# Forward Error Correction for IEEE 802.3bn EPoC

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# Outline

- Requirements for FEC in EPoC
- Code Descriptions
  - Encoding
  - Parity Matrices
- Performance Analysis
  - Simulation results for AWGN and Burst Noise
- Summary

# IEEE 802.3bn Objectives

- Objectives for IEEE 802.3bn
  - *"Provide a physical layer specification that is capable of a baseline data rate of 1 Gb/s at the MAC/PLS service interface when transmitting in 120 MHz, or less, of assigned spectrum under defined baseline plant conditions"*
  - *"PHY to have:*
    - *A downstream frame error rate better than 10^-6 at the MAC/PLS service interface*
    - *An upstream frame error rate better than 5x10^-5 at the MAC/PLS service interface"*
- Based on these objectives and on agreements achieved so far in EPoC, several requirements for the LDPC FEC can be derived
  - See next slide for further details

# FEC Requirements for EPoC – Rate and Length

- The FEC scheme should support multiple rates
  - High codes rates should be supported in order to achieve large spectral efficiency
    - The highest rate should be in the order of R = 0.9
  - Lower code rates should be supported as well in order to provide sufficient robustness in severe burst noise conditions
    - The lowest rate should be in the order of R = 0.75
- The FEC scheme should support multiple code lengths
  - For bursty upstream traffic, the shortest code length should be roughly 1000 bits to serve a 64 bytes packet + overhead
  - For continuous downstream traffic, the longest code length should be roughly 15000 – 16000 bits
  - For burst modes (FDD US, TDD DS/US) intermediate length should be available

# FEC Requirements for EPoC – Class of Codes

- The same class of LDPC codes should be applied in all EPoC modes
  - This allows having a common PHY in EPoC
- The FEC should have a deep error floor to avoid outer BCH codes
- Encoder and decoder should be implementable with low complexity
  - Quasi-cyclic LDPC codes should be applied in EPoC
    - For a rate $R = k/n$ code the information block size is $k \cdot Z$ and the code length is $n \cdot Z$
    - $Z$ is called the lifting size of a quasi-cyclic LDPC code
- All lifting sizes Z of the LDPC codes should be the identical or should have a common large factor
  - An identical lifting size enables applying the same decoder for all codes of this lifting size
  - Common factors in the lifting size enable hardware reuse for codes of different lifting size

# Design of the LDPC Codes

- All proposed LDPC codes are quasi-cyclic and binary
- The proposed LDPC codes fit to all modes in EPoC
  - A specific subset may be chosen for the continuous mode (FDD DS) and the burst modes (FDD US, TDD DS/US) in EPoC
    - E.g., codes with large lifting size may be chosen for the continuous mode
    - E.g., codes with short(er) lifting size and/or shorter code length may be chosen for burst modes
- The matrix M to calculate the parity bits has nearly upper diagonal form for all codes
  - In the proposed codes, only the first sub-diagonal of the matrix M is non-zero
  - The parity matrices H are constructed so that encoding can be realized with low complexity
    - A complete description is provided in the backup

# Proposed Set of LDPC Codes

| Code | Rate k/n | Lifting Size Z | Code Length n · Z |
|---|---|---|---|
| I | 27/30 = 0.9 | 360 | 10800 |
| II | 13/15 = 0.867 | 360 | 5400 |
| III | 37/42 = 0.88 | 360 | 15120 |
| IV | 36/40 = 0.9 | 360 | 14400 |
| V | 40/45 = 0.89 | 360 | 16200 |
| VI | 12/16 = 0.75 | 60 / 120 / 240 / 360 | 960 / 1920 / 3840 / 5760 |
| VII | 16/20 = 0.8 | 60 / 120 / 240 / 360 | 1200 / 2400 / 4800 / 7200 |
| VIII | 20/24 = 0.833 | 120 / 240 / 360 | 2880 / 5760 / 8640 |
| IX | 23/27 = 0.85 | 120 / 240 / 360 | 3240 / 6480 / 9720 |

- The parity matrices of all codes are given in the backup slides

# Edge Density, Parity Checks and Lifting Size

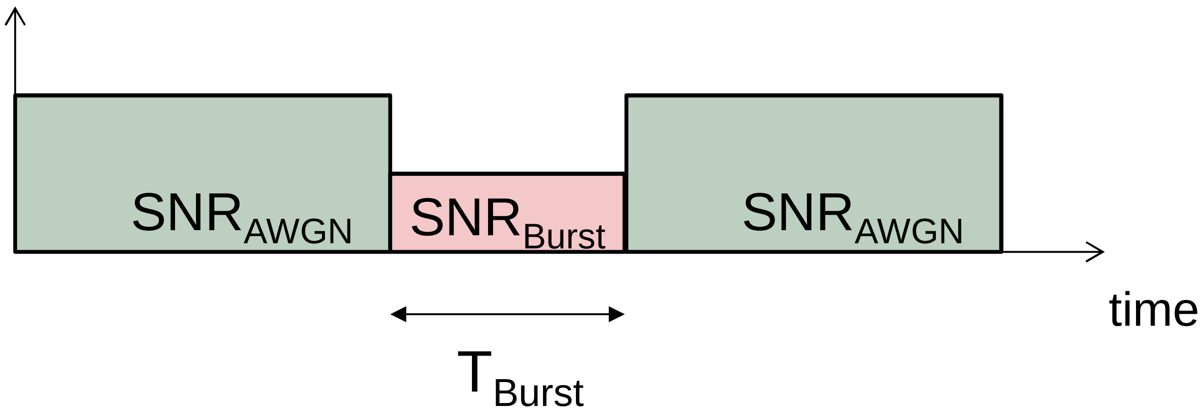
| Base n | Base k | Rate | Lifting Z | Information bits | Code word length | Parity checks | Based edges | Edge density |
|---|---|---|---|---|---|---|---|---|
| 30 | 27 | 0.9 | **360** | 9720 | 10800 | **1440** | 105 | **3.5** |
| 15 | 13 | 0.866667 | **360** | 4680 | 5400 | **1080 (1440)** | 54 (56) | **3.6 (3.73)** |
| 40 | 36 | 0.9 | **360** | 12960 | 14400 | **1800** | 137 | **3.425** |
| 42 | 37 | 0.880952 | **360** | 13320 | 15120 | **2160** | 147 | **3.5** |
| 45 | 40 | 0.888889 | **360** | 14400 | 16200 | **1800** | 156 | **3.46** |
| 16 | 12 | 0.75 | **60** | 720 | 960 | **300** | 57 | **3.56** |
| 16 | 12 | 0.75 | **120** | 1440 | 1920 | **600** | 53 | **3.31** |
| 16 | 12 | 0.75 | **240** | 2880 | 3840 | **1200** | 51 | **3.19** |
| 16 | 12 | 0.75 | **360** | 4320 | 5760 | **1800** | 51 | **3.19** |
| 20 | 16 | 0.8 | **60** | 960 | 1200 | **300** | 72 | **3.60** |
| 20 | 16 | 0.8 | **120** | 1920 | 2400 | **600** | 71 | **3.55** |
| 20 | 16 | 0.8 | **240** | 3840 | 4800 | **1200** | 69 | **3.45** |
| 20 | 16 | 0.8 | **360** | 5760 | 7200 | **1800** | 67 | **3.35** |
| 24 | 20 | 0.833333 | **120** | 2400 | 2880 | **600** | 87 | **3.63** |
| 24 | 20 | 0.833333 | **240** | 4800 | 5760 | **1200** | 85 | **3.54** |
| 24 | 20 | 0.833333 | **360** | 7200 | 8640 | **1800** | 83 | **3.46** |
| 27 | 23 | 0.851852 | **120** | 2760 | 3240 | **600** | 98 | **3.63** |
| 27 | 23 | 0.851852 | **240** | 5520 | 6480 | **1200** | 97 | **3.59** |
| 27 | 23 | 0.851852 | **360** | 8280 | 9720 | **1800** | 93 | **3.44** |

# Performance Analysis of the LDPC Codes

- In the following slides a detailed performance analysis of the proposed LDPC codes is provided
- Simulation results are shown for
  - AWGN
  - Burst noise including required time interleaving depth
  - OFDM symbol durations of 20 μs and 40 μs
- Performance is compared with the DVB-C2 LDPC code and the ITU-T G.9960 LDPC code
- Performance metric of interest is a bit error rate (BER) of 1e-8
  - A BER of 1e-8 corresponds roughly to a frame error rate of 1e-6

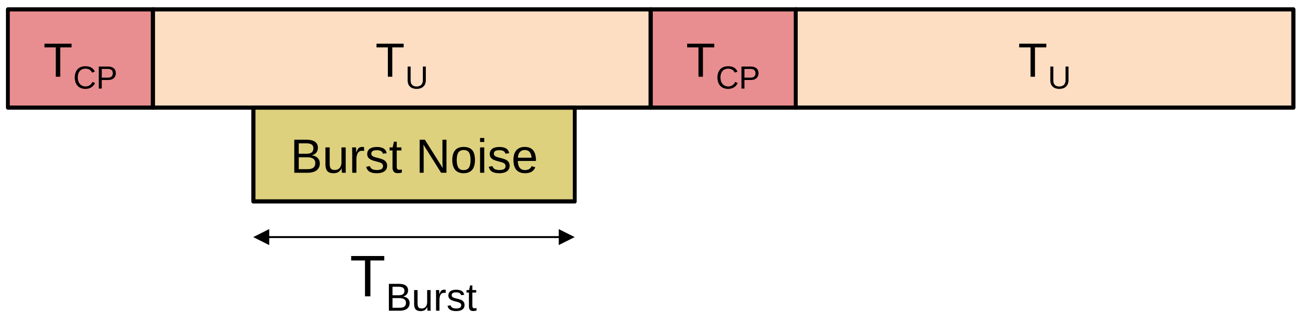
# Burst Noise in OFDM

- To analyze performance in burst noise, a simple model is chosen
  - Burst noise is modeled as white Gaussian noise with a certain $SNR_{Burst}$
    - Burst noise is assumed to be wideband
  - Burst noise is modeled with time duration $T_{burst}$ and burst SNR $SNR_{Burst}$



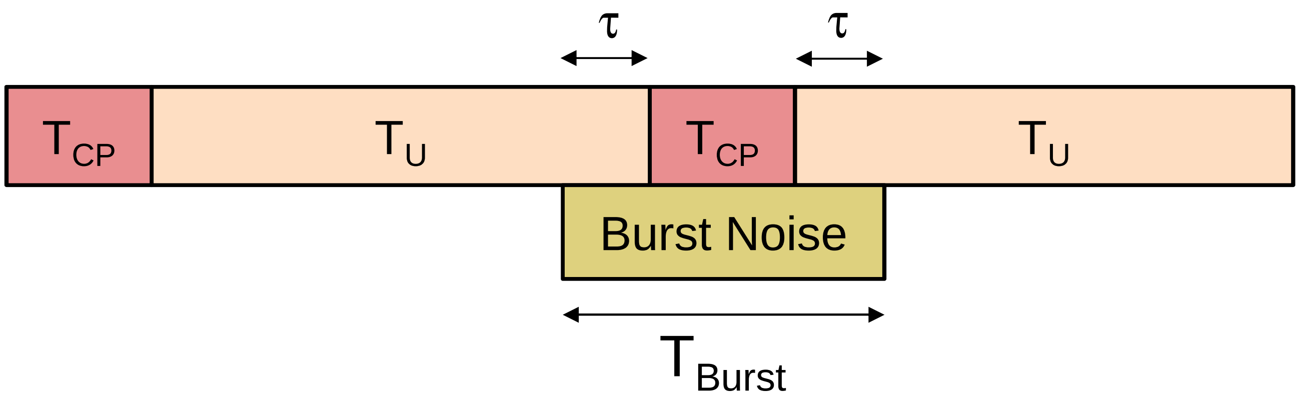

- The burst noise duration $T_{Burst}$ is assumed to be shorter than the duration of an OFDM symbol
  - In this case, burst noise can impact one or two OFDM symbols

# Burst Noise affecting One OFDM Symbol




- Effective SNR in OFDM symbols hit by burst noise
  - $SNR = -10 \cdot \log_{10}( 10\text{^}(-SNR_{Burst,\ effective}/10) + 10\text{^}(-SNR_{AWGN,\ effective}/10) )$
    - $SNR_{Burst,\ effective} = SNR_{Burst} - 10 \cdot \log_{10}(T_{Burst} / T_U)$
    - $SNR_{AWGN,\ effective} = SNR_{AWGN} - 10 \cdot \log_{10}(1 - T_{Burst} / T_U)$
- Effective SNR in OFDM symbols not hit by burst noise
  - $SNR = SNR_{AWGN}$

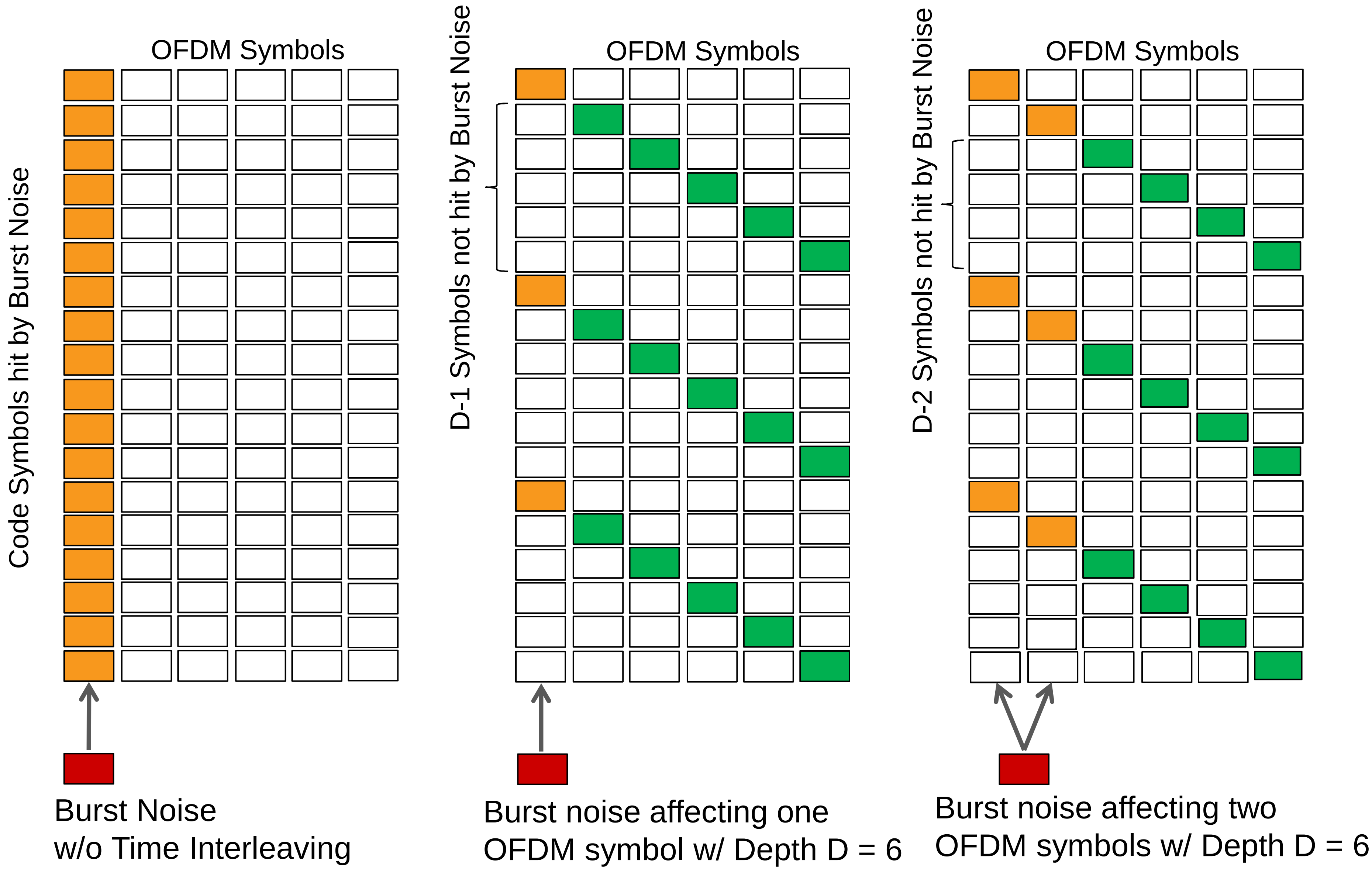
# Burst Noise affecting Two OFDM Symbols




- Effective SNR in OFDM symbols hit by burst noise
  - $SNR = -10 \cdot \log_{10}( 10\text{^}(-SNR_{Burst,\ effective}/10) + 10\text{^}(-SNR_{AWGN,\ effective}/10) )$
    – $SNR_{Burst,\ effective} = SNR_{Burst} – 10 \cdot \log_{10}(0.5 \cdot (T_{Burst} - T_{CP}) / T_U)$
    – $SNR_{AWGN,\ effective} = SNR_{AWGN} – 10 \cdot \log_{10}(1 - 0.5 \cdot (T_{Burst} - T_{CP}) / T_U)$

- Effective SNR in OFDM symbols not hit by burst noise
  - $SNR = SNR_{AWGN}$

# Frequency Domain View of Time Interleaving Depth D



# Consideration on Time Interleaving Depth D

- The depth D of the time domain interleaving impacts how many QAM symbols of a code word are affected by burst noise
  - For a larger interleaving depth D less symbols of a code word are impacted and performance improves
  - The drawback of a large interleaving depth D is increased PHY latency
    - However, if the depth D is to small, BER performance does not reach the BER target of 1e-8 anymore
- Hence, an important metric is the required interleaving depth D to achieve BER = 1e-8 at a fixed AWGN SNR
  - Interleaving depths are provided in the following
- Comments on required interleaving depth D
  - It can be shown that the required interleaving depth D is related to the inverse of the code rate R, i.e. $D \sim 1 / (1 - R)$

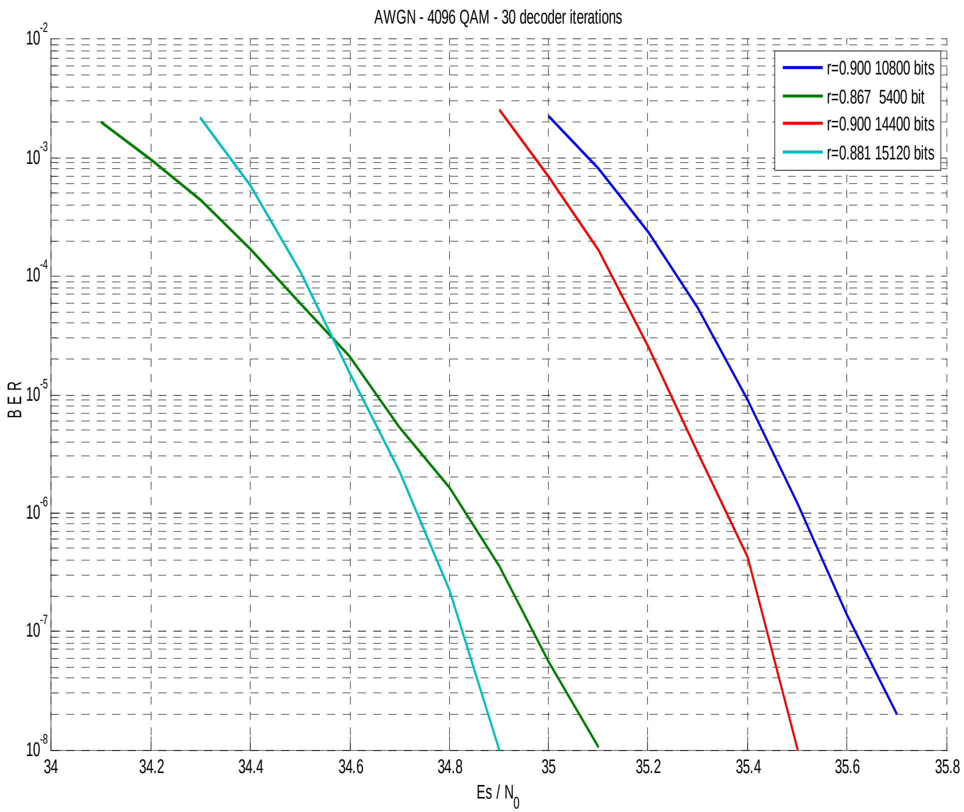
# Simulation Assumptions

- Downstream
  - 4096QAM
  - OFDM symbol durations $T_U$ = 20 μs and $T_U$ = 40 μs
  - Cyclic prefix length $T_{CP}$ = 2.5 μs
  - Burst noise
    a) $T_{Burst}$ = 16 μs, $SNR_{Burst}$ = 20 dB equally affecting two OFDM symbols
    b) $T_{Burst}$ = 16 μs, $SNR_{Burst}$ = 5 dB equally affecting two OFDM symbols
- Upstream
  - 1024QAM
  - OFDM symbol durations $T_U$ = 20 μs and $T_U$ = 40 μs
  - Cyclic prefix length $T_{CP}$ = 2.5 μs
  - Burst noise
    a) $T_{Burst}$ = 10 μs, $SNR_{Burst}$ = 10 dB equally affecting two OFDM symbols
    b) $T_{Burst}$ = 1 μs, $SNR_{Burst}$ = 0 dB affecting one OFDM symbol only

# Further Assumptions

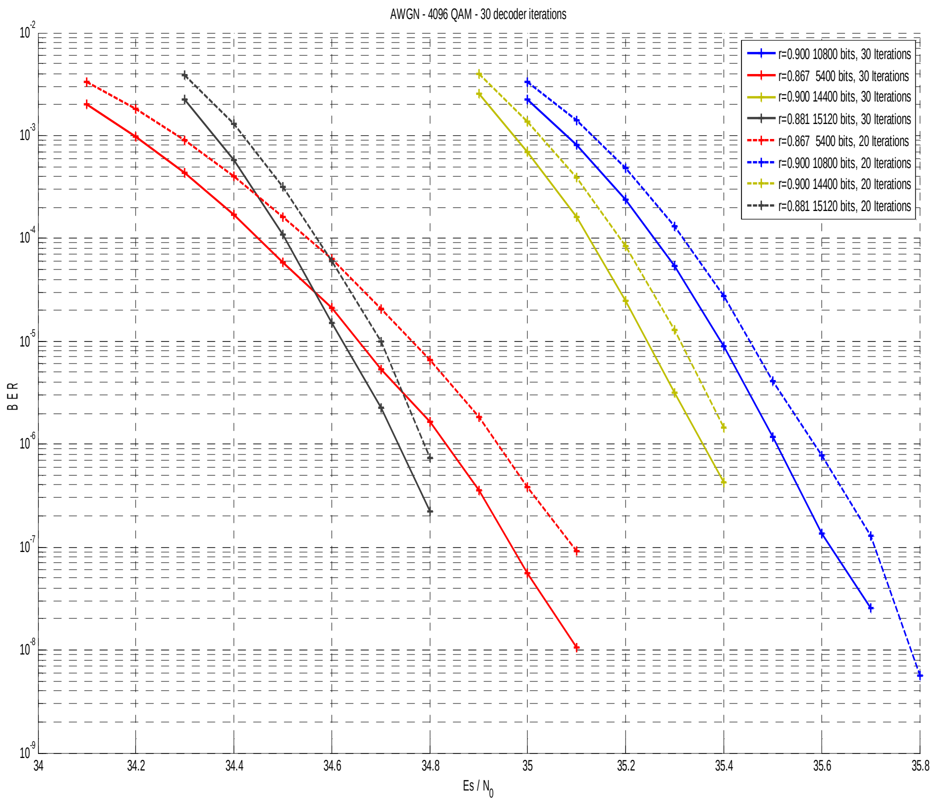
- LDPC decoder assumptions
  - Sum product decoder
  - Flooding schedule
    - No layered iterations are applied
  - The maximal number of iterations is set to 20 or 30, respectively
    - In the hardware implementation, layered iterations would be applied
      - This allows reducing the number of iterations roughly by 50%
      - Since the implementation and performance of a layered schedule is LDPC code specific, it is not used for code comparison
- Performance results for Codes I – IV and Code VIII are presented in the following slides
  - The burst noise results are for the downstream scenarios
- Still missing simulations
  - Codes V – IX for AWGN and burst noise scenarios
    - Results will be updated later

# Performance of Codes I – IV in AWGN



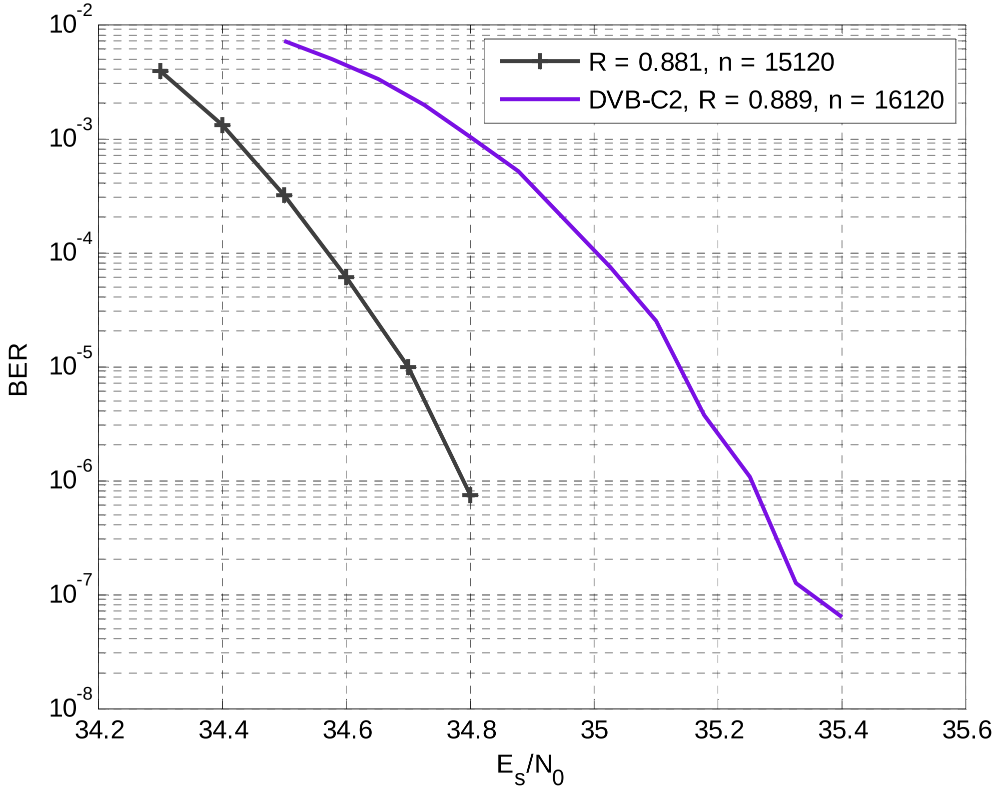

- Performance of Codes I – IV for max. 30 iterations with flooding schedule
- 4096QAM, AWGN
- Simulations still ongoing for BER ≤ 1e-8

# Performance of Codes I – IV with 20 & 30 Iterations




- Performance of Codes I – IV for max. 20 & 30 iterations with flooding schedule
- 4096QAM, AWGN
- The gain of 10 additional iterations is in the order of 0.1 dB

# Comparison of Code III with DVB-C2 in AWGN




- Comparison of Code III and the DVB-C2 code
  - Code III: R = 0.881, n = 15120
  - DVB-C2: R = 0.889, n = 16200
- 4096QAM, AWGN
- Max. 20 iterations with flooding schedule
- Code III outperforms the DVB-C2 code by more than 0.4 dB at BER = 1e-6



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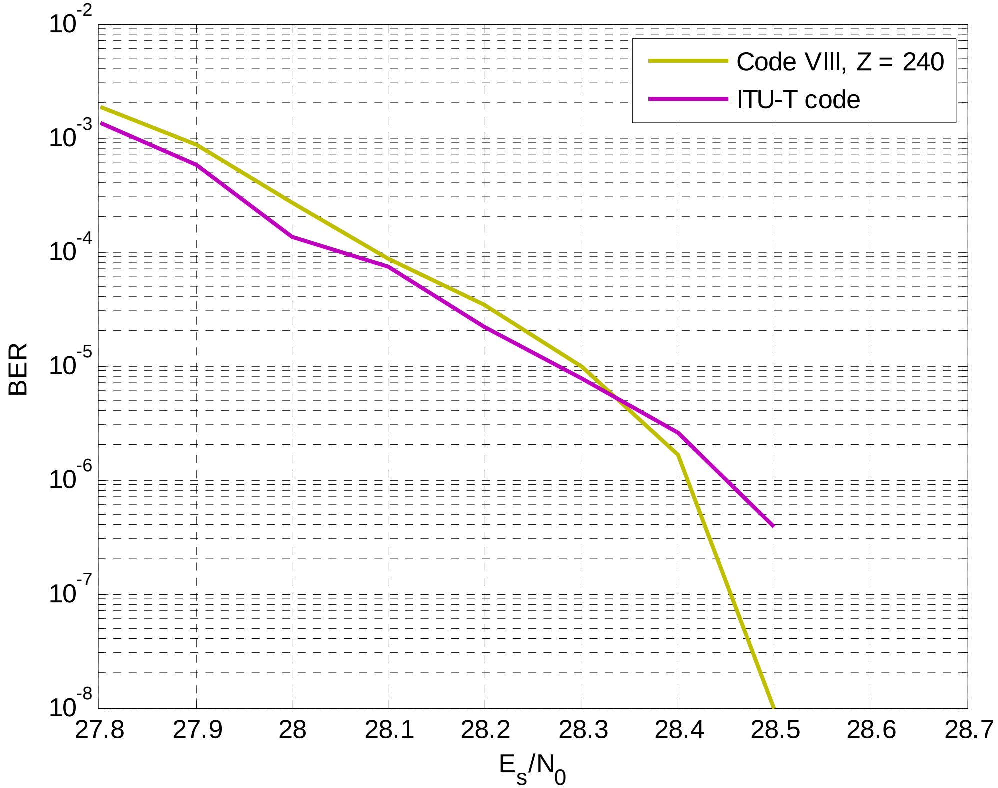
# Comparison of Code VIII, Z=240 with ITU-T G.9960




- Comparison of Code VIII and the ITU-T G.9960 code
  - Code VIII: R = 0.833, n = 5760, Z = 240
  - ITU-T: R = 0.883, n = 5184
- 1024QAM, AWGN
- Max. 30 iterations with flooding schedule
- Preliminary result
  - At low BER Code VIII outperforms G.9960 code
  - Simulations still ongoing for BER ≤ 1e-8

# Performance in Burst Noise impacting One Symbol

| Required Interleaving Depth @ BER ≤ 1e-8 | Rate R / Length N | AWGN SNR [dB] | 20 μs OFDM symbol duration | | 40 μs OFDM symbol duration | |
|---|---|---|---|---|---|---|
| | | | 20 dB burst noise | 5 dB burst noise | 20 dB burst noise | 5 dB burst noise |
| **Code I** | R = 0.9<br>N = 10800 | 38 dB | 12 | 21 | 10 | 18 |
| **Code II** | R = 0.867<br>N = 5400 | 37 dB | 12 | > 20 | 9 | 18 |
| **Code III** | R = 0.881<br>N = 15120 | 37 dB | 10 | 17 | ≤ 8 | 17 |
| **Code IV** | R = 0.9<br>N = 14400 | 38 dB | 10 | 18 | 9 | 17 |

# Performance in Burst Noise impacting Two Symbols

| Required Interleaving Depth @ BER ≤ 1e-8 | Rate R / Length N | AWGN SNR [dB] | 20 μs OFDM symbol duration | | 40 μs OFDM symbol duration | |
|---|---|---|---|---|---|---|
| | | | 20 dB burst noise | 5 dB burst noise | 20 dB burst noise | 5 dB burst noise |
| **Code I** | R = 0.9<br>N = 10800 | 38 dB | 18 | 34 | ≤ 14 | 31 |
| **Code II** | R = 0.867<br>N = 5400 | 37 dB | 17 | > 35 | 13 | 32 |
| **Code III** | R = 0.881<br>N = 15120 | 37 dB | 15 | 33 | 12 | 29 |
| **Code IV** | R = 0.9<br>N = 14400 | 38 dB | 16 | > 32 | 12 | 30 |

# Conclusions

- A set of quasi-cyclic LDPC codes has been proposed that is suited for all modes in EPoC
  - Codes with large lifting size may be chosen for the continuous mode in EPoC
  - Codes with short(er) lifting size and/or shorter code length may be chosen for burst modes in EPoC
- Low complexity implementation is ensured by the code structure and the choice of the lifting sizes
- Performance comparison
  - Code III (R = 0.88, n = 15120) outperforms the DVB-C2 LDPC code by more than 0.4 dB for 4096QAM
  - Code VIII (R = 0.833, n = 5760, Z = 240) outperforms the ITU-T G.9960 LDPC code at low BER for 1024QAM

# Thank you

# Backup

# LDPC Parity Check Matrix Description

- In the following slides the parity check matrices H of the LDPC codes are given
- Description
  - In all tables the top row indexes columns of the parity check matrix
  - The second row of the tables indicates information (1) and parity (0) columns
  - The third row of the tables indicates transmitted columns (1) and punctured columns (0)

# Parity Matrices for Code I and Code II

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 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 | 0 | 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 |
| 0 | 16 | · | 13 | · | · | 2 | · | 277 | 112 | · | 233 | 272 | 85 | 277 | 104 | 310 | 355 | 168 | 43 | 198 | 105 | 142 | 67 | 85 | 277 | 334 | 258 | 156 | 20 | 5 |
| 0 | 241 | 235 | 58 | 157 | 218 | · | 39 | 209 | 19 | 269 | · | · | · | 94 | 323 | 55 | 64 | · | 46 | 325 | 158 | 118 | 122 | 167 | 344 | 126 | 281 | 40 | 85 | 222 |
| · | 241 | 122 | 0 | 187 | 66 | 216 | 351 | 208 | · | 59 | 111 | 114 | 277 | · | 64 | 57 | · | 333 | 182 | 159 | 175 | 77 | 256 | 284 | 92 | 148 | 185 | 86 | 184 | 93 |
| · | · | 122 | 90 | 29 | 224 | 168 | 97 | · | 30 | 254 | 114 | 334 | 169 | 132 | · | · | 353 | 141 | 217 | 105 | 84 | 138 | 136 | 31 | 97 | 3 | 144 | 20 | 6 | 354 |

Figure 1: Base code information bits: 27; (max) block length: 30. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | · | · | 45 | · | 92 | 28 | · | 137 | 111 | 344 | 2 | 338 | 190 | 258 | 328 | 13 |
| 0 | 241 | · | · | 284 | · | · | 186 | · | 198 | 185 | 334 | 76 | 148 | 236 | 93 | 190 |
| · | 241 | 122 | 119 | 171 | 17 | 244 | 303 | 218 | 356 | 258 | 53 | 181 | 330 | 271 | 279 | 150 |
| · | · | 122 | 0 | 287 | 36 | 135 | 84 | 72 | 245 | 208 | 303 | 239 | 124 | 176 | 284 | 121 |

Figure 2: Base code information bits: 13; (max) block length: 15. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

# Parity Matrices for Code III and Code IV

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 151 | · | · | · | 186 | · | 275 | 240 | · | · | 305 | · | · | · | 27 | 163 | 179 | · | 114 | · | 54 | · | 280 | 37 |
| 0 | 61 | · | · | · | · | · | · | 193 | 90 | 357 | · | · | 49 | 135 | · | · | · | 153 | · | · | 20 | 322 | 243 | · |
| · | 61 | 122 | 184 | · | · | 153 | · | 306 | · | 11 | 164 | · | · | · | · | · | 306 | 3 | 53 | 124 | · | 243 | · | 71 |
| · | · | 122 | 183 | · | 355 | 314 | 32 | · | · | 27 | · | 298 | 121 | 76 | 90 | · | 266 | · | · | · | 259 | · | · | 141 |
| · | · | · | 183 | 244 | · | · | 266 | · | 278 | · | 145 | 86 | · | 183 | · | 2 | · | 56 | · | 103 | · | · | 344 | · |
| · | · | · | · | 244 | 345 | 119 | · | · | 78 | · | · | 24 | 221 | · | 301 | 145 | · | · | 76 | 259 | · | 119 | · | 215 |

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| 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 1 | 1 | 1 | 0 |
| · | 125 | 122 | 258 | 220 | 111 | 296 | · | · | 122 | 64 | · | · | 88 | 43 | · | 74 | 252 |
| 17 | 273 | 106 | · | 119 | · | 182 | 72 | · | 168 | 238 | 228 | 270 | 127 | · | · | 309 | 278 |
| 126 | 306 | · | 156 | 194 | 234 | 111 | 42 | 280 | · | · | · | 252 | 313 | · | 320 | · | 221 |
| · | · | · | · | · | 342 | · | 76 | 355 | 153 | 43 | 233 | 55 | 320 | 101 | 150 | 169 | 132 |
| 164 | 208 | 182 | 65 | 290 | 352 | · | 140 | 174 | 35 | · | 36 | · | · | 114 | 331 | · | 17 |
| 159 | · | 16 | 13 | · | · | 151 | · | 195 | · | 39 | 259 | 70 | · | 307 | 231 | 92 | 46 |

Figure 3: Base code information bits: 37; (max) block length: 42. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 |
| 0 | 151 | · | · | 234 | · | · | 82 | 241 | 101 | 129 | 60 | · | 69 | 82 | 242 | 275 | 140 | · | · |
| 0 | 61 | · | · | · | 117 | 59 | · | · | · | 69 | 249 | · | · | 123 | 211 | 178 | 168 | 350 | 73 |
| · | 61 | 122 | · | · | 53 | · | · | 142 | 156 | · | 211 | 144 | 125 | 354 | · | · | · | 159 | 278 |
| · | · | 122 | 183 | 309 | 155 | 124 | 3 | 260 | 261 | · | · | 179 | · | · | · | 132 | 133 | · | · |
| · | · | · | 183 | 158 | · | 190 | 248 | · | · | 112 | · | 231 | 98 | · | 162 | · | · | 12 | 41 |

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| 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| · | 93 | 84 | · | · | 318 | · | 0 | 99 | 299 | · | 78 | 344 | 278 | 316 | 105 | 20 | 149 | · | 335 | 341 |
| · | · | · | 313 | 304 | 232 | 281 | 14 | 324 | 114 | 349 | 312 | 336 | · | · | · | 192 | 129 | 83 | 27 | 141 |
| 345 | · | 239 | 27 | · | 8 | 64 | 8 | 88 | · | 271 | 91 | 0 | 252 | 48 | 114 | 215 | · | 20 | · | 91 |
| 161 | 268 | · | 262 | 242 | 343 | 98 | · | · | 106 | 210 | 240 | 79 | 233 | 5 | 163 | · | 230 | 330 | 278 | 70 |
| 84 | 155 | 111 | · | 202 | · | 244 | 170 | 354 | 336 | 119 | · | · | 99 | 348 | 210 | 313 | 231 | 155 | 214 | 256 |

Figure 4: Base code information bits: 36; (max) block length: 40. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

# Parity Matrix for Code V

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0 | 149 | · | · | · | 218 | · | 108 | · | · | · | · | 44 | 218 | 145 | 234 | · | 101 | · | 127 | 226 | 164 | · | 77 |
| 0 | 59 | · | · | · | · | 243 | · | · | 171 | 311 | · | 210 | · | · | · | 159 | 329 | · | · | 204 | · | 238 | 28 |
| · | 59 | 122 | 184 | · | · | · | 71 | 300 | · | 237 | 222 | · | · | · | 7 | · | · | · | 110 | · | 39 | 285 | · |
| · | · | 122 | 183 | · | 27 | 313 | · | · | 35 | · | 102 | · | · | 316 | 150 | · | · | 223 | · | · | · | 226 | 19 |
| · | · | · | 183 | 238 | · | · | · | 232 | · | 147 | · | · | 71 | 218 | · | 129 | · | 189 | 266 | 357 | 226 | · | · |
| · | · | · | · | 238 | 17 | 82 | 164 | 341 | 189 | · | 55 | 69 | 89 | · | · | 297 | 176 | 262 | · | · | · | · | · |

...

...

| 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| · | · | · | · | 202 | · | 255 | 22 | 52 | · | 334 | · | 239 | · | · | 18 | 25 | 134 | 325 | 321 | 266 | 136 |
| 56 | · | 353 | 195 | 184 | 90 | 11 | · | · | 358 | · | 176 | 169 | 26 | · | 103 | · | 308 | · | 220 | 172 | 293 |
| 191 | 169 | · | 45 | 291 | 25 | 223 | · | · | · | 35 | 52 | · | 173 | 6 | · | 219 | · | 183 | 112 | 216 | 255 |
| · | 165 | 188 | 295 | · | 274 | 120 | 34 | 45 | 29 | 341 | · | 167 | · | 274 | 273 | 213 | · | · | 274 | · | 274 |
| · | 179 | 70 | · | 276 | 2 | · | 266 | 32 | 311 | · | 95 | · | 107 | 341 | 232 | 167 | 334 | 299 | · | · | 248 |
| 207 | · | · | 110 | · | · | · | 80 | 263 | 62 | 179 | 242 | 82 | 242 | 345 | · | · | 242 | 296 | · | 351 | 247 |

Figure 5: Base code information bits: 40; (max) block length: 45. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

# Parity Matrices for Code VI, Z = 60 & 120

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 0 | 0 | 0 | 0 | 0 | 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 | 0 |
| 0 | 14 | · | · | 8 | · | 53 | 11 | 50 | · | · | 38 | 53 | 35 | 4 | 48 | 55 |
| 0 | 59 | · | · | · | 42 | 56 | · | · | 23 | 16 | 9 | 16 | · | 50 | 7 | 16 |
| · | 59 | 58 | 55 | · | 54 | · | 31 | 27 | · | 55 | · | 2 | 13 | 30 | 50 | 39 |
| · | · | 35 | 58 | 59 | 26 | 54 | · | · | 13 | 29 | 16 | · | 39 | · | 50 | 26 |
| · | · | · | 7 | 43 | · | · | 19 | 29 | 40 | 35 | 12 | 57 | 5 | 56 | · | 49 |

Figure 6: Base code information bits: 12; (max) block length: 16. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 60

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 0 | 0 | 0 | 0 | 0 | 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 | 0 |
| 0 | 28 | · | · | 21 | 6 | 83 | 95 | 24 | · | · | · | 7 | · | 31 | 43 | 80 |
| 0 | 118 | · | · | · | 95 | · | · | · | 11 | 31 | 71 | 94 | 12 | · | 22 | 25 |
| · | 118 | 62 | · | · | · | · | 27 | 33 | · | 67 | 14 | 9 | 109 | 102 | 7 | 104 |
| · | · | 62 | 3 | 10 | · | 31 | · | 36 | 92 | 59 | · | · | 118 | 65 | 110 | 62 |
| · | · | · | 3 | 5 | 78 | 74 | 61 | · | 65 | · | 61 | · | 103 | 7 | · | 90 |

Figure 7: Base code information bits: 12; (max) block length: 16. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 120

# Parity Matrices for Code VI, Z = 240 & 360

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 0 |
| 0 | 61 | · | · | 154 | · | · | · | 230 | 70 | 209 | · | 171 | · | 193 | 75 | 224 |
| 0 | 1 | · | · | · | 10 | 134 | 131 | 47 | 188 | · | · | 11 | 188 | · | · | 206 |
| · | 1 | 113 | · | · | 143 | 55 | · | · | · | 236 | 27 | · | 37 | 199 | 68 | 61 |
| · | · | 113 | 174 | 198 | 167 | · | 139 | · | 210 | 172 | 126 | 207 | · | · | 50 | 192 |
| · | · | · | 174 | 199 | · | 225 | 2 | 221 | · | · | 216 | · | 193 | 188 | 228 | 223 |

Figure 8: Base code information bits: 12; (max) block length: 16. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 240

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 0 |
| 0 | 88 | · | · | 123 | · | · | · | 142 | 10 | 26 | · | 21 | · | 229 | 65 | 230 |
| 0 | 358 | · | · | · | 265 | 301 | 153 | 264 | 107 | · | · | 131 | 341 | · | · | 349 |
| · | 358 | 62 | · | · | 288 | 119 | · | · | · | 261 | 88 | · | 331 | 331 | 81 | 20 |
| · | · | 62 | 243 | 114 | 340 | · | 20 | · | 121 | 110 | 269 | 189 | · | · | 309 | 303 |
| · | · | · | 243 | 197 | · | 250 | 230 | 356 | · | · | 150 | · | 217 | 325 | 85 | 92 |

Figure 9: Base code information bits: 12; (max) block length: 16. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

# Parity Matrices for Code VII, Z = 60 & 120

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 0 |
| 0 | 46 | · | · | 53 | 53 | · | 10 | 44 | · | 7 | · | · | 32 | 27 | 43 | 2 | 7 | 58 | · | 25 |
| 0 | 31 | 5 | · | · | · | 24 | 22 | · | 20 | · | 8 | 4 | 21 | 46 | · | 9 | 38 | 21 | 9 | 11 |
| · | 31 | 52 | 54 | · | · | 49 | · | 23 | 41 | 0 | · | 6 | · | · | 7 | 53 | 8 | 56 | 20 | 14 |
| · | · | 52 | 31 | 7 | 10 | 44 | 41 | · | · | · | 9 | 3 | 13 | 50 | 9 | · | · | 5 | 27 | 50 |
| · | · | · | 31 | 52 | 53 | · | · | 40 | 14 | 28 | 3 | 30 | 18 | 31 | 32 | 34 | 12 | · | 36 | 1 |

Figure 10: Base code information bits: 16; (max) block length: 20. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 60

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 0 |
| 0 | 89 | · | · | 88 | · | 58 | 26 | · | 109 | 27 | · | 68 | 101 | 42 | 99 | 98 | · | · | 58 | 90 |
| 0 | 59 | · | · | · | 106 | · | · | · | 46 | 36 | 59 | 50 | 67 | 1 | 57 | 87 | 73 | 118 | · | 85 |
| · | 59 | 79 | 26 | · | 3 | 69 | · | 106 | · | 50 | · | 112 | · | 27 | 3 | · | 91 | 77 | 30 | 54 |
| · | · | 61 | 42 | 77 | · | 78 | 84 | 10 | · | · | 114 | · | 38 | · | 42 | 68 | 83 | 57 | 32 | 107 |
| · | · | · | 26 | 56 | 38 | · | 93 | 37 | 76 | · | 104 | 106 | 30 | 29 | · | 90 | 43 | 57 | 15 | 109 |

Figure 11: Base code information bits: 16; (max) block length: 20. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 120

# Parity Matrices for Code VII, Z = 240 & 360

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 0 |
| 238 | 85 | · | · | 17 | · | 27 | 129 | 204 | 18 | · | · | 2 | 99 | 62 | 73 | · | · | 141 | 29 | 84 |
| 238 | 25 | · | · | · | 125 | 113 | 47 | · | · | · | 51 | 236 | 89 | 177 | 65 | 145 | 107 | 54 | · | 91 |
| · | 25 | 122 | · | · | 74 | · | · | · | 136 | 40 | 34 | 153 | 26 | · | · | 158 | 223 | 139 | 86 | 35 |
| · | · | 122 | 63 | 67 | 100 | 93 | · | 5 | · | 25 | · | · | 110 | 76 | 167 | 176 | 25 | · | 141 | 199 |
| · | · | · | 63 | 105 | · | · | 134 | 136 | 140 | 84 | 186 | · | · | 74 | 25 | 38 | 74 | 178 | 26 | 80 |

Figure 12: Base code information bits: 16; (max) block length: 20. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 240

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 0 |
| 354 | 85 | · | · | 317 | · | · | · | · | 266 | 155 | 168 | 61 | 228 | 101 | 261 | 125 | · | 305 | 70 | 285 |
| 354 | 355 | · | · | · | 136 | 132 | 358 | · | · | 185 | · | 187 | 341 | · | 223 | · | 137 | 121 | 327 | 39 |
| · | 355 | 62 | · | · | 268 | 189 | 83 | 341 | · | · | 211 | · | · | 132 | 204 | 328 | 113 | 220 | · | 83 |
| · | · | 62 | 183 | 304 | · | 136 | · | 140 | 49 | 209 | · | · | 7 | 261 | 327 | 6 | 349 | · | 28 | 278 |
| · | · | · | 183 | 37 | 0 | · | 58 | 172 | 344 | · | 100 | 203 | · | · | · | 78 | 208 | 185 | 233 | 347 |

Figure 13: Base code information bits: 16; (max) block length: 20. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

# Parity Matrices for Code VIII, Z = 120 & 240

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 91 | · | · | 74 | 85 | 74 | · | 103 | 102 | · | · | 87 | 82 | 28 | 14 | 77 | 73 | 17 | 35 | · | · | 48 | 101 | 90 |
| 0 | 61 | 57 | · | · | · | · | 37 | 111 | 53 | 3 | 11 | · | · | 79 | 86 | · | 23 | 92 | 67 | 97 | 110 | 55 | 112 | 114 |
| · | 61 | 0 | 107 | · | 86 | 110 | · | · | · | 81 | · | 82 | 113 | · | 108 | 2 | 75 | · | 88 | 80 | 78 | 9 | 61 | 113 |
| · | · | 0 | 57 | 30 | · | 27 | 91 | · | 114 | · | 108 | 44 | 17 | 78 | · | 67 | · | 109 | · | 44 | 86 | 30 | 67 | 50 |
| · | · | · | 57 | 0 | 104 | · | 21 | 12 | · | 63 | 7 | · | 41 | 113 | 8 | 5 | 73 | 19 | 4 | 70 | 80 | · | · | 9 |

Figure 14: Base code information bits: 20; (max) block length: 24. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 120

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 122 | · | · | 237 | · | · | · | 14 | 143 | · | 79 | 213 | 115 | 197 | · | · | 166 | 88 | 118 | 114 | 54 | 113 | 210 | 180 |
| 0 | 62 | · | · | · | 229 | 95 | 82 | · | · | 47 | 137 | 4 | · | · | 123 | 185 | 78 | · | 183 | 0 | 94 | 51 | 146 | 131 |
| · | 62 | 79 | 42 | · | 65 | 27 | · | 174 | 53 | · | · | · | 38 | 20 | 101 | 231 | 196 | 224 | · | · | 143 | 27 | 213 | 217 |
| · | · | 61 | 58 | 106 | 135 | · | 112 | · | 92 | 90 | · | 8 | · | 221 | 177 | 131 | 107 | 147 | 136 | 147 | · | · | 134 | 59 |
| · | · | · | 42 | 85 | · | 46 | 116 | 123 | · | 34 | 72 | · | 119 | 140 | 78 | 124 | · | 171 | 133 | 155 | 150 | 71 | · | 213 |

Figure 15: Base code information bits: 20; (max) block length: 24. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 240

# Parity Matrices for Code VIII, Z = 360 and Code IX, Z = 120

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | · | · | · | 61 | 356 | 63 | · | 107 | 229 | 131 | · | · | · | 38 | 279 | 172 | 215 | 7 | 313 | · | 3 | · | 107 | 340 |
| 0 | 61 | · | · | · | 106 | 229 | 123 | · | · | 52 | · | 14 | 242 | 305 | 111 | 249 | · | 189 | 57 | 205 | · | 140 | 137 | 46 |
| · | 61 | 122 | · | · | · | · | 188 | 280 | 240 | · | 167 | 283 | · | 185 | · | · | 84 | 68 | 267 | 323 | 336 | 122 | 264 | 299 |
| · | · | 122 | 210 | 332 | · | 176 | · | 319 | · | · | 343 | 288 | 259 | 119 | 183 | 240 | 203 | · | · | 248 | 129 | 120 | 64 | 216 |
| · | · | · | 210 | 331 | 133 | · | 262 | · | 221 | 274 | 125 | · | 273 | · | 126 | 135 | 148 | 289 | 354 | 73 | 254 | 251 | · | 195 |

Figure 16: Base code information bits: 20; (max) block length: 24. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 91 | · | · | 72 | 23 | · | · | · | 47 | · | 34 | 53 | 114 | 5 | 61 | 97 | 106 | · | · | 86 | 19 | 6 | · | 53 | 79 | 6 | 112 |
| 0 | 61 | 11 | · | · | 2 | · | 89 | 68 | 117 | 43 | · | 7 | · | 31 | 29 | 112 | 88 | 86 | 7 | · | 10 | 62 | 69 | 58 | 85 | · | 9 |
| · | 61 | 74 | 102 | · | · | 72 | 101 | · | · | 88 | · | 30 | 110 | 96 | 91 | · | · | 68 | 90 | 41 | 23 | 114 | 53 | · | 43 | 104 | 40 |
| · | · | 74 | 52 | 28 | 20 | 10 | 38 | 55 | · | · | 117 | · | · | 25 | · | 92 | 112 | 12 | 11 | 100 | · | · | 0 | 102 | 111 | 115 | 87 |
| · | · | · | 52 | 118 | · | 25 | · | 75 | 29 | 3 | 109 | · | 84 | · | 52 | 93 | 42 | 78 | 79 | 104 | 89 | 105 | 77 | 0 | · | 94 | 13 |

Figure 17: Base code information bits: 23; (max) block length: 27. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 120

# Parity Matrices for Code IX, Z = 240 & Z = 360

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 0 | 173 | · | · | 216 | 52 | 25 | 141 | 173 | · | 238 | · | · | 172 | 71 | · | · | 62 | 128 | 46 | · | 16 | 70 | 129 | 7 | 108 | · | 94 |
| 0 | 113 | · | · | · | · | · | · | · | 193 | 126 | · | 164 | 197 | 81 | 15 | 146 | 94 | 195 | · | 99 | 43 | 66 | 80 | · | 162 | 109 | 47 |
| · | 113 | 79 | 26 | · | 191 | · | 124 | 213 | 47 | 190 | 171 | · | · | · | 107 | · | 234 | 118 | 92 | 37 | 114 | · | 98 | 222 | · | 167 | 155 |
| · | · | 61 | 42 | 85 | 131 | 33 | · | 168 | 114 | · | 56 | 166 | 175 | · | · | 206 | · | 225 | 172 | 25 | · | 166 | · | 88 | 45 | 19 | 120 |
| · | · | · | 26 | 64 | · | 79 | 53 | · | · | · | 152 | 109 | · | 29 | 189 | 131 | · | · | 96 | 132 | 166 | 196 | 213 | 225 | 150 | 52 | 228 |

Figure 18: Base code information bits: 23; (max) block length: 27. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 240

| 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 354 | · | · | · | 220 | · | 97 | 68 | 205 | 315 | · | · | · | · | 222 | 252 | 55 | 210 | · | 355 | 170 | 278 | 200 | 10 | 233 | 279 | · | 322 |
| 354 | 241 | · | · | · | · | 174 | · | 216 | 76 | 170 | 318 | 88 | 239 | · | · | 0 | 306 | 257 | 27 | 98 | 85 | 217 | · | 135 | · | 64 | 117 |
| · | 241 | 98 | · | · | 44 | 162 | 240 | · | · | · | 59 | · | 94 | 97 | 60 | 358 | 182 | 47 | 36 | · | · | 38 | 295 | 101 | 162 | 235 | 261 |
| · | · | 98 | 57 | 351 | 58 | · | 124 | · | · | 188 | · | 39 | 325 | · | 346 | 93 | · | 316 | · | 101 | 284 | · | 135 | 35 | 111 | 268 | 110 |
| · | · | · | 57 | 175 | 266 | · | · | 9 | 28 | 228 | 349 | 34 | · | 68 | · | · | 73 | 305 | 290 | 205 | 0 | 170 | 345 | · | 226 | 29 | 229 |

Figure 19: Base code information bits: 23; (max) block length: 27. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

# Encoding of the LDPC Codes

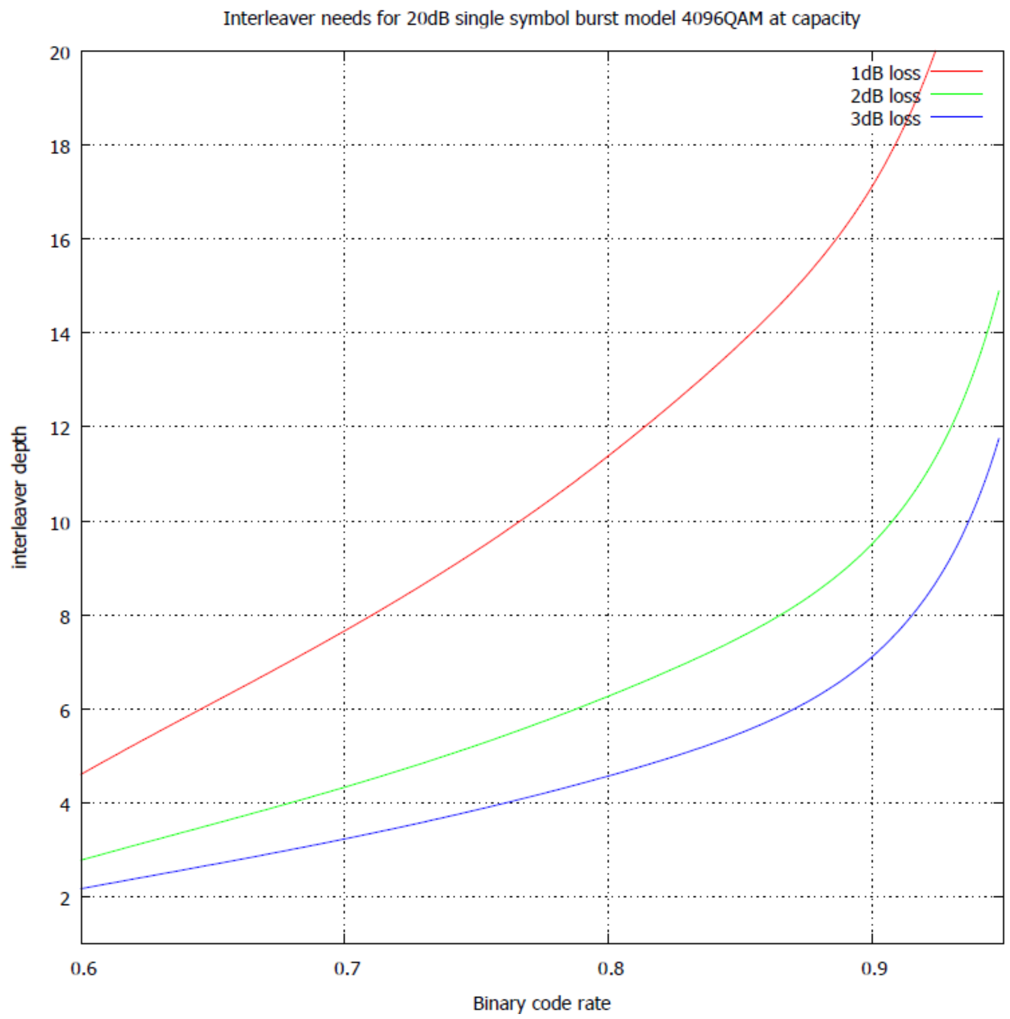
- The attached document includes a detailed description of the codes and its encoding

LDPC Code Description for EPoC

# Consideration on Time Interleaving Depth D

- The depth D of the time domain interleaving impacts how many QAM symbols of a code word are affected by burst noise
  - For a larger interleaving depth D less symbols of a code word are impacted and performance improves
  - The drawback of a large interleaving depth D is increased PHY latency
    - However, if the depth D is to small, BER performance does not reach the BER target of 1e-8 anymore
- Hence, an important metric is the required interleaving depth D to achieve BER = 1e-8 at a fixed AWGN SNR
  - Interleaving depths are provided in the following
- Comments on required interleaving depth D
  - It can be shown that the required interleaving depth D is related to the inverse of the code rate R, i.e. $D \sim 1 / (1 - R)$

# Code Rate and Interleaving Depth




- In burst noise a higher AWGN SNR is needed for the same capacity
  - This increase in SNR is called loss in the figure
  - This can be seen as required SNR margin for burst noise
- For a given margin, the figure shows the required interleaving depth as a function of code rate
- Codes with higher rate require higher interleaving depth
  - In comparisons for burst noise performance, code rates must be identical