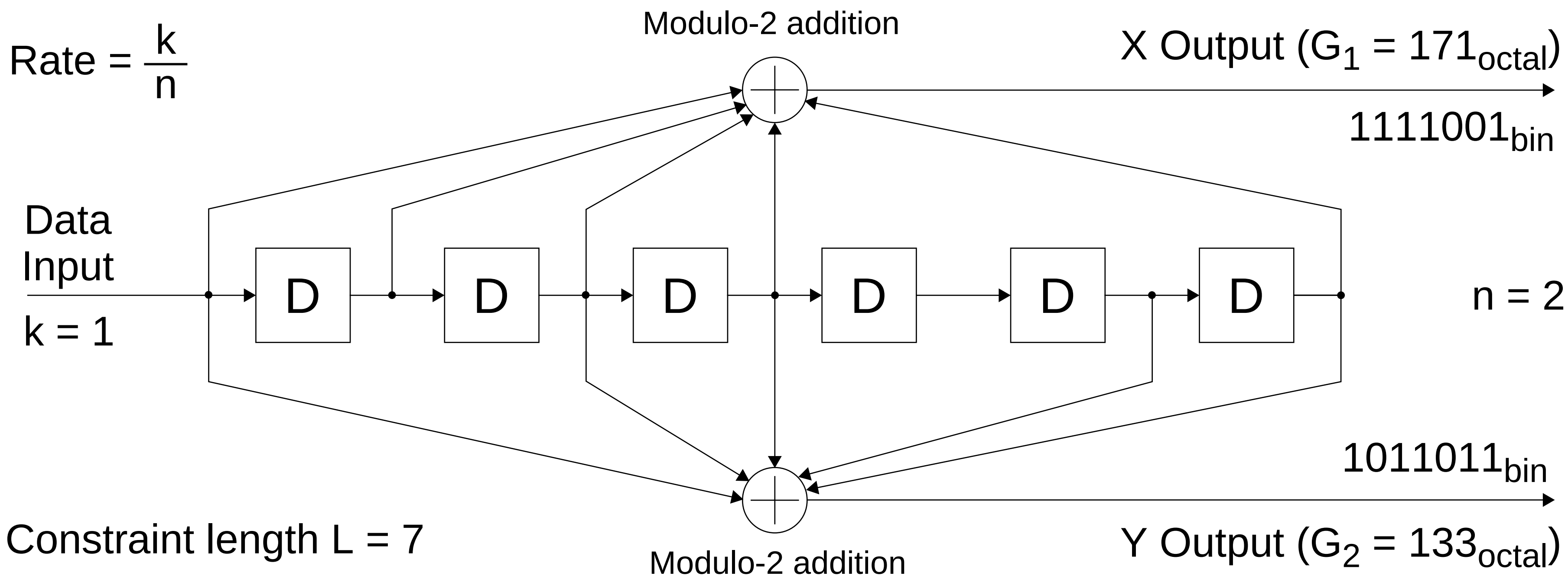
3. Outer interleaver / deinterleaver



The SYNC or $\overline{\text{SYNC}}$ byte always passes through branch 0 to provide synchronisation.

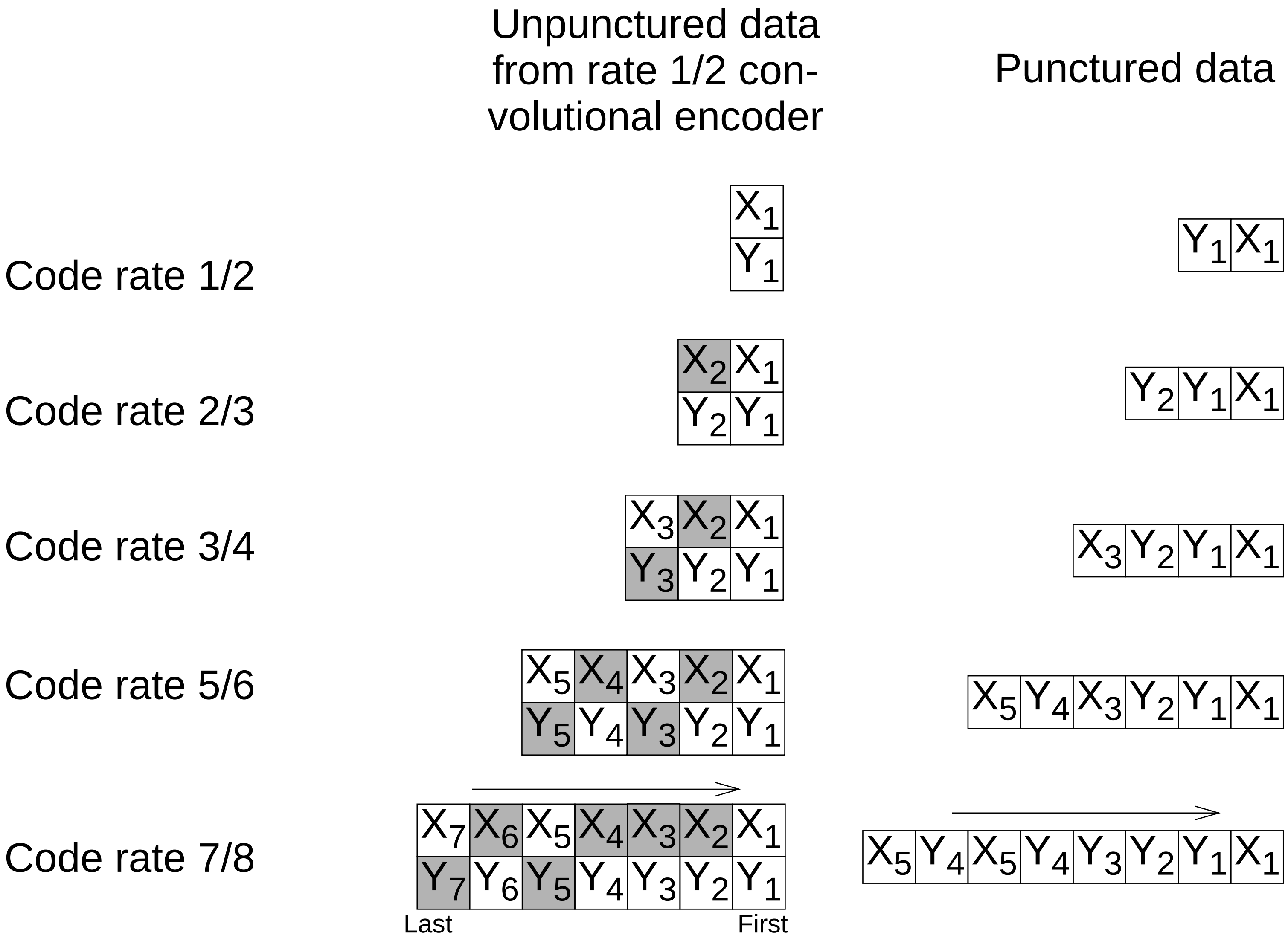
- Convolutional, byte-wise interleaving, with depth I=12 is used.
- Break down any lengthy bursts of errors reaching the outer decoder (RS) in the receiver.

4. Inner, convolutional coder, rate 1/2

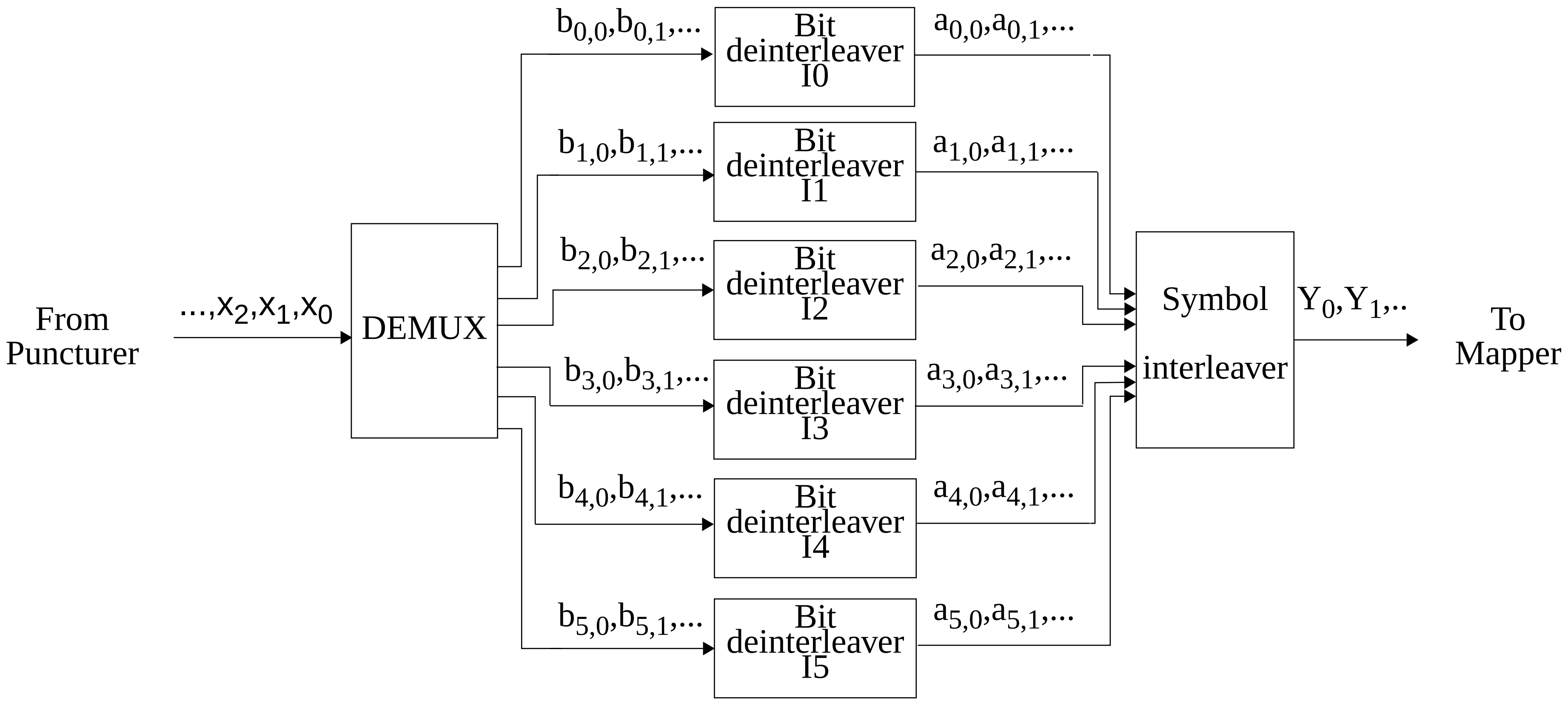


- Convolutional coding with bit-level error correcting capability.
- Convolutional code, with rate 1:2 and $2^{(L-1)\cdot k}$ = 64 states.
- The DVB-T system also allows punctured rates of 2:3, 3:4, 5:6 and 7:8.

5. Puncturing



6. Bit-wise interleaving

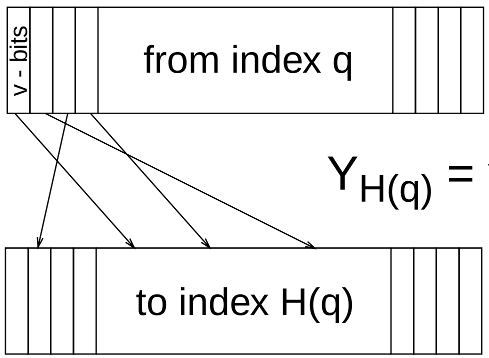


- Interleaving block size is 126 bits. Interleaving sequence is different for each interleaver.
- This block-based, bit-wise interleaving is repeated:
  - 12 times/OFDM symbol (12 * 126 = 1512 bits), 48 times/OFDM symbol (48 * 126 = 6048 bits)

7. Symbol interleaver / deinterleaver

Even OFDM symbols

$Y' = (y'_0, y'_1, y'_2, \ldots, y'_{Nmax-1})$



$Y_{H(q)} = y'_q$

$Y = (y_0, y_1, y_2, \ldots, y_{Nmax-1})$

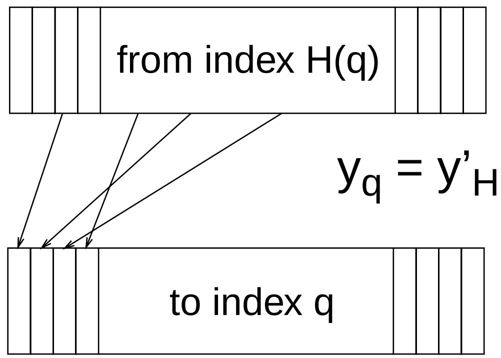
$0 \leq H(q) < N_{max}$

$q = 0, \ldots, N_{max}-1$

$$N_{max} = \begin{cases} 1512 \text{ in 2k} \\ 6048 \text{ in 8k} \end{cases}$$

Odd OFDM symbols

$Y' = (y'_0, y'_1, y'_2, \ldots, y'_{Nmax-1})$

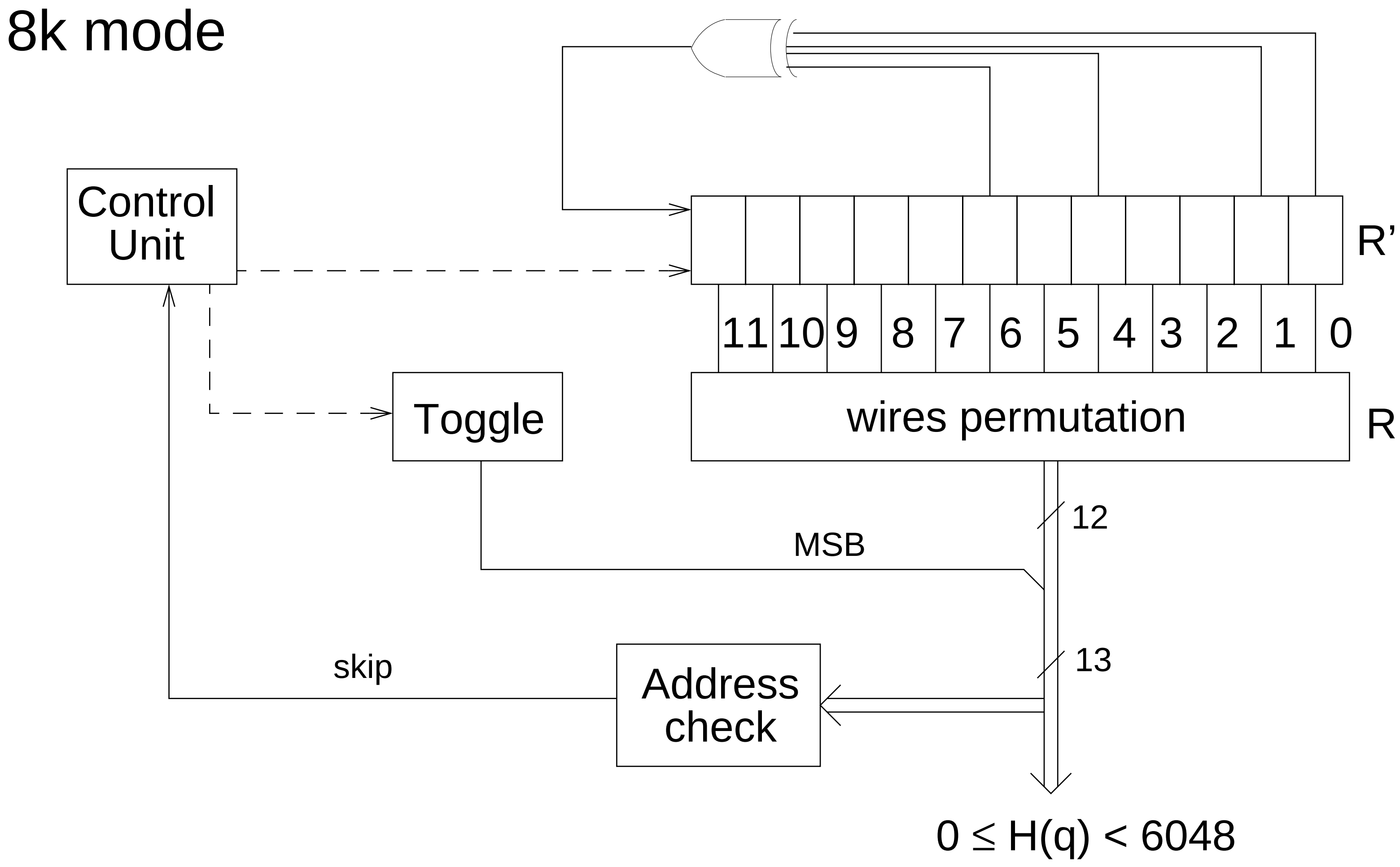


$y_q = y'_{H(q)}$

$Y = (y_0, y_1, y_2, \ldots, y_{Nmax-1})$

- Performs interleaving of data symbols within one OFDM symbol.
- Frequency interleaving.
- Repeated 68 times for each OFDM frame.

Permutation function H(q)



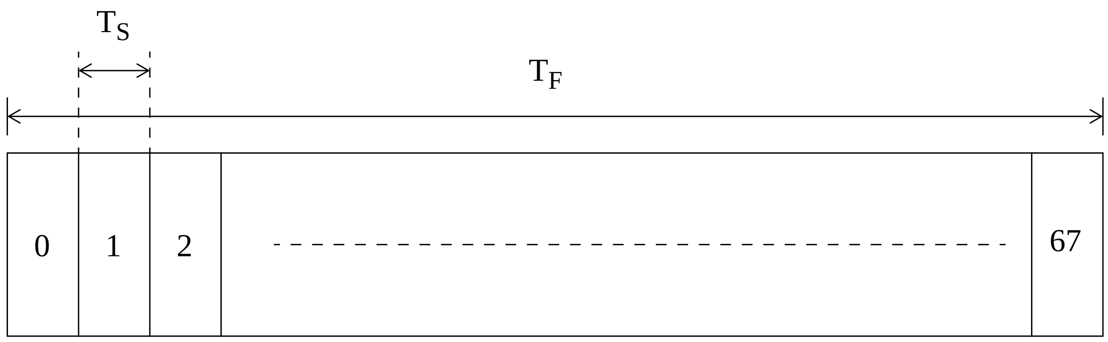
8. Signal constellations and mapping

- The system uses Orthogonal Frequency Division Multiplexing (OFDM) transmission.
- Carrier modulation: All data carriers in one OFDM frame are either:

- QPSK - 16-QAM - 64-QAM - non-uniform-16QAM - non-uniform-64QAM	} modulated

- Selecting a certain type of modulation directly affects:
  - available data transmission capacity in a given channel, and
  - the robustness with regard to noise and interference.
- The choice of code rate of the inner coder can be used to fine-tune the performance of the system.

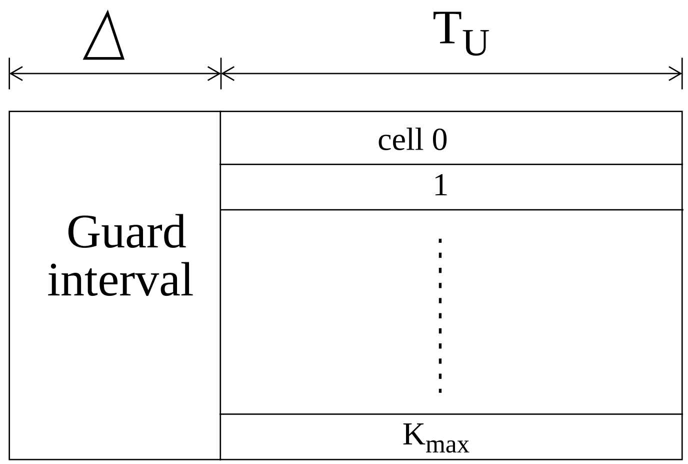
OFDM frame structure



1 OFDM frame

- Each OFDM-frame has a duration of T_F and consist of 68 symbols.
- Each symbol has duration of T_S and is constituted by:
  - a set of 1705 carriers in 2k-mode.
  - a set of 6817 carriers in 8k-mode.

OFDM symbol structure



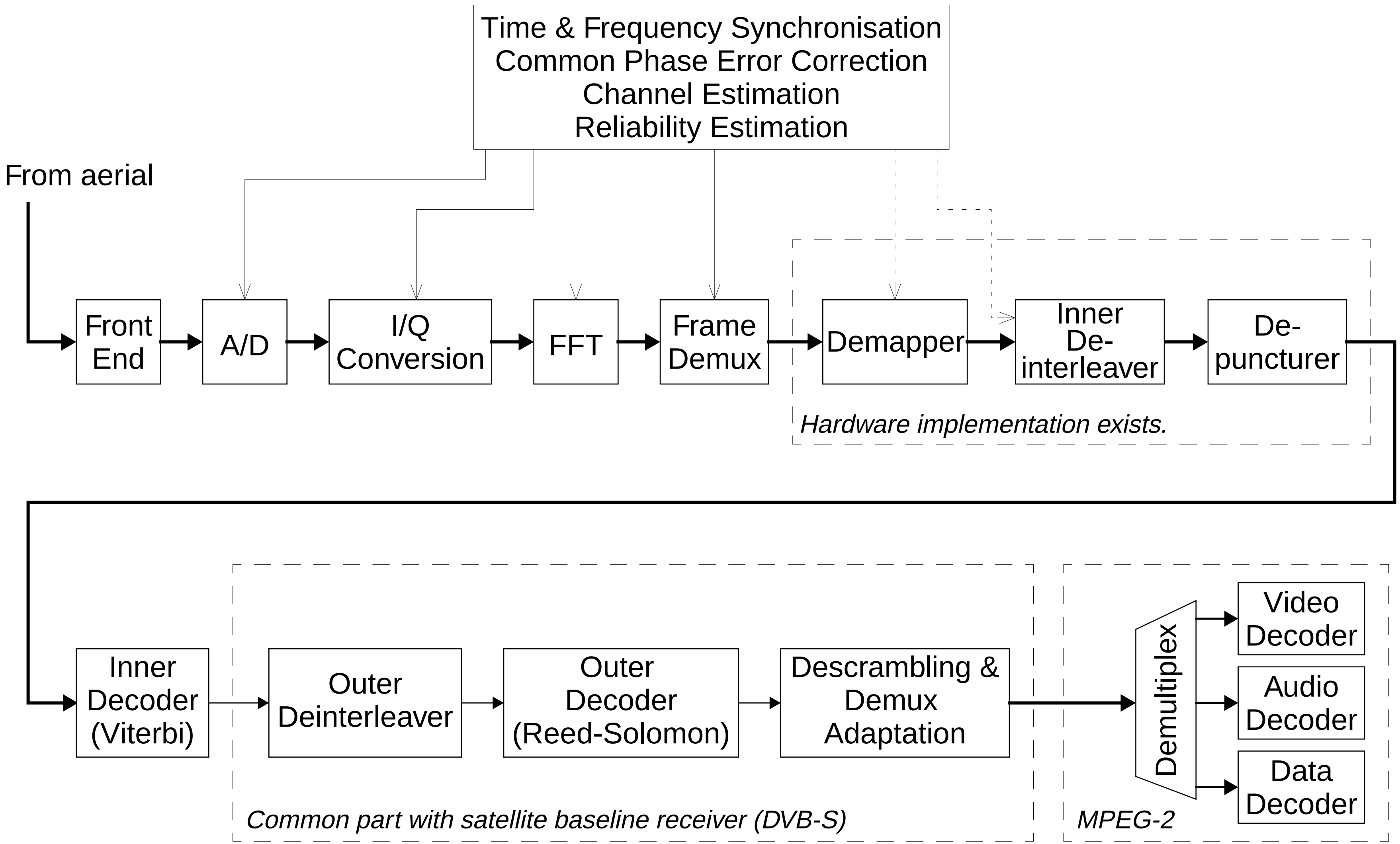
1 OFDM symbol

- A symbol is composed by two parts:
  - a useful part with duration T_u
  - and a guard interval with duration Δ, which consist of a cyclic continuation of the useful part, for protection against multipath and to support SFN:s.
  - Δ/T_u can be: 1/4, 1/8, 1/16, 1/32. These are called guard interval ratios.
- Each symbol can be considered divided into cells, each corresponding to the modulation carried on one carrier during one symbol.

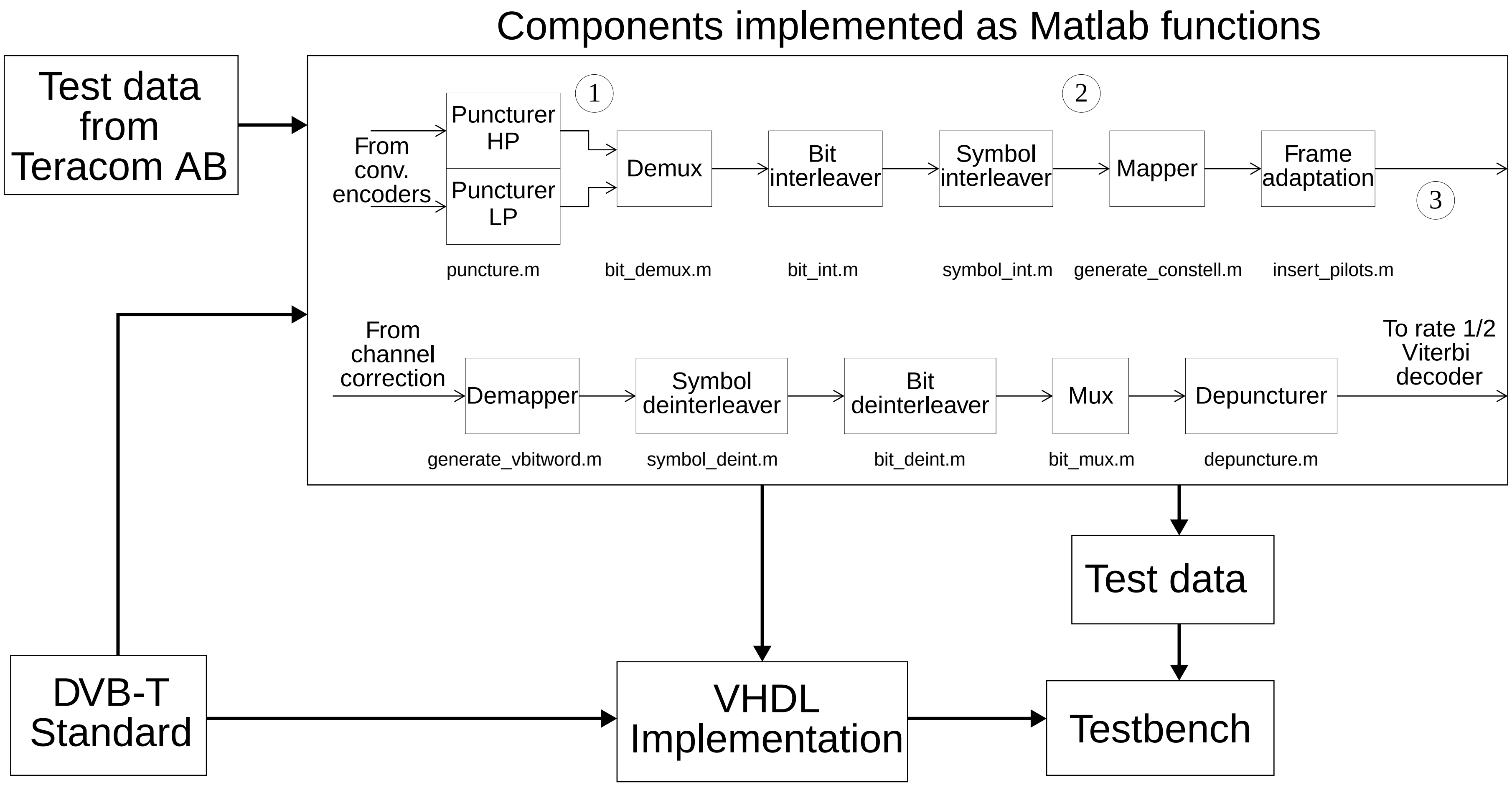
OFDM frame structure

- In addition to the transmitted data the OFDM frame contains:
  - Scattered pilot cells
  - Continual pilot carriers
  - TPS carriers (Transmission Parameter Signalling)
- The pilots are used for:
  - frame synchronization
  - time synchronisation
  - channel estimation
  - transmission mode identification

DVB-T receiver overview

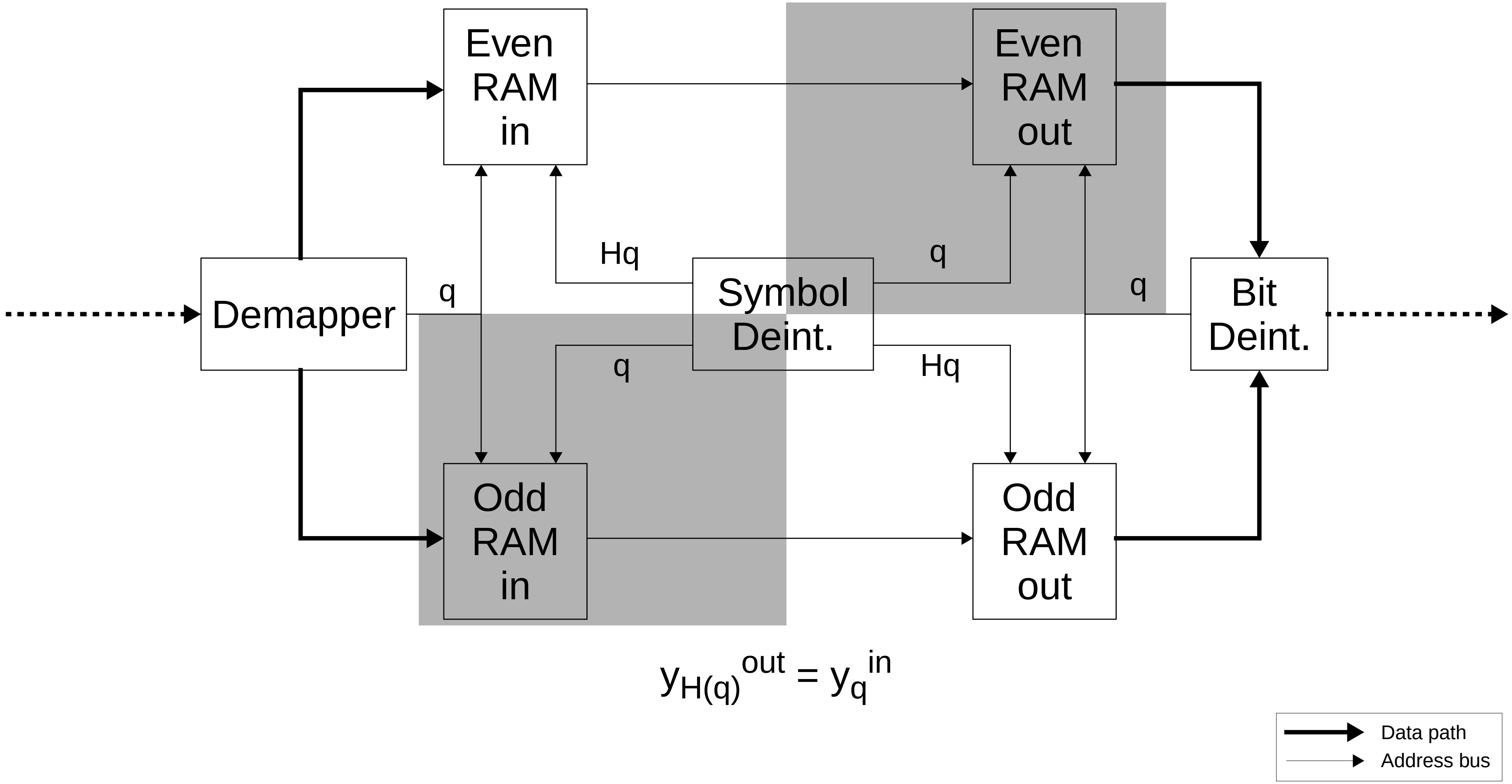


Design Flow


Components implemented as Matlab functions
Test data from Teracom AB
From conv. encoders
Puncturer HP
Puncturer LP
1
Demux
Bit interleaver
Symbol interleaver
2
Mapper
Frame adaptation
3
puncture.m
bit_demux.m
bit_int.m
symbol_int.m
generate_constell.m
insert_pilots.m
From channel correction
Demapper
Symbol deinterleaver
Bit deinterleaver
Mux
Depuncturer
To rate 1/2 Viterbi decoder
generate_vbitword.m
symbol_deint.m
bit_deint.m
bit_mux.m
depuncture.m
Test data
DVB-T Standard
VHDL Implementation
Testbench

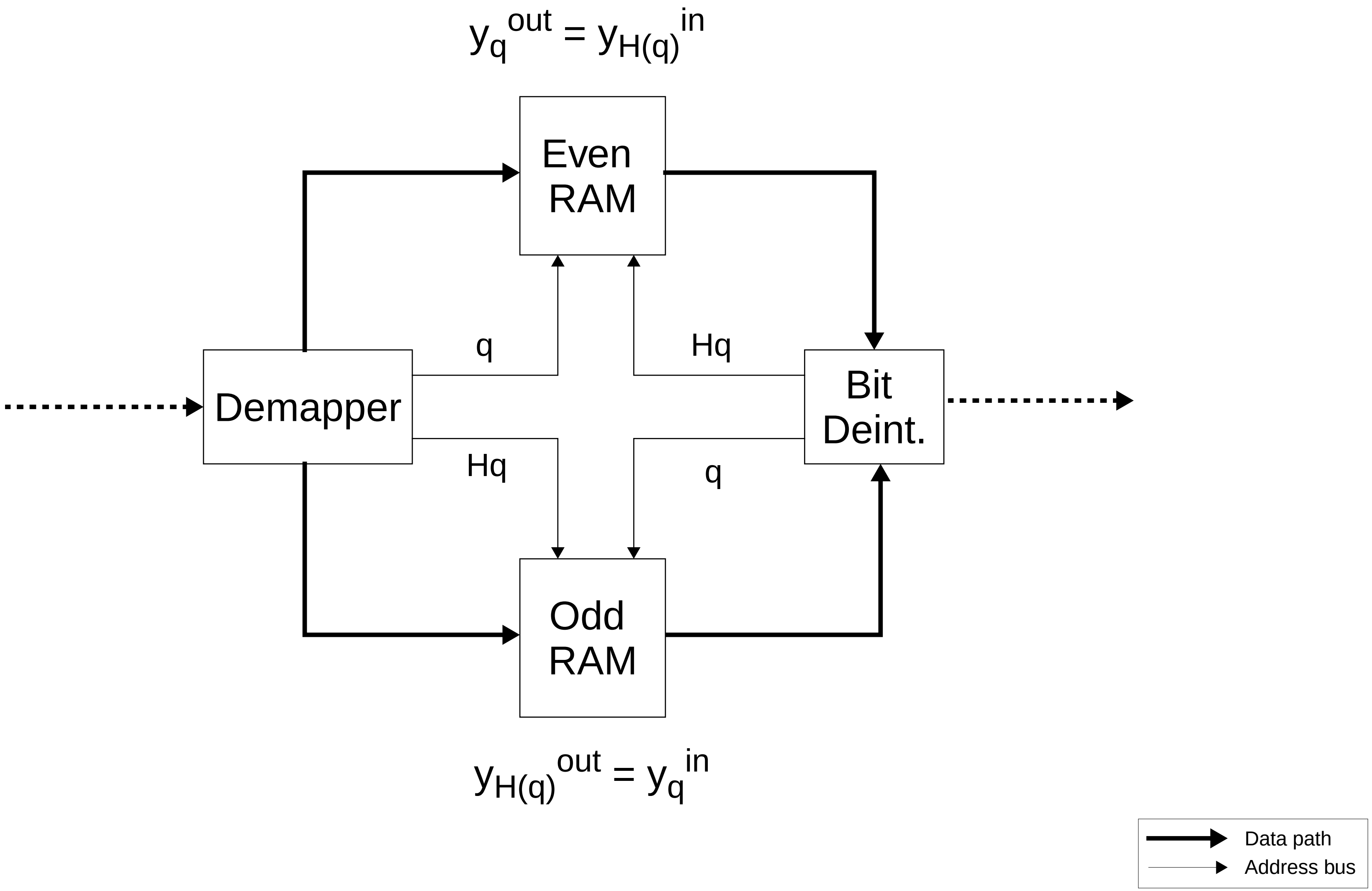
Initial Design

$$y_q^{out} = y_{H(q)}^{in}$$

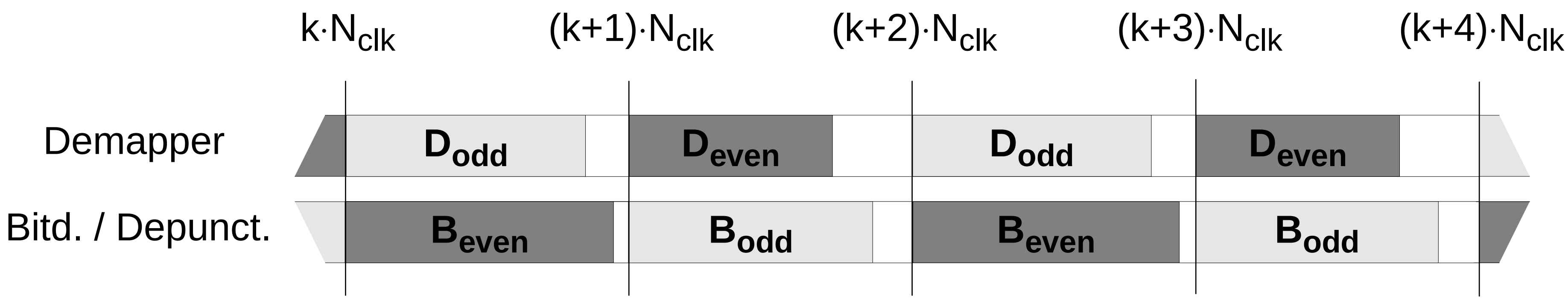


$$y_{H(q)}^{out} = y_q^{in}$$

Improved design



Improved design, operation sequence



$N_{clk} = \begin{cases} 8448 \text{ in 2k mode [231 ms x (256/7) MHz]} \\ 33792 \text{ in 8k mode [924 ms x (256/7) MHz]} \end{cases}$

D : Number of clock cycles required to demap an OFDM symbol.

B : Number of clock cycles required to bit deinterleave / depuncture an OFDM symbol.

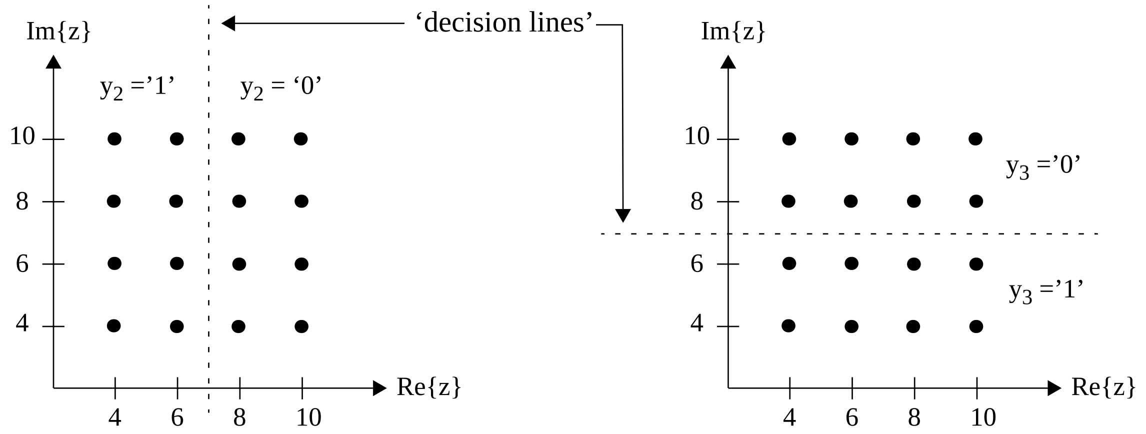
Timing limits, required for correct operation:

- $D_{odd}, D_{even} < N_{clk}$
- $B_{odd}, B_{even} < N_{clk}$

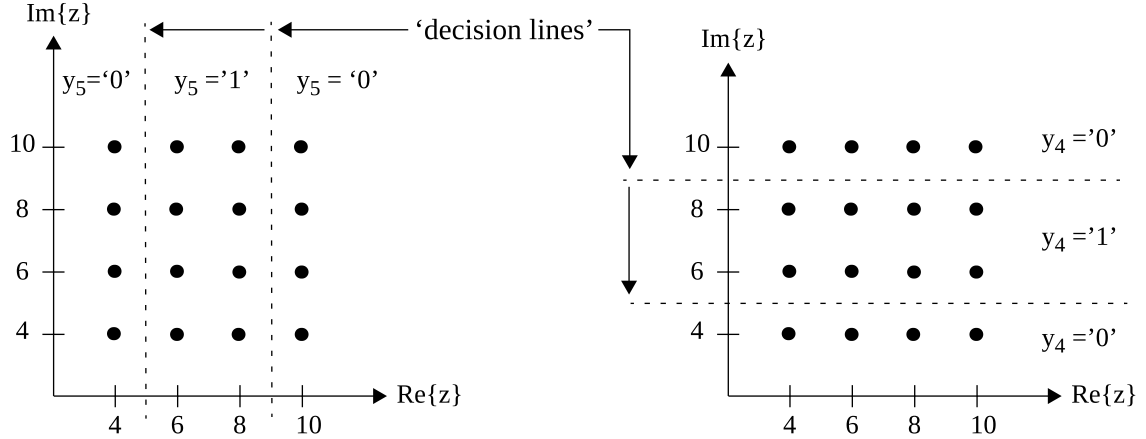
MUSCOD Algorithm

- The imaginary- and real axes are the ‘decision lines’ for y_0 and y_1. (*$y_0 = 0$ if $Re > 0$*)

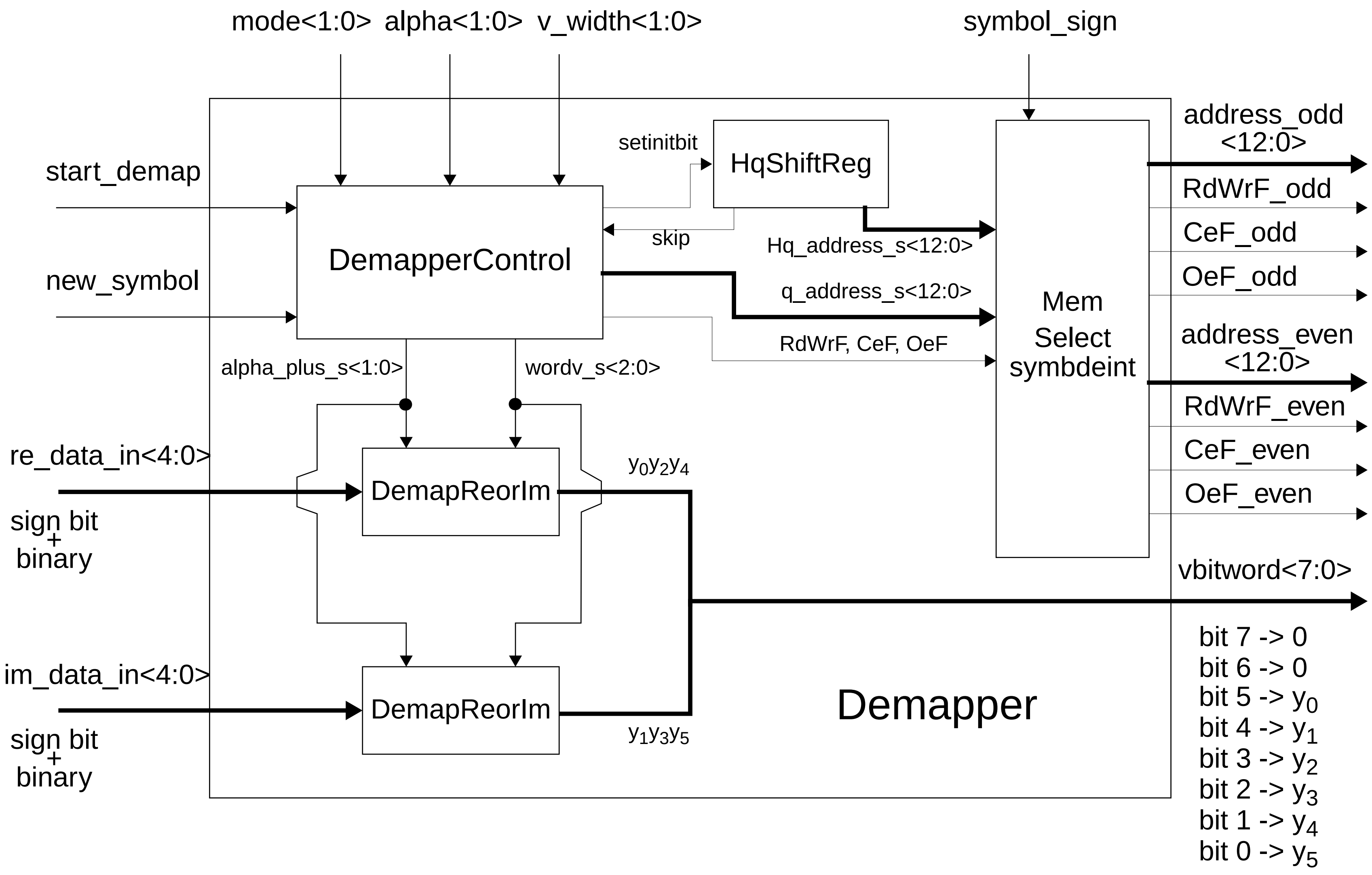
- ‘decision lines’ for y_2 and y_3 in non-uniform-64-QAM, with α=4



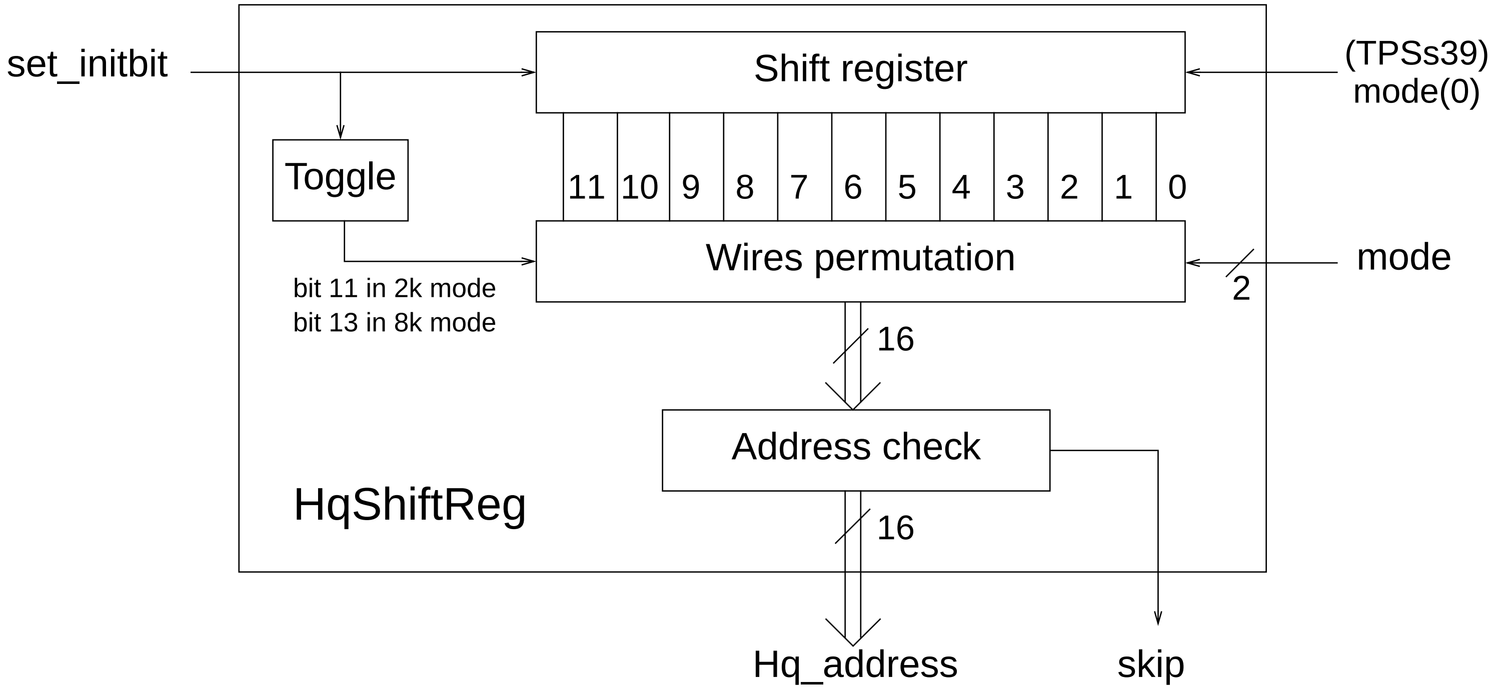
- ‘decision lines’ for y_4 and y_5 in non-uniform-64-QAM, with α=4

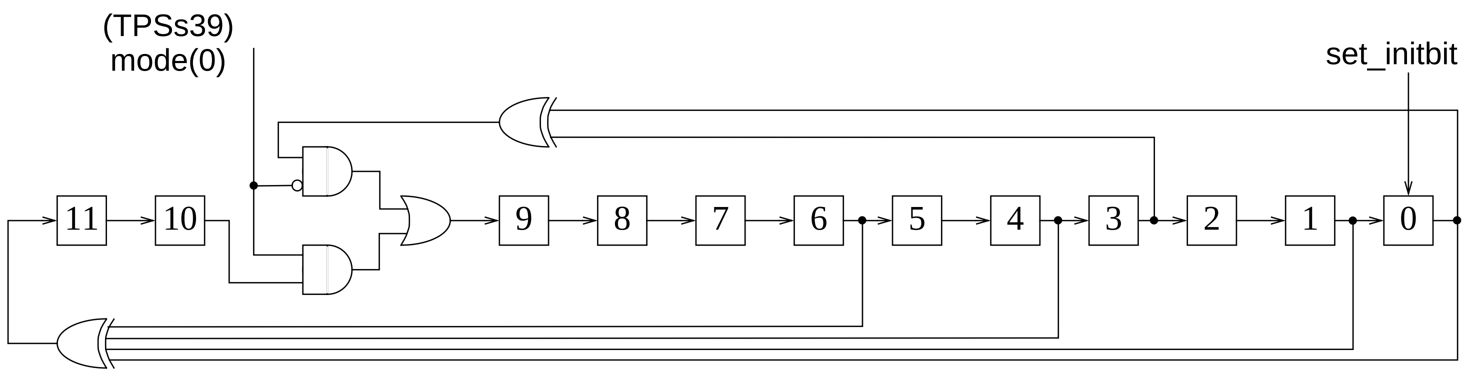


Demapper

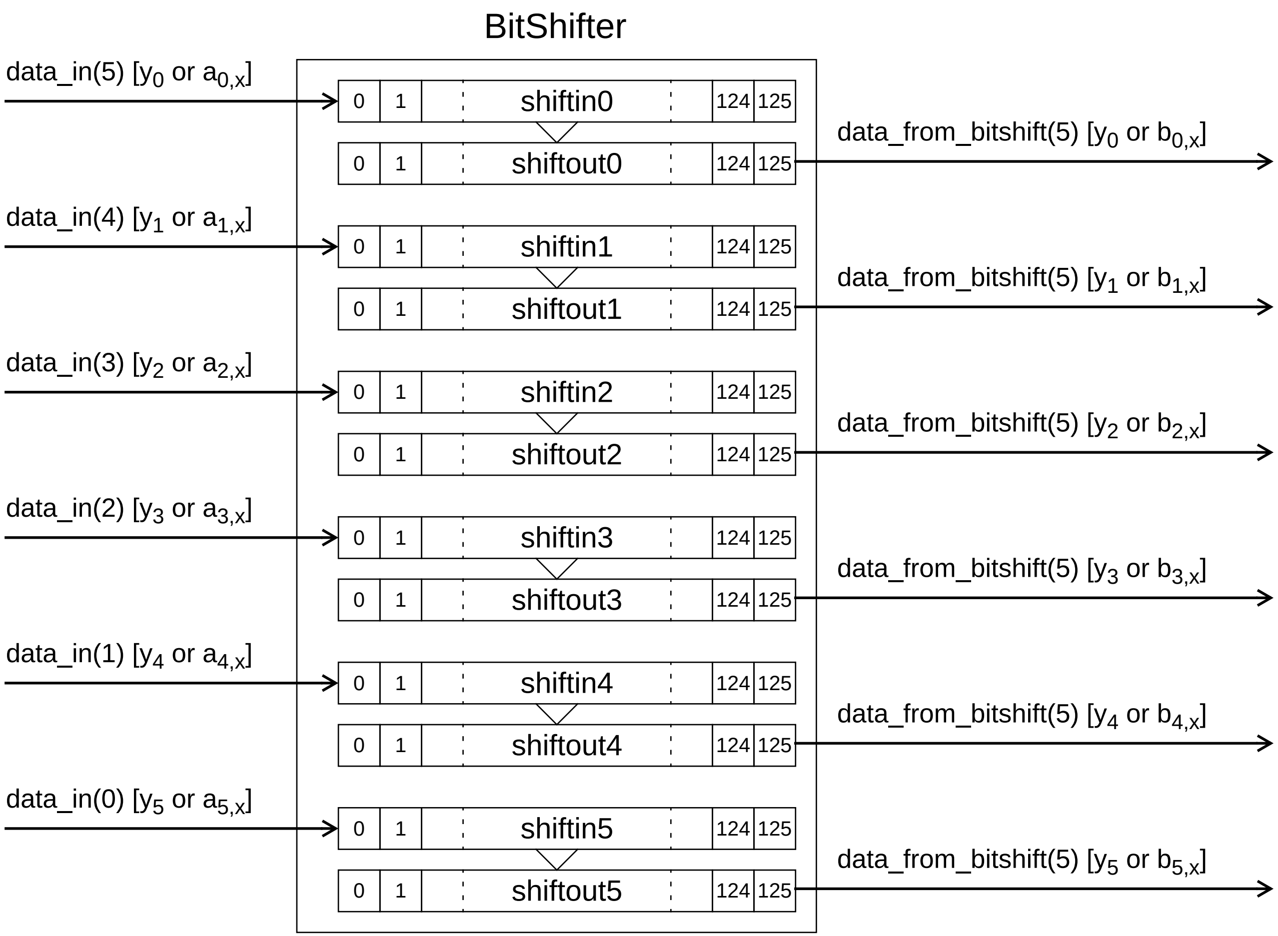

mode<1:0>
alpha<1:0>
v_width<1:0>
symbol_sign
start_demap
new_symbol
setinitbit
HqShiftReg
skip
DemapperControl
Hq_address_s<12:0>
q_address_s<12:0>
RdWrF, CeF, OeF
Mem
Select
symbdeint
address_odd
<12:0>
RdWrF_odd
CeF_odd
OeF_odd
address_even
<12:0>
RdWrF_even
CeF_even
OeF_even
alpha_plus_s<1:0>
wordv_s<2:0>
re_data_in<4:0>
sign bit
+
binary
DemapReorIm
$y_0y_2y_4$
vbitword<7:0>
im_data_in<4:0>
sign bit
+
binary
DemapReorIm
$y_1y_3y_5$
Demapper
bit 7 -> 0
bit 6 -> 0
bit 5 -> y_0
bit 4 -> y_1
bit 3 -> y_2
bit 2 -> y_3
bit 1 -> y_4
bit 0 -> y_5

Hq Address Generator



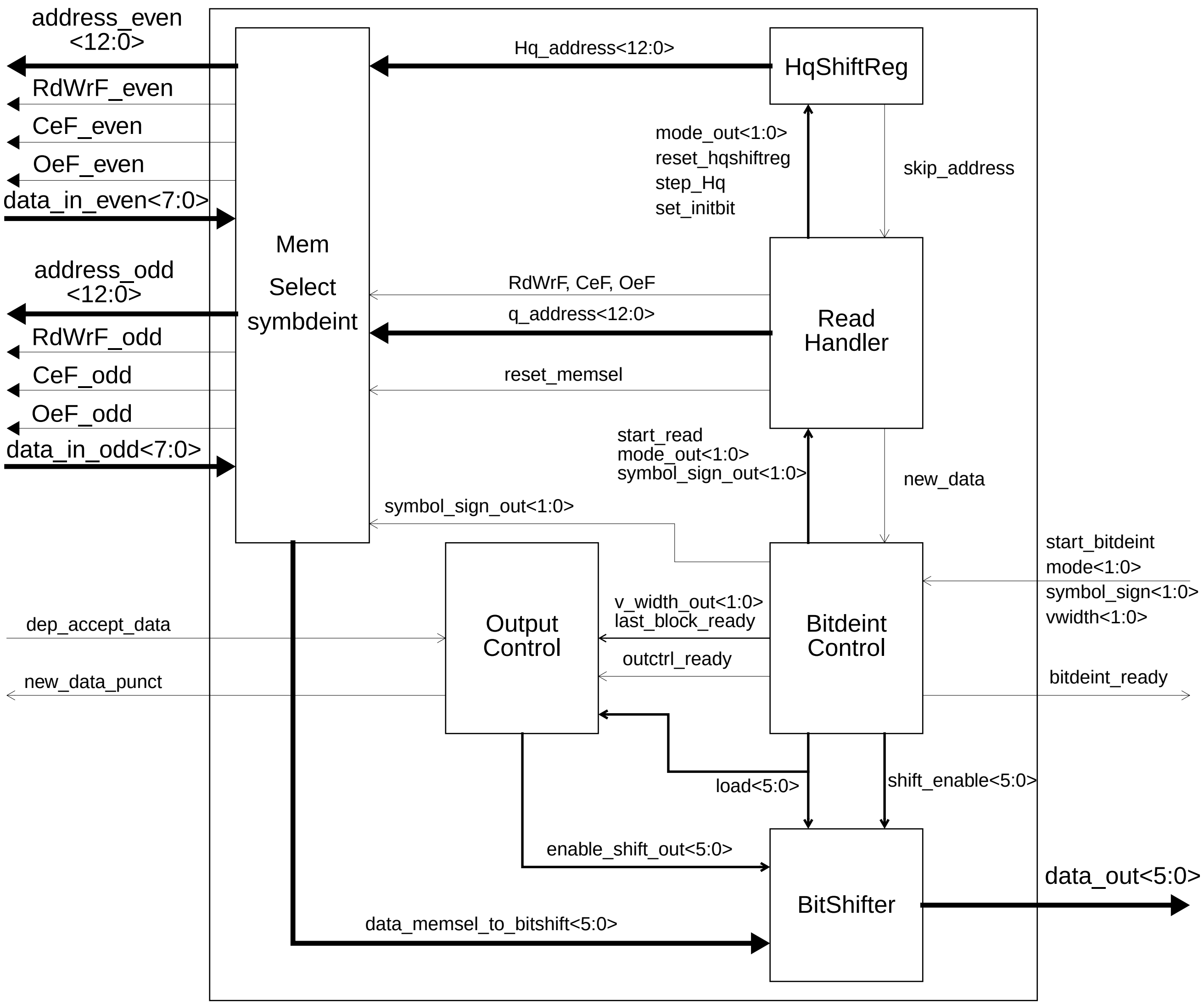


Bit deinterleaving



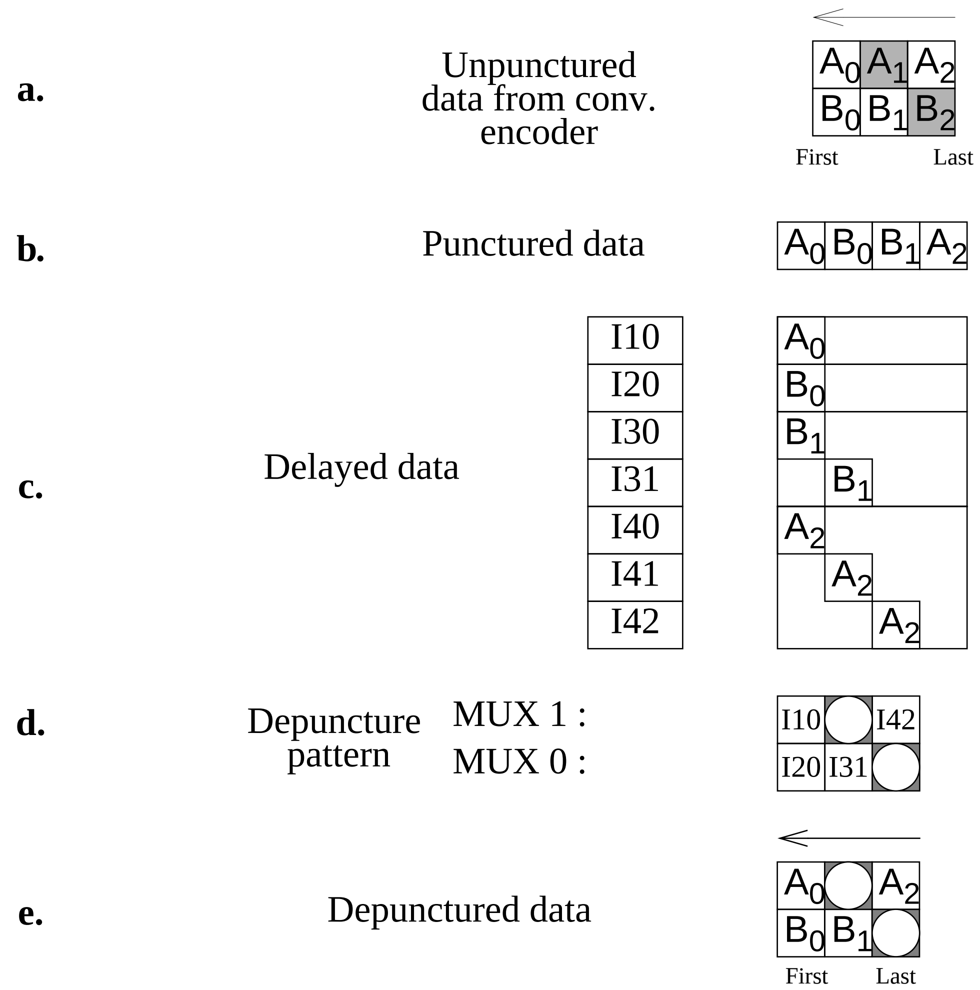
Power management: QPSK: BitShifters 0 and 1 are enabled
16-QAM: BitShifters 0, 1, 2 and 3 are enabled
64-QAM: All BitShifters are enabled

Bit deinterleaver

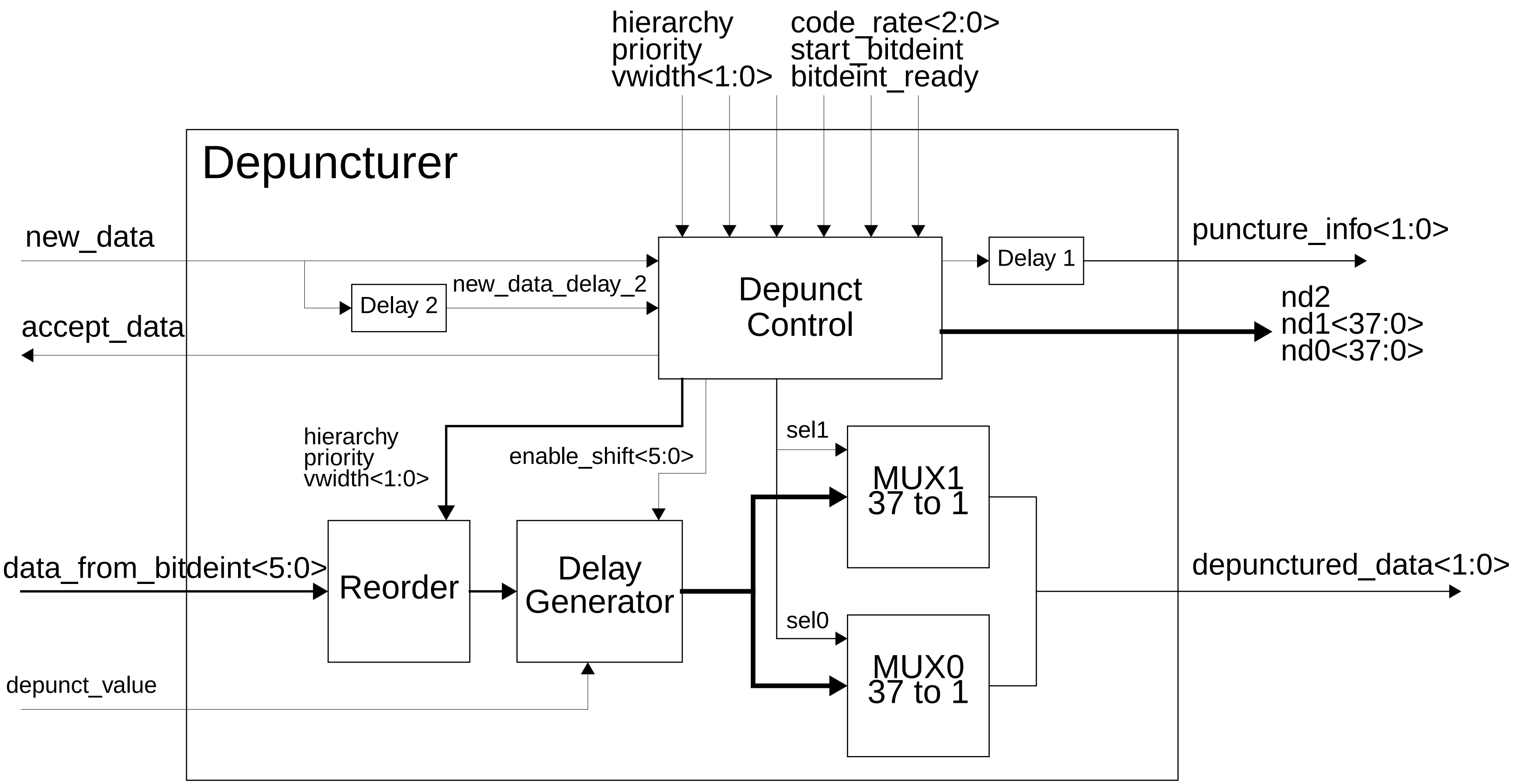


Puncturing / Depuncturing

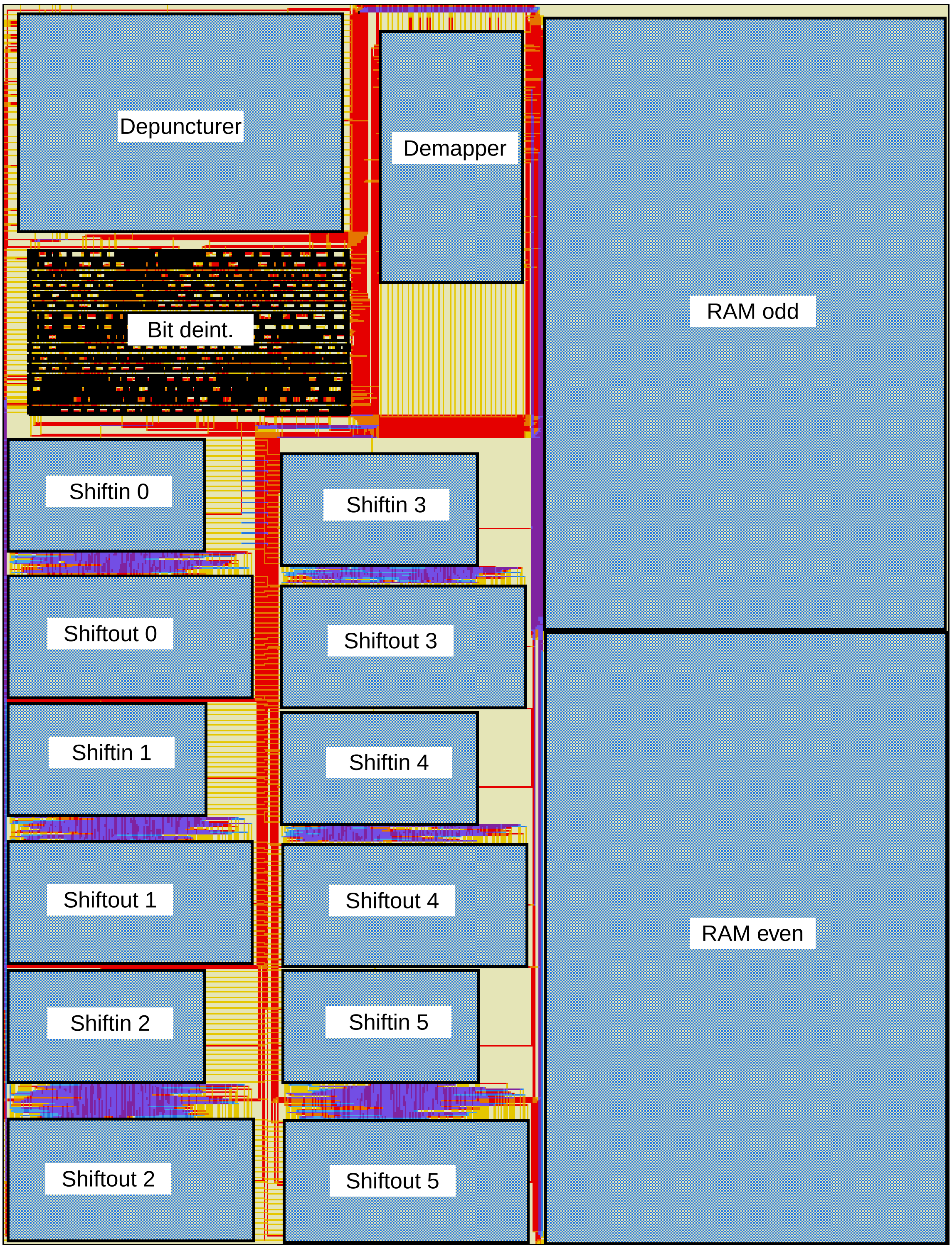
Depuncture pattern for: 64-QAM (v = 6) hierarchical transmission, low priority stream with code rate 3/4.
16-QAM (v = 4), non-hierarchical transmission with code rate 3/4.



Depuncturer

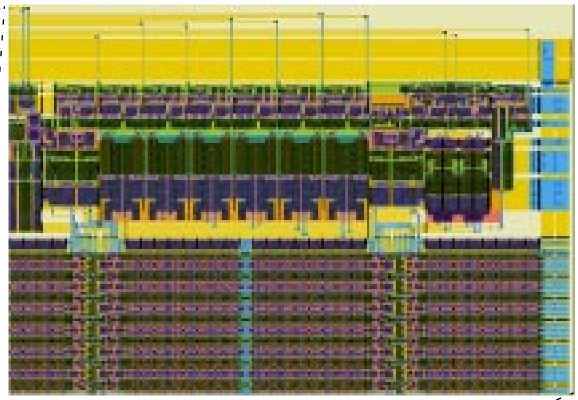


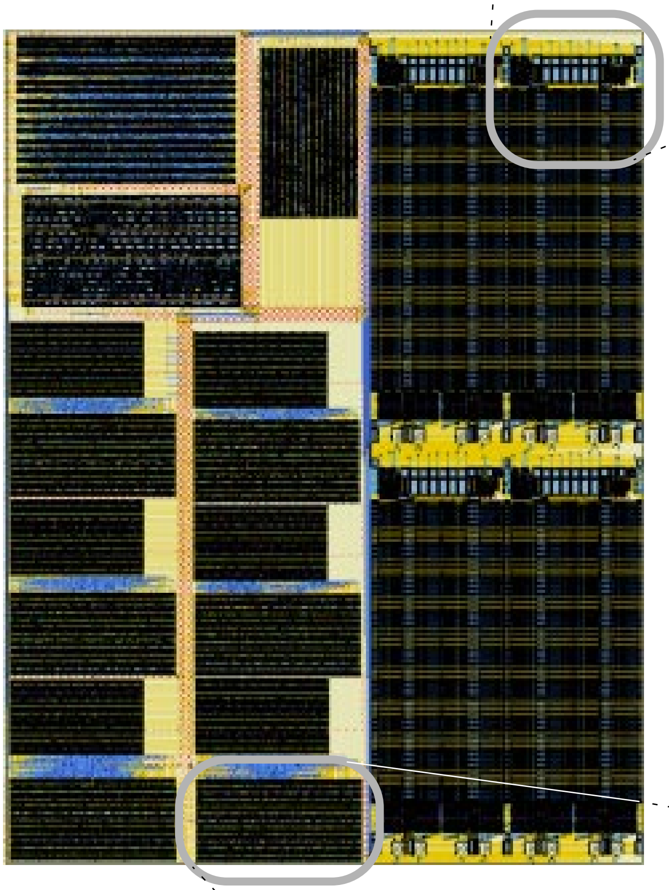
Chip Compiler: place & route



Compass Layout2

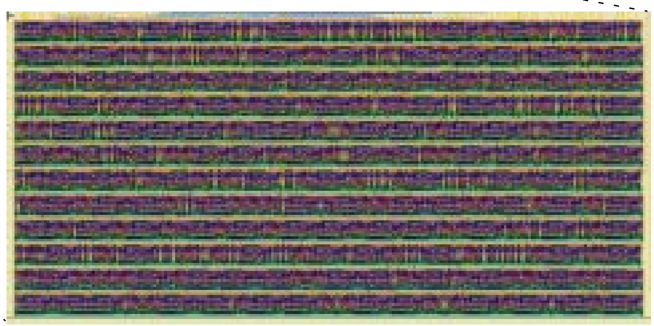
a. Part of the odd RAM





b. The layout of the chip
Size: 7,21mm x 9,45 mm
Area: 68,1 mm^2

c. Shiftout block
6573 transistors
Size: 1,88 mm x 0,95 mm
Area: 1,80 mm^2



IC properties

Clock frequency	36,57 MHz (4 x 64/7 MHz)
Technology	0.6µm, 3.3V CMOS
Max. Power dissipation	~0,41 W
Width x Height	7,21 mm x 9,71 mm
Area (without pads)	68,2 mm^2
No of transistors (RAMs not included)	98894
RAM type	Compass, Asynchronous RAM Compiler, 0.6µm, 3.3V CMOS
RAM size	8 x 3 x 2048 bits = 49152 bits = 6 Kbytes

System performance

Table 1: Performance of the implemented subsystems

Demapper, max. input bit-rate (8k, 64-QAM, even)	91,4 Mbits/s
Demapper, max. output bit-rate (8k, 64-QAM, even)	54,8 Mbits/s
Bit deint., max input / output bit-rate (several modes)	53,5 Mbits/s
Depuncturer, max. output bit rate (8k, 64-QAM, 7/8, even)	71,8 Mbits/s

Table 2: Practical transmission system performance

DVB-T (Terrestrial)	4,98 - 31,97 Mbits/s
DVB-C (Cable)	Up to 38 Mbits/s
DVB-S (Satellite)	25 - 50 Mbits/s

Conclusions and future work

- DVB-T uses a very effective digital communication method for transmitting MPEG2 video/audio streams.
- DVB-T got a wide acceptance in Europe, with potential expansion to support future mobile communications and data exchange.
- DVB-T receiver is cost effective, with low-power implementation possiblities.
- A high-data rate, low power implementation of the demapper, inner deinterleaver and depuncturer, used in the OFDM chain, was proposed and implemented.
- Future work will concentrate on finding an ultra-low power implementation for the bit deinterleaver.