The Consultative Committee for Space Data Systems

# Research and Development for Space Data System Standards

# FLEXIBLE SERIALLY CONCATENATED CONVOLUTIONAL TURBO CODES WITH NEAR-SHANNON BOUND PERFORMANCE FOR TELEMETRY APPLICATIONS

## EXPERIMENTAL SPECIFICATION

## CCSDS 131.2-O-1

September 2007

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# FOREWORD

This document describes a Serially Concatenated Convolutional turbo Coding (SCCC) scheme for telemetry applications. The flexibility, performance and proper architecture of the proposed coding scheme together with a new frame structure make the scheme suitable for achieving a significantly high spectral and power efficiency while maintaining compatibility with the existing data layer protocols.

The proposed coding scheme and its associated frame structure are specifically designed to support reconfiguration of the downlink channel (variable or adaptive coding and modulation) and to provide means for reliable synchronization at the Physical layer and the Data Link layer.

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# PREFACE

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# DOCUMENT CONTROL

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# 1 INTRODUCTION

## 1.1 BACKGROUND

In recent years, there has been an ever-growing demand for high data rate in multimedia satellite communications and earth observation missions such as COSMO and METEOSAT third generation. In order to satisfy this demand, innovative modulation and coding schemes with high spectral and energy efficiency are required to match the bandwidth- and/or power-limited conditions of satellite channels.

Further improvements in the average system throughput are envisaged by using adaptive Physical layer techniques that allow for reconfiguration of the coding and modulation scheme. The change of coding and modulation scheme is envisaged based on either estimates of channel condition or a predetermined schedule (for example, as a function of variation in the elevation angle). Such improvements require more flexibility in the Physical and MAC layer of the transmitter and receiver architecture.

This document describes a new coding/modulation scheme featuring simplicity and versatility while offering performance close to theoretical bounds. The proposed scheme provides a wide range of spectral efficiency values that can be reconfigured without interrupting the data transfer over the physical channel. The implementation of the encoder can be realized with certain degrees of parallelism without any significant increase in memory or computation requirements. This feature makes the scheme attractive in particular for on-board implementation.

## 1.2 PURPOSE AND SCOPE

The proposed coding scheme belongs to a family of ‘turbo-like codes’ that is structured as a serial concatenation of two convolutional codes through an interleaver (reference [B1]). The main criteria used for the code design can be highlighted as follows:

– *flexibility*, i.e., use a single mother code for all modulations and code rates;

– *simplicity*, i.e., build a code as compact and simple as possible;

– *performance*, i.e., approach Shannon capacity bounds.

The proposed SCCC scheme supports flexible design of a wide range of spectral efficiency values based on a single coding structure. A parallel structure for implementation of the encoder and decoder is possible for high data rate links.

The performance results of the coding and modulation schemes approach the theoretical limits over a Gaussian channel. This includes achievable performance even at high coding rates.

An important feature of the new scheme is its simplicity. The use of similar four-state encoder structures for the inner and the outer code leads to a significant reduction in implementation complexity. This is especially important in the case of high-speed decoders that require a highly parallelized architecture.

The frame structure governing the data transfer from the upper Data Link layers to the Physical layer is described. The data transfer frame structures at baseband and Physical layer are designed such that the data flow is compatible with the format used in the upper stream modules while providing support for maintaining synchronization during transition from one spectral efficiency mode to another. The reconfiguration of the modulation and coding is supported during operation without any interruption or significant delay in data transmission.

# 2 ARCHITECTURE OVERVIEW

A general view of the functional blocks of the proposed architecture for the synchronization and channel coding sublayer is presented in figure 2-1. The synchronization and channel coding sublayer provides the following functions:

– Transfer Frame data interfacing (buffering and ACM format adaptation);

– Transfer Frame synchronization and pseudo-randomization;

– Forward error coding based on serially concatenated convolutional coding;

– Physical Layer Framing, synchronization, and pseudo-randomization (optional).

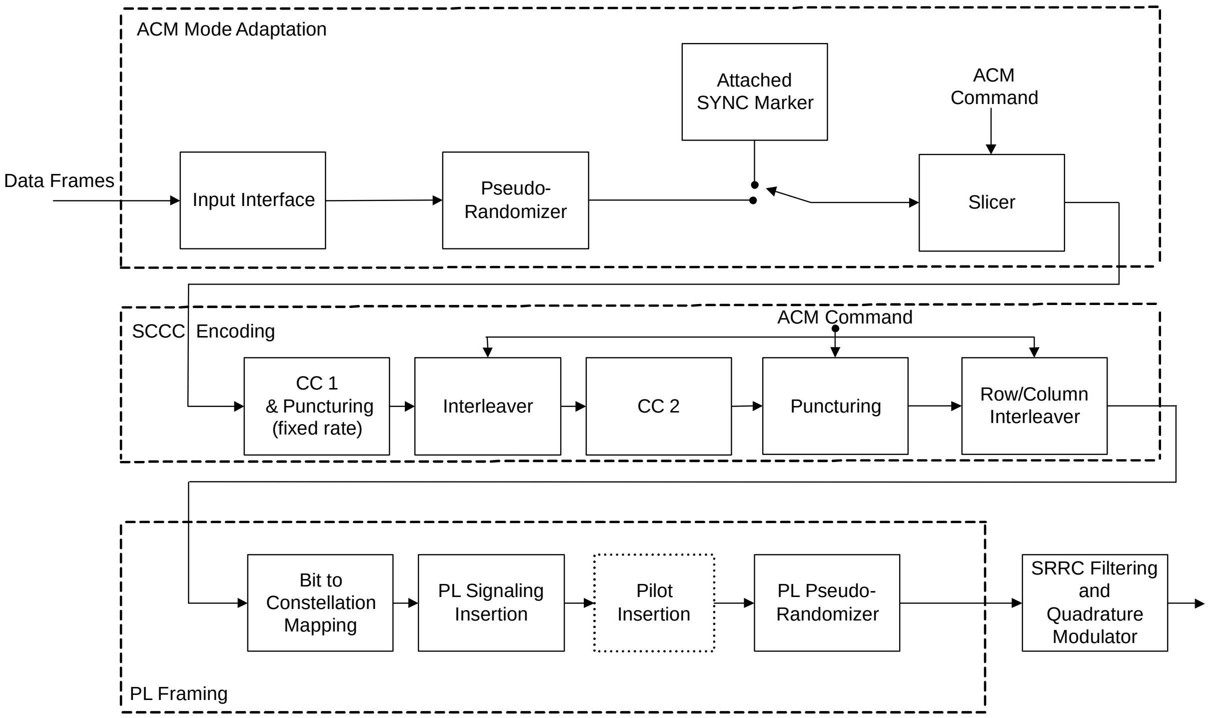



**Figure 2-1: Functional Diagrams of Synchronization and Channel Coding Sublayer**

Figure 2-2 illustrates the frame structures and stream formats at different stages of processing in synchronization and channel coding subsystems. The input data stream, transferred via the Transfer Frames, is compliant with proposed Data Link protocol in TM (reference [B4]) and AOS (reference [B5]).

Attached SYNC markers are inserted between Transfer Frames prior to encoding. The information blocks at the input of the encoder are formed by slicing the input data stream (after ASM insertion) into blocks of length *K*. The information block size varies depending on selected modulation and coding scheme (see table 4-3). A similar coding and modulation scheme is applied to every 16 consecutive blocks that form a Physical Layer (PL) frame. The length of encoded blocks (*N* bits) is determined according to the modulation scheme (independent of the coding rate as shown in table 4-3). The length of encoded symbol blocks after encoding and mapping to modulation symbols is constant (8100 symbols) independent of the modulation and coding scheme. Maintaining constant symbol block sizes facilitates frame synchronization at the Physical layer.

Each subsystem is described in more detail in the following sections.

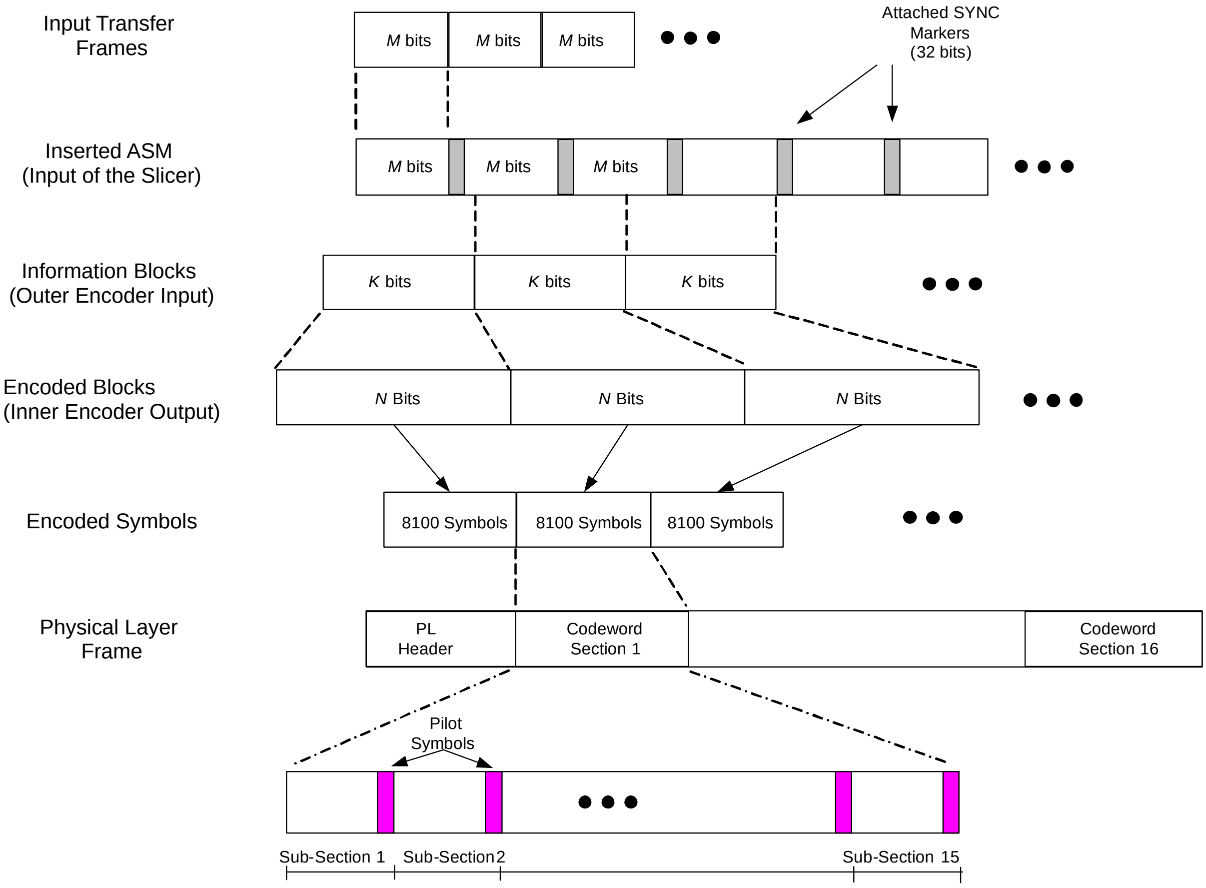



**Figure 2-2: Stream Format at Different Stages of Synchronization and Channel Coding**

# 3 MODE ADAPTATION

## 3.1 GENERAL

The mode adaptation unit provides the interface between the upstream units (data handling systems) and the on-board modulator. The input interface of this unit maps the input electrical format into a stream of logical bit format.

The data stream is passed through a pseudo-randomizer to ensure adequate bit transition density. In order to facilitate the frame synchronization at Data Link layer, a known sequence of bits, known as the Attached SYNC Marker (ASM), precedes each data Transfer Frame. The length of the ASM is fixed and the content is optimized to ensure a proper detection of the start of the Transfer Frame.

The Transfer Frame length at the input of the mode adaptation unit is predetermined. Neither the TM Space Data Link Protocol (reference [B4]) nor AOS Space Data Link Protocol (reference [B5]) specifies the Transfer Frame length. However, to maintain backward compatibility with the existing data link subsystems, the Transfer Frame length in bits (denoted as $M$ in figure 2-2) is selected from one of the following values, as previously proposed in reference [B3]:

– 1784 bits (=223 x 1 octets);

– 3568 bits (=223 x 2 octets);

– 7136 bits (=223 x 3 octets);

– 8920 bits (=223 x 5 octets);

– 16384 bits.

The information block size is adjusted according to the spectral efficiency mode. A sub-module denoted as ‘slicer’ in figure 2-1 performs the mapping of the input bits (from the transfer data frame and ASM) into information blocks.

**Mode Selection Mechanism**

Several approaches for adjusting the modulation and coding schemes can be envisaged. One approach relies on the signal quality estimation (or prediction) provided by the ground station through a feedback channel (e.g., Telecommand). Alternative approach is to pre-schedule the change of modulation and coding schemes for each satellite pass based on geometrical information (elevation angle).

The choice of modulation and coding is communicated to the Synchronization and Coding modules via the ‘ACM Command’ signal. Using this command, the input data along with the SYNC markers are mapped into information blocks with a proper size to be processed by the outer encoder. Other functions such as interleaving, puncturing and bit-to-symbol mapping will also be adjusted according to the selected ACM format.

## 3.2 BASEBAND PSEUDO-RANDOMIZER

In order to ensure a proper detection of Transfer Frames at the receiver, the data stream must be sufficiently random. A pseudo-randomizer, similar to that described in reference [B3] is considered.

The pseudo-random sequence is applied starting with the first bit of the Transfer Frame. The Transfer Frame is randomized by exclusive-ORing the first bit of the Transfer Frame with the first bit of the pseudo-random sequence, followed by the second bit of the Transfer Frame with the second bit of the pseudo-random sequence, and so on. The pseudo-randomizer is not applied to the ASM. The attached SYNC marker is used to synchronise the pseudo-randomizer (reference [B3]). Figure 3-1 illustrates the pseudo-randomizer configuration.

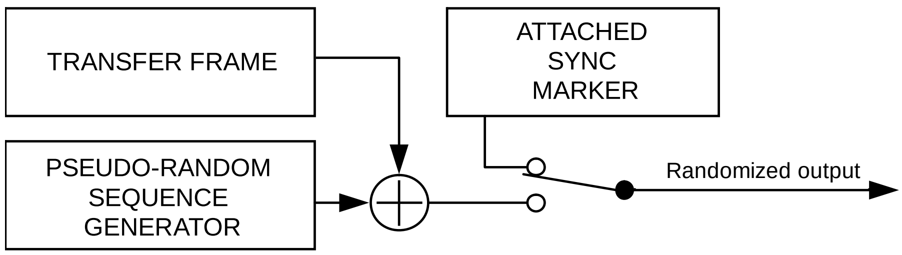



**Figure 3-1: Pseudo-Randomizer Configuration**

The pseudo-random sequence is generated using the following polynomial:

$$h(x) = x^8 + x^7 + x^5 + x^3 + 1 \quad (3\text{-}1)$$

This sequence begins at the first bit of the Transfer Frame and repeats after 255 bits, continuing repeatedly until the end of the Transfer Frame. The sequence generator is re-initialized to an all-ones state during each ASM period.

The first 40 bits of the pseudo-random sequence from the generator are shown below; the left-most bit is the first bit of the sequence to be exclusive-ORed with the first bit of the Transfer Frame; the second bit of the sequence is exclusive-ORed with the second bit of the Transfer Frame, and so on.

1111 1111 0100 1000 0000 1110 1100 0000 1001 1010 ....

The pseudo-random sequence is added (Modulo 2) to the input Transfer Frame starting from the first bit of the Transfer Frame. Figure 3-2 shows the logical diagram of the pseudo-random sequence generator.

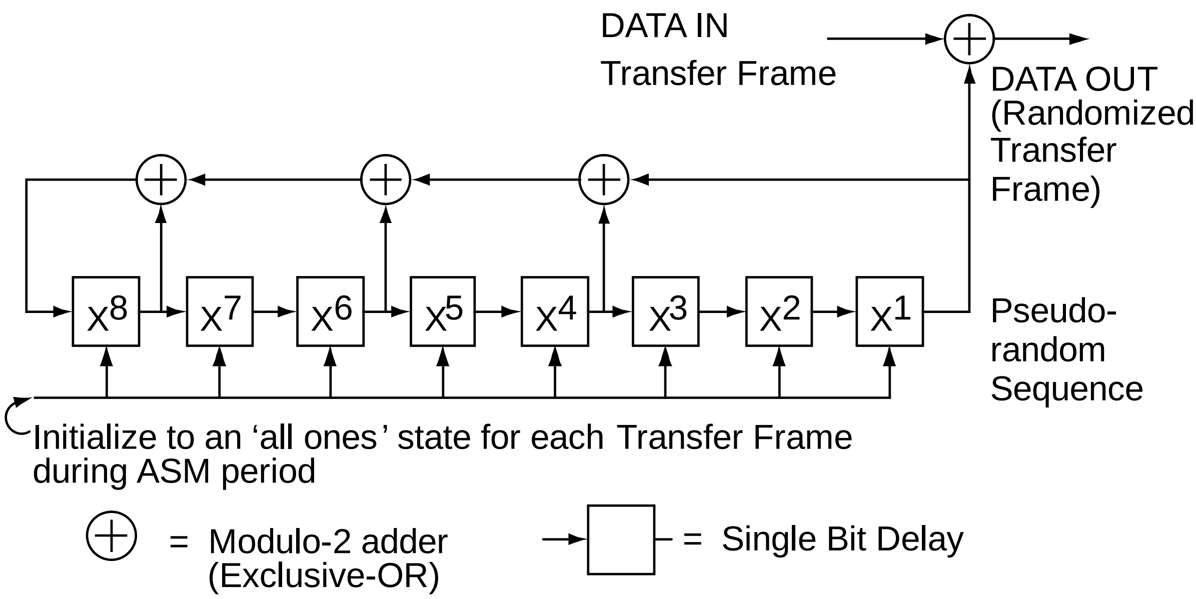



**Figure 3-2: Pseudo-Randomizer Logic Diagram**

## 3.3 ATTACHED SYNC MARKER

A 32-bit sequence of known bits is inserted between Transfer Frames in order to ensure frame synchronization at the receiver at the Data Link layer. The selected 32-bit ASM bit pattern in hexadecimal notation is shown in table 3-1 (similar to the 32-bit ASM pattern reported in reference [B3]).

**Table 3-1: ASM Marker**

| | |
|---|---|
| ASM length | 32 bits |
| ASM sequence (Hex) | 1ACFFC1D |

The same ASM length is used for all different Transfer Frames and all ACM formats. Since there are additional synchronization symbols at the Physical layer, the ASM sequence is mainly used to detect the start of the Transfer Frame. The ASM sequence is encoded along with the Transfer Frame. The probability of bit error in the ASM sequence at the nominal operating point is extremely low. Therefore, there is no need for a longer-than-32–bit ASM sequence for Data Link layer synchronization.

## 3.4 SLICER

The information block size at the input of SCCC encoder is determined based on the selected modulation and coding (ACM format). Prior to encoding of each information block, the input

Transfer Frames along with the attached SYNC markers are grouped into blocks of length *K*, corresponding to the information block size of the selected ACM format. No particular alignment between the Transfer Frame and the information blocks is considered. At the receiver side, the attached SYNC markers are used to reconstruct the Transfer Frames after decoding the information blocks.

The buffer size in the slicer should be dimensioned properly such that the switching between ACM formats is supported without insertion of a dummy frame or drop of any Transfer Frame. Table 3-2 summarizes the information block sizes of 27 selected ACM formats.

**Table 3-2: Information Block Sizes for Different ACM Formats**

| ACM Format | Information Block Size (bits) | ACM Format | Information Block Size (bits) |
|---|---|---|---|
| 1 | 5758 | 15 | 23518 |
| 2 | 6958 | 16 | 25918 |
| 3 | 8398 | 17 | 28318 |
| 4 | 9838 | 18 | 25918 |
| 5 | 11278 | 19 | 25318 |
| 6 | 13198 | 20 | 30958 |
| 7 | 11278 | 21 | 33358 |
| 8 | 13198 | 22 | 35998 |
| 9 | 14878 | 23 | 33358 |
| 10 | 17038 | 24 | 35998 |
| 11 | 19198 | 25 | 38638 |
| 12 | 21358 | 26 | 41038 |
| 13 | 19198 | 27 | 43678 |
| 14 | 21358 | | |

# 4 SCCC ENCODER DESCRIPTION

## 4.1 OVERVIEW

Figure 4-1 shows the block diagram of the SCCC encoder. As described in 3.4, the input bits to the encoder are mapped into frames of size *K*. The frame size is selected according to the specific modulation order and coding rate (ACM format) with the objective of maintaining a constant length for modulated symbols per frame. The length of modulation symbols per frame is set to 8100 symbols.

Each frame is first encoded by an outer convolutional encoder at rate 1/2 followed by a fixed puncturing scheme which sets the rate of the outer code to $r$=2/3. The resulting frame has $I$=3/2 ($K$+2) encoded bits. The terminating bits are included in order to drive the code trellis to the zero state.

The intermediate frame of systematic and parity bits is interleaved according to an ad-hoc permutation law. An inner convolutional encoder has a coding structure that is similar to that of the outer code. The puncturing rule determines the actual SCCC code rate.

The SCCC scheme provides performance results close to the theoretical bounds. Such performance is achieved even at high coding rate. The good performance at high coding rate is due to the special arrangement of the encoding and the puncturing at the SCCC output. The impact of this structure at the receiver is that the information exchange between the two Soft-Input Soft-Output (SISO) modules in the iterative decoder corresponds to the cascade of a true rate 2/3 encoder (the outer code) with a true rate 1/2 encoder (the inner code). Subsequently, the interleaver gain that is typically larger for a lower outer code rates is maintained even in the case of a heavy puncturing of the outer code. This is mainly the reason for the good performance of the scheme, in terms of error floor, even at very high code rates.

In the following sections, each block of the SCCC encoder is described in more details.

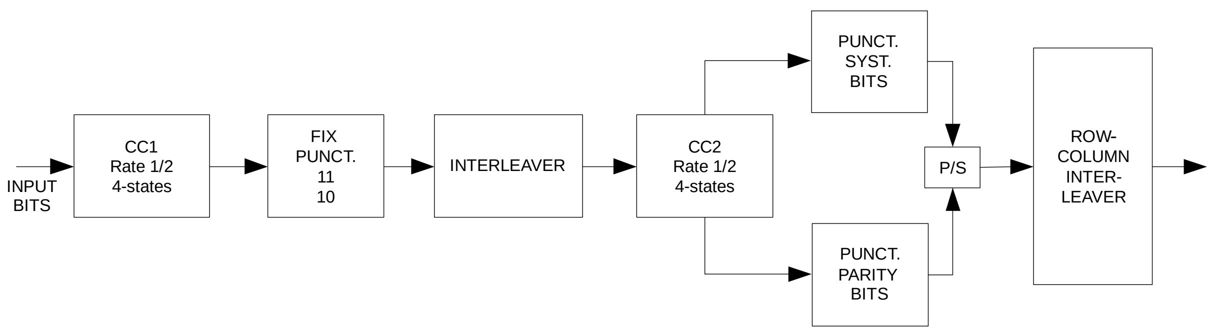



**Figure 4-1: Block Diagram of the SCC Turbo Coding Scheme**

## 4.2 CONVOLUTIONAL ENCODING

Both inner and outer convolutional encoders are based on the same four-state, rate 1/2 recursive, systematic encoder. The code structure is shown in figure 4-2.

For all SCCC rates the outer encoder is punctured to a rate 2/3 through the optimal puncturing scheme by maintaining all the systematic bits while decimating the parity bits by half, as shown in figure 4-3. The overall coding rate adjustment is carried out by puncturing the output bits of the inner code. A detailed description of the puncturing scheme is provided in 4.4.

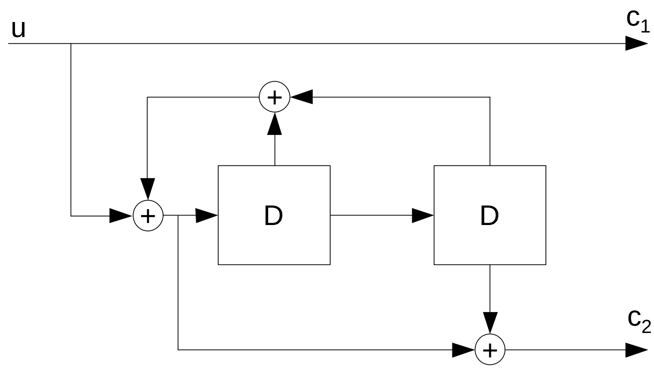



**Figure 4-2: The Convolutional Encoder Block Diagram for CC1 and CC2**

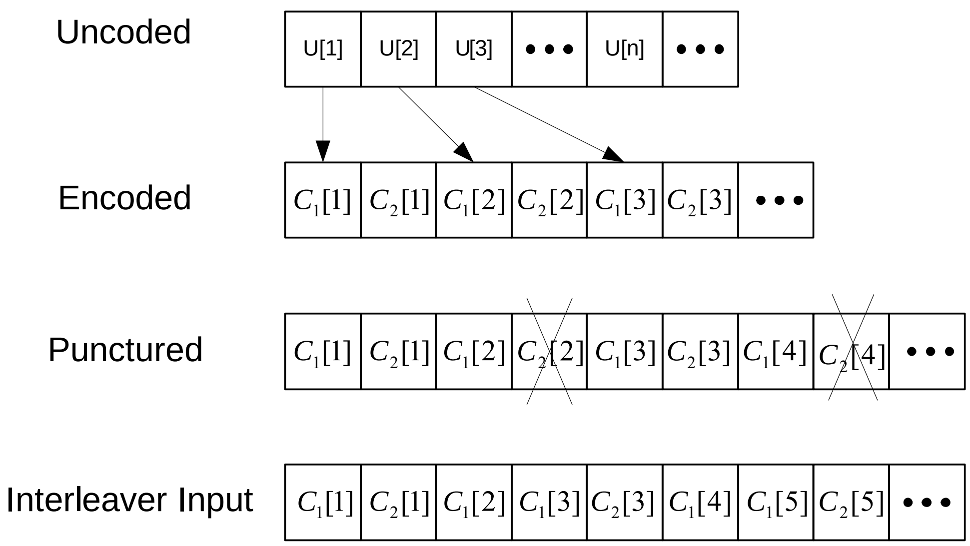



**Figure 4-3: Outer Code Puncturing Scheme**

## 4.3 INTERLEAVER

A proper selection of interleaver is a crucial part of the code design. The interleaver length *I* and the corresponding permutation law are selected according to the ACM format so as to keep the length of the frame after modulation mapping to a constant 8100 modulated symbols.

The interleaver is described by an ad-hoc permutation law which is reported in annex C. Table 4-1 lists interleaver sizes corresponding to different ACM formats. It is worth noting that for 27 selected ACM formats there are 19 different interleaver sizes.

**Table 4-1: Interleaver Sizes for Different ACM Formats**

| ACM Format | Interleaver Length (bits) | ACM Format | Interleaver Length (bits) |
|---|---|---|---|
| 1 | 8640 | 15 | 35280 |
| 2 | 10440 | 16 | 38880 |
| 3 | 12600 | 17 | 42480 |
| 4 | 14760 | 18 | 38880 |
| 5 | 16920 | 19 | 42480 |
| 6 | 19800 | 20 | 46440 |
| 7 | 16920 | 21 | 50040 |
| 8 | 19800 | 22 | 54000 |
| 9 | 22320 | 23 | 50040 |
| 10 | 25560 | 24 | 54000 |
| 11 | 28800 | 25 | 57960 |
| 12 | 32040 | 26 | 61560 |
| 13 | 28800 | 27 | 65520 |
| 14 | 32040 | | |

## 4.4 CODING RATE ADJUSTMENT

### 4.4.1 GENERAL

In order to obtain the desired coding rate, puncturing is performed at the output of the inner encoder. The upper register at the output of the inner encoder (as shown in figure 4-1) contains the inner systematic bits, which coincide with the interleaved outer codeword as well as two additional bits terminating the inner trellis. The lower register, instead, contains the $I$+2 parity-check bits generated by the inner encoder. Two different puncturing algorithms are used to puncture bits in the upper and lower registers, corresponding to the inner systematic and parity bits accordingly.

Puncturing in the upper register is performed on the $I$ inner systematic bits (excluding the two inner code terminating bits that are always transmitted) according to a periodic puncturing pattern. The puncturing period is based on 200 trellis steps, which corresponds to 300 outer coded bits.

It is worth noting that the systematic bits of the inner encoder correspond to the entire encoded bits generated by the outer encoder. The puncturing pattern of the systematic bits has been designed to maximise the free distance of the outer encoder, taking into account the impact of interleaving.

In practice, an exhaustive search for identifying optimal puncturing patterns is computationally infeasible. As a result, a suboptimal searching algorithm with manageable computation complexity has been devised. The penalty of using a sub-optimal puncturing pattern in the achievable performance is minimal. The search is performed incrementally, in a rate-compatible fashion, so that the punctured positions for a given rate are also punctured for all higher rates.

The optimisation of the upper register puncturing pattern involves both the number and the position of bits to be punctured. The outer code ‘equivalent’ rate, as seen from the SCCC output is approximated as:

$$R_o \approx \frac{200 \cdot n_p - 2}{S_{\mathrm{sur}} \cdot n_p + 2} \qquad (4\text{-}1)$$

where $S_{\mathrm{sur}}$ denotes the number of surviving bits in each 300-bit segment of the upper register after puncturing, and $n_p$ is the number of puncturing segments in the interleaver, i.e., $n_p=I/300$.

Since $n_p$ is not in general an integer number, the exact number $S$ of transmitted systematic bits depends not only on the parameter $S_{\mathrm{sur}}$ but also on the interleaver size and on the puncturing pattern. The last two terminating bits of the inner encoder are always transmitted.

### 4.4.2 PUNCTURING SYSTEMATIC BITS

The design procedure for the outer code puncturing yielding outer code rates in the whole range $200/300 \leq R_o \leq 200/201$ can be described as follows:

1) Loop on all successive puncturing positions $i$=1,…,99 leading to a number of surviving systematic bits, out of 300, $S_{sur}$=300-$i$.
2) Loop on all $S_{sur}$ remaining positions $j$ that can be punctured in order to increase the outer code rate.
3) Set the new candidate position to $j$.
4) Compute the Weight-Enumerating Function (WEF) $A(d)$ of the outer encoder.
5) Save the position $j$ and its WEF if it is better than the previous one. The position is ‘better’ if it has orderly small coefficients $A(1)$, $A(2)$,…up to $A(8)$.
6) Consider the next candidate position.
7) Store the best position.
8) Next rate 200/ $S_{sur}$.

The search results for the optimal puncturing positions are reported in table 4-2. For each index $i$ and parameter $S_{sur}$, the corresponding outer code rate (obtained by puncturing the bit in the position reported in the same row and all preceding ones) is given. From the implementation complexity point of view, the storage of the optimal puncturing pattern simply requires storing of the 100 puncturing positions reported in column 4 and 8 of table 4-2.

## Table 4-2: Best Incremental Puncturing Positions

| Index | $S_{sur}$ | Rate | Punct. Pos. | Index | $S_{sur}$ | Rate | Punct. Pos. |
|---|---|---|---|---|---|---|---|
| 1 | 299 | 0.6689 | **76** | 51 | 249 | 0.8032 | **72** |
| 2 | 298 | 0.6711 | **1** | 52 | 248 | 0.8065 | **15** |
| 3 | 297 | 0.6734 | **145** | 53 | 247 | 0.8097 | **297** |
| 4 | 296 | 0.6757 | **214** | 54 | 246 | 0.8130 | **210** |
| 5 | 295 | 0.6780 | **256** | 55 | 245 | 0.8163 | **138** |
| 6 | 294 | 0.6803 | **37** | 56 | 244 | 0.8197 | **102** |
| 7 | 293 | 0.6826 | **109** | 57 | 243 | 0.8230 | **174** |
| 8 | 292 | 0.6849 | **181** | 58 | 242 | 0.8264 | **39** |
| 9 | 291 | 0.6873 | **277** | 59 | 241 | 0.8299 | **249** |
| 10 | 290 | 0.6897 | **235** | 60 | 240 | 0.8333 | **57** |
| 11 | 289 | 0.6920 | **55** | 61 | 239 | 0.8368 | **120** |
| 12 | 288 | 0.6944 | **127** | 62 | 238 | 0.8403 | **156** |
| 13 | 287 | 0.6969 | **163** | 63 | 237 | 0.8439 | **84** |
| 14 | 286 | 0.6993 | **19** | 64 | 236 | 0.8475 | **228** |
| 15 | 285 | 0.7018 | **199** | 65 | 235 | 0.8511 | **192** |
| 16 | 284 | 0.7042 | **91** | 66 | 234 | 0.8547 | **282** |
| 17 | 283 | 0.7067 | **289** | 67 | 233 | 0.8584 | **261** |
| 18 | 282 | 0.7092 | **244** | 68 | 232 | 0.8621 | **24** |
| 19 | 281 | 0.7117 | **64** | 69 | 231 | 0.8658 | **237** |
| 20 | 280 | 0.7143 | **268** | 70 | 230 | 0.8696 | **60** |
| 21 | 279 | 0.7168 | **223** | 71 | 229 | 0.8734 | **201** |
| 22 | 278 | 0.7194 | **136** | 72 | 228 | 0.8772 | **294** |
| 23 | 277 | 0.7220 | **172** | 73 | 227 | 0.8811 | **132** |
| 24 | 276 | 0.7246 | **28** | 74 | 226 | 0.8850 | **96** |
| 25 | 275 | 0.7273 | **100** | 75 | 225 | 0.8889 | **159** |
| 26 | 274 | 0.7299 | **190** | 76 | 224 | 0.8929 | **33** |
| 27 | 273 | 0.7326 | **10** | 77 | 223 | 0.8969 | **264** |
| 28 | 272 | 0.7353 | **46** | 78 | 222 | 0.9009 | **114** |
| 29 | 271 | 0.7380 | **118** | 79 | 221 | 0.9050 | **177** |
| 30 | 270 | 0.7407 | **154** | 80 | 220 | 0.9091 | **225** |
| 31 | 269 | 0.7435 | **81** | 81 | 219 | 0.9132 | **78** |
| 32 | 268 | 0.7463 | **207** | 82 | 218 | 0.9174 | **12** |
| 33 | 267 | 0.7491 | **259** | 83 | 217 | 0.9217 | **150** |
| 34 | 266 | 0.7519 | **292** | 84 | 216 | 0.9259 | **51** |
| 35 | 265 | 0.7547 | **232** | 85 | 215 | 0.9302 | **273** |
| 36 | 264 | 0.7576 | **67** | 86 | 214 | 0.9346 | **204** |
| 37 | 263 | 0.7605 | **280** | 87 | 213 | 0.9390 | **105** |
| 38 | 262 | 0.7634 | **247** | 88 | 212 | 0.9434 | **3** |
| 39 | 261 | 0.7663 | **147** | 89 | 211 | 0.9479 | **240** |
| 40 | 260 | 0.7692 | **30** | 90 | 210 | 0.9524 | **168** |
| 41 | 259 | 0.7722 | **111** | 91 | 209 | 0.9569 | **69** |
| 42 | 258 | 0.7752 | **183** | 92 | 208 | 0.9615 | **123** |
| 43 | 257 | 0.7782 | **6** | 93 | 207 | 0.9662 | **21** |
| 44 | 256 | 0.7813 | **48** | 94 | 206 | 0.9709 | **216** |
| 45 | 255 | 0.7843 | **93** | 95 | 205 | 0.9756 | **285** |
| 46 | 254 | 0.7874 | **165** | 96 | 204 | 0.9804 | **141** |
| 47 | 253 | 0.7905 | **129** | 97 | 203 | 0.9852 | **252** |
| 48 | 252 | 0.7937 | **219** | 98 | 202 | 0.9901 | **186** |
| 49 | 251 | 0.7968 | **195** | 99 | 201 | 0.9950 | **205** |
| 50 | 250 | 0.8000 | **270** | 100 | 200 | 1.0000 | **36** |

### 4.4.3 PUNCTURING PARITY BITS

#### 4.4.3.1 General

Puncturing positions of the lower register, corresponding to the $I$+2 parity-check bits generated by the inner encoder, are determined using a rate-matching algorithm. This algorithm is described in detail in 4.4.3.2.

The puncturing of parity bits results in deleting a set of equally spaced bits. The number of deleted parity bits is determined based on the rate matching parameter $\Delta/I$, representing the ratio between the number of deleted parity bits $\Delta$ and the overall number of parity bits $I$ before puncturing:

$$\Delta = I - (P - 2) \tag{4-2}$$

where $P=N-S$ is the total number of transmitted parity check bits. It should be noted that the last two terminating parity check bits are always transmitted.

Some care must be taken in the choice of the parameter $\Delta$, as explained below. The combination of the four-state trellis structure of the outer encoder and the fixed puncturing pattern of rate 2/3 outer code results in a periodic encoder impulse response with a period of three bits.[1] If the parameter $\Delta$ is chosen such that the distance between two consecutive deleted parity bits is an integer multiple of three, the performance of the code will be degraded catastrophically. In fact, in this case there exist input sequences with weight 1 that will generate output sequences with weight 2. In other words, the inner encoder behaves as a feed-forward code, and the advantages of the recursive encoder structure disappear.

#### 4.4.3.2 Rate Matching Algorithm

Given the two parameters $\Delta$ (number of bits to be deleted) and $I$ (total number of bits), the rate-matching algorithm can be described using the following procedure:

1) Set the variable $e$=1.
2) For all possible positions $i$ from 0 to $I$-1:
    a) if $e$>0 transmit the $i^{th}$ bit, else set $e=e+I$,
    b) set $e=e-\Delta$;
3) Continue.

It should be noted that the last two terminating bits are always transmitted.

---

[1] The encoder impulse response is defined as the code sequence corresponding to a weight-1 input information sequence.

For each SCCC overall coding rate the optimisation of the coding scheme requires determining the parameter $S_{sur}$ and the positions of the upper register punctured bits as reported in table 4-2. This first step is achieved via a mixed heuristic-simulation approach.

In each case, the value of $S_{sur}$ determines the overall number of transmitted systematic bits $S$ and, subsequently, the number of transmitted parity check bits $P$ and the parameter $\Delta$ used by the rate-matching algorithm.

The optimisation campaign has been carried out for a set of desired SCCC rates. Table 4-3 shows required parameters that describe the encoder for 27 selected ACM formats.

**Table 4-3: Main Encoder Parameters for 27 Selected ACM Formats**

| ACM format | $m$ | $S_{sur}$ | $K$ | $I$ | $S$ | $P$ | $N$ | $\Delta$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 300 | 5758 | 8640 | 8642 | 7558 | 16200 | 1084 |
| 2 | 2 | 300 | 6958 | 10440 | 10442 | 5758 | 16200 | 4684 |
| 3 | 2 | 274 | 8398 | 12600 | 11510 | 4690 | 16200 | 7912 |
| 4 | 2 | 251 | 9838 | 14760 | 12351 | 3849 | 16200 | 10913 |
| 5 | 2 | 234 | 11278 | 16920 | 13200 | 3000 | 16200 | 13922 |
| 6 | 2 | 218 | 13198 | 19800 | 14390 | 1810 | 16200 | 17992 |
| 7 | 3 | 292 | 11278 | 16920 | 16470 | 7830 | 24300 | 9092 |
| 8 | 3 | 240 | 13198 | 19800 | 15842 | 8458 | 24300 | 11344 |
| 9 | 3 | 250 | 14878 | 22320 | 18602 | 5698 | 24300 | 16624 |
| 10 | 3 | 234 | 17038 | 25560 | 19939 | 4361 | 24300 | 21201 |
| 11 | 3 | 221 | 19198 | 28800 | 21218 | 3082 | 24300 | 25720 |
| 12 | 3 | 214 | 21358 | 32040 | 22857 | 1443 | 24300 | 30599 |
| 13 | 4 | 255 | 19198 | 28800 | 24482 | 7918 | 32400 | 20884 |
| 14 | 4 | 241 | 21358 | 32040 | 25741 | 6659 | 32400 | 25383 |
| 15 | 4 | 230 | 23518 | 35280 | 27051 | 5349 | 32400 | 29933 |
| 16 | 4 | 220 | 25918 | 38880 | 28515 | 3885 | 32400 | 34997 |
| 17 | 4 | 211 | 28318 | 42480 | 29880 | 2520 | 32400 | 39962 |
| 18 | 5 | 245 | 25918 | 38880 | 31755 | 8745 | 40500 | 30137 |
| 19 | 5 | 234 | 28318 | 42480 | 33137 | 7363 | 40500 | 35119 |
| 20 | 5 | 224 | 30958 | 46440 | 34677 | 5823 | 40500 | 40619 |
| 21 | 5 | 217 | 33358 | 50040 | 36197 | 4303 | 40500 | 45739 |
| 22 | 5 | 210 | 35998 | 54000 | 37802 | 2698 | 40500 | 51304 |
| 23 | 6 | 236 | 33358 | 50040 | 39366 | 9234 | 48600 | 40808 |
| 24 | 6 | 228 | 35998 | 54000 | 41042 | 7558 | 48600 | 46444 |
| 25 | 6 | 220 | 38638 | 57960 | 42507 | 6093 | 48600 | 51869 |
| 26 | 6 | 214 | 41038 | 61560 | 43915 | 4685 | 48600 | 56877 |
| 27 | 6 | 208 | 43678 | 65520 | 45429 | 3171 | 48600 | 62351 |

## 4.5 ROW-COLUMN INTERLEAVER

Prior to the bit-to-symbol mapping at the transmitter, a row-column interleaver is used to pseudo-randomize the selection of bits that are assigned to one modulation symbol. This is to ensure that the correlation between bits assigned to one symbol does not adversely affect the decoding process. This technique is known as Bit Interleaved Coded Modulation (BICM), as introduced in reference [B8].

Figure 4-4 illustrates the bit-interleaving scheme. The interleaver depth (number of rows) is equal to the size of one codeword section (i.e., 8100 symbols) and the number of columns is equal to $m$, where $m$ is the modulation order.

The maximum memory size to implement the bit-interleaver is $m\times8100 = 6\times8100 = 48600$ locations, each containing one bit, for the 64 APSK modulation scheme. The memory can be seen as a matrix composed of *m* columns and 8100 rows. The number of rows is independent of the code rate and modulation scheme.

To implement the pragmatic code permutation, the output of the inner encoder, after puncturing, is bit interleaved using the block interleaving shown in figure 4-4. The input data is serially written into the interleaving column-wise and serially read out row-wise (the most significant bit is read out first).

Systematic bits (corresponding to the upper branch of the inner convolutional encoder) are first written sequentially in the register followed by the parity check bits (corresponding to the lower branch of the convolutional encoder). As a results of this scheduling, the systematic bits are mapped into the most significant bits and parity check bits to the least significant bits of the labels of the modulation symbols. The choice of modulation mapping, as described in 4.6, guarantees a higher protection for systematic bits.

The bit interleaving structure has 8100 rows, independent of the ACM format, and *m* columns where *m* is the modulation efficiency. The first symbol carries the bits positioned at index 0, 8100, 16200, 24300, 32400, 40500, 48600, for 64 APSK for instance. The second symbol carries bits at position 1, 8101, 16201, 24301, 32401, 40501, 48601 and so on up to the last symbol (carrying bits 8099, 16199, 24299, 32399, 40499, 48599).

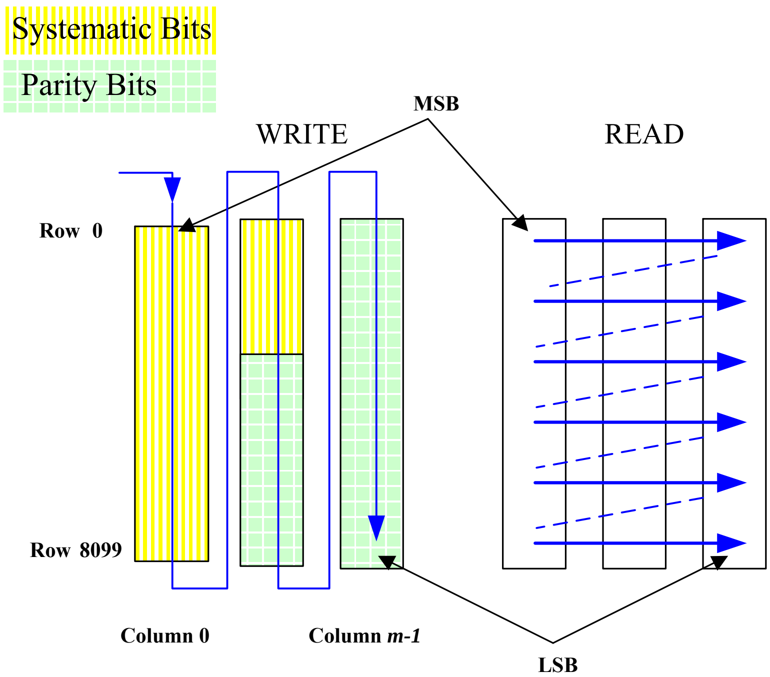



**Figure 4-4: Row-Column Bit-Interleaving Scheme**

## 4.6 BIT-TO-CONSTELLATION MAPPING

Figure 4-5 shows the selected modulation constellations along with the associated bits-to-symbols mapping laws (reference [B7]).

**PSK Modulations**

**QPSK** A conventional Gray-Coded QPSK modulation with absolute mapping (no differential coding) is considered. The normalized average energy per symbol is equal to one (Radius=1).

**8PSK** A conventional Gray-Coded 8PSK modulation with absolute mapping (no differential coding) is considered. The normalized average energy per symbol is equal to one (Radius=1).

**APSK Modulations**

The ratios between the radii of APSK constellations are denoted as $\gamma_1 = R_2/R_1$, $\gamma_2 = R_3/R_1$ and $\gamma_3 = R_4/R_1$. Figure 4-5 illustrates the bit-to-symbol mapping for APSK modulation schemes.

**16APSK**: This constellation is composed of two concentric circumferences, whose number of points is set to $N_1 = 4$ and $N_2 = 12$. Optimal values of $\gamma_1$ for 16APSK modulation schemes and linear channels are reported in table 4-4. Two possibilities for the normalization of modulated symbol are considered:

– the average signal energy is set to one: $[R_1]^2 + 3\ [R_2]^2 = 4$;

– the radius of the outer constellation circle is set to one: $R_2=1$.

**32APSK**: This constellation is composed of three concentric circumferences whose number of points is set to $N_1 = 4$, $N_2 = 12$ and $N_3 = 16$. Optimal values of $\gamma_1$ and $\gamma_2$ for 32APSK modulation schemes are reported in table 4-4. Two possibilities for the normalization of modulated symbol are considered:

– the average signal energy is set to one: $[R_1]^2 + 3\ [R_2]^2 + 4\ [R_3]^2 = 8$;

– the radius of the outer constellation circle is set to one: $R_3=1$.

**64APSK**: This constellation is composed of four concentric circumferences, whose number of points is set to $N_1 = 4$, $N_2 = 12$, $N_3 = 20$ and $N_4 = 28$. For 64APSK modulation schemes, a set of parameters that maximize the minimum Euclidean distance are as follows: $\gamma_1 = 2.73$, $\gamma_2 = 4.52$ and $\gamma_3 = 6.31$. Further optimization of these parameters can be achieved by using similar methods reported in reference [B6] for linear and non-linear channels.

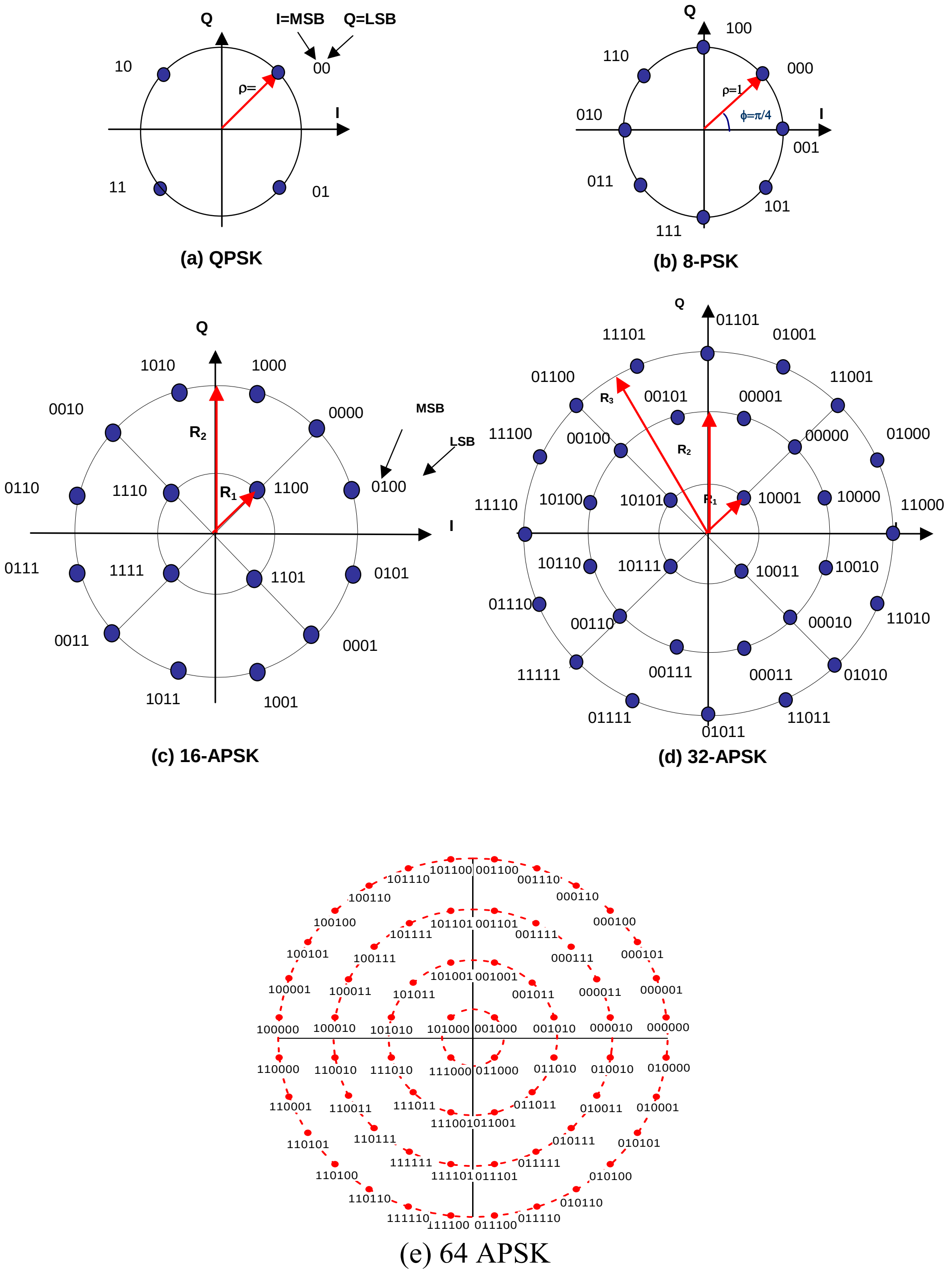
Two possibilities for the normalization of modulated symbol are considered:

– the average signal energy is set to one, $4[R_1]^2 + 12\,[R_2]^2 + 20\,[R_3]^2 + 28\,[R_4]^2 = 64$;

– the radius of the outer constellation circle is set to one: $R_4$=1.

**Table 4-4: Optimum Constellation Radius Ratios for 16APSK and 32APSK**

| ACM Format | Modulation | Coding Rate | $\gamma_1$ | $\gamma_2$ |
|---|---|---|---|---|
| 13 | 16-APSK | 0.5925 | 3.82 | N/A |
| 14 | 16-APSK | 0.6592 | 3.20 | N/A |
| 15 | 16-APSK | 0.7259 | 2.95 | N/A |
| 16 | 16-APSK | 0.7999 | 2.75 | N/A |
| 17 | 16-APSK | 0.8740 | 2.60 | N/A |
| 18 | 32-APSK | 0.6400 | 3.00 | 5.91 |
| 19 | 32-APSK | 0.6992 | 2.95 | 5.65 |
| 20 | 32-APSK | 0.7644 | 2.82 | 5.20 |
| 21 | 32-APSK | 0.8237 | 2.65 | 4.67 |
| 22 | 32-APSK | 0.8888 | 2.55 | 4.34 |




# Figure 4-5: Bit Mapping into Constellations

## 4.7 SPECTRAL EFFICIENCY AND SUPPORTED SET OF ACM FORMATS

Table 4-5 presents a set of supported coding and modulation schemes (ACM formats) and related parameters. The rationale for selecting the set of ACM formats is highlighted below:

– The operating $E_s/N_0$ of selected formats covers steps of roughly one dB.

– The maximum coding rate is set to $R_c$=9/10.

– The maximum spectral efficiency is 5.4, corresponding to coding rate $r$=9/10 and 64-APSK modulation.

– The spectral efficiency from the unconstrained capacity formula for complex signals is given as:

$$\eta = \log_2\left(1+\frac{E_s}{N_0}\right) \qquad (4\text{-}3)$$

Considering the maximum coding rate and equation 4-1, the modulation order can be determined as:

$$m = \left\lceil \frac{10}{9}\eta \right\rceil \qquad (4\text{-}4)$$

– The number of *modulation symbols* in each codeword section is set to 8100 and imposed by the framing structure (this constraint simplifies frame synchronization significantly). This leads to a variable number of encoded bits $N$.

– A fixed size for the codeword section imposes constraints on the selection of nominal values of the SCCC encoder parameters (the information block size $K$, the interleaver length $I$, and the codeword size $N$).

– Constraints imposed on the interleaver length that depend on the architecture and degree of parallelism cause a slight change in the selected size of the interleaver $I$ (to be become $I'$ as shown in table 4-5). Subsequently, the information block size $K$, the spectral efficiency and the theoretical $E_s/N_0$ (based on the capacity expression) change slightly as well. The resulting $E_s/N_0$ step is reported in the last column of table 4-5.

This approach defines the main 19 ACM formats in table 4-5, reported with regular font. The two highest spectral efficiencies for each modulation scheme have also been included with the modulation scheme with higher cardinality. This overlap is necessary since the coded-modulator performance can be different depending on the channel impairments.

In summary, a total of 27 ACM formats are supported, providing about 20 dB range in the required $E_s/N_0$ for the link budget. The expressions used in each column of table 4-5 are described below:

– eta: nominal spectral efficiency yielding the desired SNR according to the unconstrained capacity formula;

– $K$: nominal information block size;

– $I$: nominal interleaver length;

– $N$: number of encoded bits;

– $m$: modulation efficiency (defined as $\log_2$ of the modulator cardinality);

– $E_s/N_0$: nominal signal-to-noise ratio thresholds derived from unconstrained Shannon Capacity Bound and nominal spectral efficiency eta (η):

$$\frac{E_s}{N_0} = 10 \log_{10}(2^{\eta} - 1) \qquad (4\text{-}5)$$

– *code rate*: overall rate of the code ($K/N$);

– $K'$: Information block size obtained applying the constraints on the interleaver block size that derives from parallelism.

– $I'$: Interleaver size applying the constraints that derive from required parallelism.

– eta′ : actual spectral efficiency, applying the constraints on the interleaver block size that derive from parallelism.

– $E_s/N_0'$: signal-to-noise ratio thresholds derived from the capacity bound by applying the constraints on the interleaver block size due to parallelism.

$$\left(\frac{E_s}{N_0}\right)' = 10 \log_{10}(2^{\eta'} - 1) \qquad (4\text{-}6)$$

– *delta*: actual signal-to-noise ratio step.

## Table 4-5: ACM Formats of the SCCC Encoder

| | Nominal values | | | | | | | | Interleaver constrained | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Es/N0 | eta | K | I | N | m | Code Rate | K' | I' | eta' | Es/N0' | delta |
| QPSK | 1 | -1.85 | 0.7254 | 5,876 | 8,816 | 16,200 | 2 | 0.36 | 5,758 | 8,640 | 0.7109 | -1.96 | |
| | 2 | -0.85 | 0.8659 | 7,014 | 10,523 | 16,200 | 2 | 0.43 | 6,958 | 10,440 | 0.8590 | -0.89 | 1.07 |
| | 3 | 0.15 | 1.0254 | 8,306 | 12,461 | 16,200 | 2 | 0.51 | 8,398 | 12,600 | 1.0368 | 0.22 | 1.11 |
| | 4 | 1.15 | 1.2039 | 9,752 | 14,630 | 16,200 | 2 | 0.60 | 9,838 | 14,760 | 1.2146 | 1.21 | 0.99 |
| | 5 | 2.15 | 1.4012 | 11,350 | 17,027 | 16,200 | 2 | 0.70 | 11,278 | 16,920 | 1.3923 | 2.11 | 0.90 |
| | 6 | 3.15 | 1.6164 | 13,092 | 19,640 | 16,200 | 2 | 0.81 | 13,198 | 19,800 | 1.6294 | 3.21 | 1.10 |
| 8PSK | 7 | 2.15 | 1.4012 | 11,350 | 17,027 | 24,300 | 3 | 0.47 | 11,278 | 16,920 | 1.3923 | 2.11 | -1.10 |
| | 8 | 3.15 | 1.6164 | 13,092 | 19,640 | 24,300 | 3 | 0.54 | 13,198 | 19,800 | 1.6294 | 3.21 | 1.10 |
| | 9 | 4.15 | 1.8484 | 14,972 | 22,460 | 24,300 | 3 | 0.62 | 14,878 | 22,320 | 1.8368 | 4.10 | 0.89 |
| | 10 | 5.15 | 2.0958 | 16,976 | 25,466 | 24,300 | 3 | 0.70 | 17,038 | 25,560 | 2.1035 | 5.18 | 1.08 |
| | 11 | 6.15 | 2.3568 | 19,090 | 28,637 | 24,300 | 3 | 0.79 | 19,198 | 28,800 | 2.3701 | 6.20 | 1.02 |
| | 12 | 7.15 | 2.6299 | 21,302 | 31,955 | 24,300 | 3 | 0.88 | 21,358 | 32,040 | 2.6368 | 7.18 | 0.98 |
| 16APSK | 13 | 6.15 | 2.3568 | 19,090 | 28,637 | 32,400 | 4 | 0.59 | 19,198 | 28,800 | 2.3701 | 6.20 | -0.98 |
| | 14 | 7.15 | 2.6299 | 21,302 | 31,955 | 32,400 | 4 | 0.66 | 21,358 | 32,040 | 2.6368 | 7.18 | 0.98 |
| | 15 | 8.15 | 2.9133 | 23,598 | 35,399 | 32,400 | 4 | 0.73 | 23,518 | 35,280 | 2.9035 | 8.12 | 0.94 |
| | 16 | 9.15 | 3.2056 | 25,966 | 38,951 | 32,400 | 4 | 0.80 | 25,918 | 38,880 | 3.1998 | 9.13 | 1.01 |
| | 17 | 10.15 | 3.5053 | 28,392 | 42,590 | 32,400 | 4 | 0.88 | 28,318 | 42,480 | 3.4960 | 10.12 | 0.99 |
| 32APSK | 18 | 9.15 | 3.2056 | 25,966 | 38,951 | 40,500 | 5 | 0.64 | 25,918 | 38,880 | 3.1998 | 9.13 | -0.99 |
| | 19 | 10.15 | 3.5053 | 28,392 | 42,590 | 40,500 | 5 | 0.70 | 28,318 | 42,480 | 3.4960 | 10.12 | 0.99 |
| | 20 | 11.15 | 3.8111 | 30,870 | 46,307 | 40,500 | 5 | 0.76 | 30,958 | 46,440 | 3.8220 | 11.19 | 1.07 |
| | 21 | 12.15 | 4.1220 | 33,388 | 50,084 | 40,500 | 5 | 0.82 | 33,358 | 50,040 | 4.1183 | 12.14 | 0.95 |
| | 22 | 13.15 | 4.4370 | 35,940 | 53,912 | 40,500 | 5 | 0.89 | 35,998 | 54,000 | 4.4442 | 13.17 | 1.03 |
| 64APSK | 23 | 12.15 | 4.1220 | 33,388 | 50,084 | 48,600 | 6 | 0.69 | 33,358 | 50,040 | 4.1183 | 12.14 | -1.03 |
| | 24 | 13.15 | 4.4370 | 35,940 | 53,912 | 48,600 | 6 | 0.74 | 35,998 | 54,000 | 4.4442 | 13.17 | 1.03 |
| | 25 | 14.15 | 4.7555 | 38,520 | 57,782 | 48,600 | 6 | 0.79 | 38,638 | 57,960 | 4.7701 | 14.20 | 1.02 |
| | 26 | 15.15 | 5.0766 | 41,120 | 61,682 | 48,600 | 6 | 0.85 | 41,038 | 61,560 | 5.0664 | 15.12 | 0.92 |
| | 27 | 16.15 | 5.4000 | 43,740 | 65,612 | 48,600 | 6 | 0.90 | 43,678 | 65,520 | 5.3923 | 16.13 | 1.01 |

# 5 PHYSICAL LAYER FRAMING

Figure 5-1 illustrates the Physical layer frame structure that consists of the following segments:

– Frame Header which consists of two fields:

  - Frame Marker: 256 known symbols used for start of frame detection and synchronization;

  - Frame Descriptor: 64 symbols carrying 7 bits of information to identify the ACM format used per each physical frame as well as the presence or absence of pilot symbols;

– Codeword Sections: 16 sections of modulation symbols (with additional pilot symbols as option).

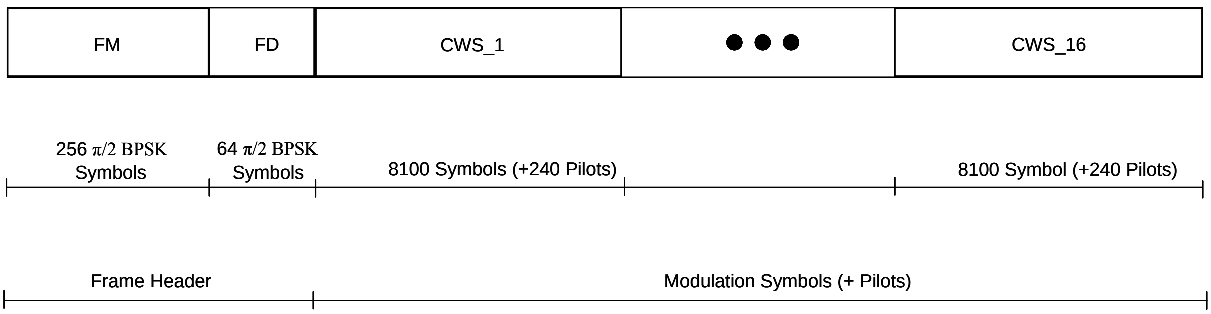



**Figure 5-1: Physical Layer Frame Structure**

## 5.1 FRAME MARKER

The Frame Marker consists of 256 known bits mapped into 256 π/2-BPSK modulated symbols. The Frame Marker is used for detecting the start of the frame as well as initial timing and coarse carrier synchronization. The length and the modulating bit sequence of the Frame Marker are selected such that the start of frame can be detected with a low probability of detection error (misdetection as well as false alarm) in the presence of severe channel impairments.

The bit pattern used in the Frame Marker is generated using a Gold sequence. Figure 5-2 shows the logical block diagram of the proposed sequence generator using shift registers and exclusive-OR operators. The generator polynomials used for the feedback loop are:

$$g_1(x) = x^8 + x^6 + x^5 + x^4 + 1$$
$$g_2(x) = x^8 + x^6 + x^5 + x^4 + x^3 + x + 1 \quad (5\text{-}1)$$

The upper and the lower shift registers are initialized as shown in figure 5-2. The first 40 bits of the Frame Marker sequence for the generator are shown below. The left-most bit corresponds to the first modulating bit of the Frame Marker:

```
1111 1011 0100 0100 0001 1111 0001 1101 1011 1101 …
```

The mapping of the Frame Marker sequence into π/2-BPSK symbols is described in the next section.

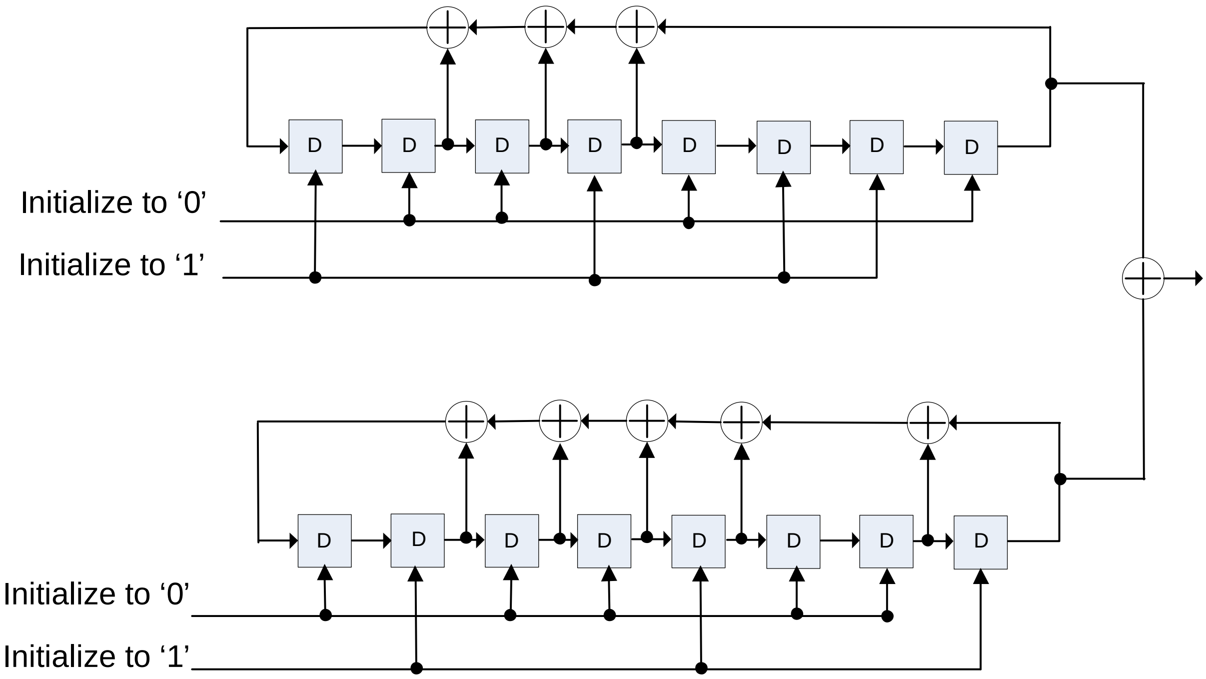



**Figure 5-2: Frame Marker Sequence Generator**

## 5.2 FRAME DESCRIPTOR STRUCTURE

### 5.2.1 GENERAL

The Frame Descriptor carries seven bits of information. These bits identify the ACM format of codeword sections within a PL frame (five bits) as well as the absence or presence of distrusted pilots.

Information bits in the Frame Descriptor are encoded using a non-symmetric binary code of length 64 and dimension 7 with minimum distance $d_{min}$=32. The code is similar to that used in reference [B2] for Physical layer signalling. The content of the Frame Descriptor is shown in table 5-1.

**Table 5-1: Frame Descriptor Information Content**

| Bit Number | Content |
|---|---|
| $b_1$-$b_5$ | ACM Formats (Decimal values 1 to 27 are used) |
| $b_6$ | Distributed Pilot On (=1) / Off (=0) |
| $b_7$ | Reserved (Default =0) |

The code is constructed using a bi-orthogonal (32,6) code and extended as shown in figure 5-3.

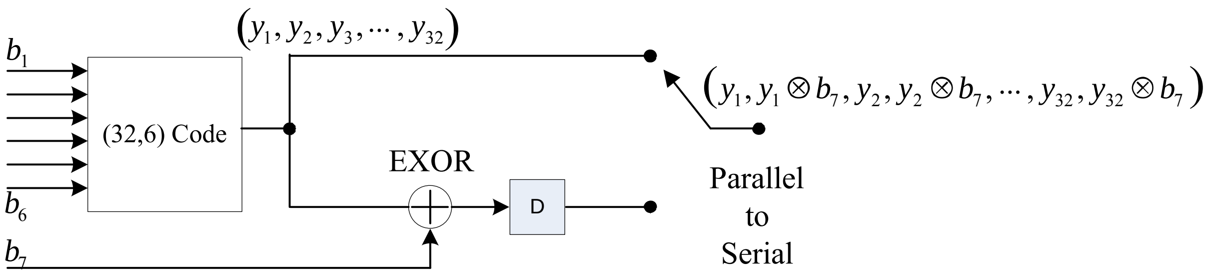



**Figure 5-3: Frame Descriptor Code Structure**

The first six bits, $b_1$-$b_6$, are encoded using a linear block code of length 32 with the following generator matrix:

$$G = \begin{bmatrix} 01010101010101010101010101010101 \\ 00110011001100110011001100110011 \\ 00001111000011110000111100001111 \\ 00000000111111110000000011111111 \\ 00000000000000001111111111111111 \\ 11111111111111111111111111111111 \end{bmatrix}$$

**Figure 5-4: Generator Matrix for (32,6) Code**

The most significant bit is multiplied with the first row of the matrix, the following bit with the second row, and so on. The 32 coded bits is denoted as ($y1$ $y2$ … $y32$). By default, the least significant bit of the Frame Descriptor is 0 and the final output is ($y1$ $y1$ $y2$ $y2$… $y32$ $y32$); i.e., each symbol shall be repeated. The 64-bit output code is further scrambled by the following binary sequence:

0111000110011101100000111100100101010011010000100010110111111010.

### 5.2.2 FRAME HEADER MODULATION

The frame header, which consists of the Frame Marker (256 bits) and Frame Descriptor (64 bits), is modulated into 320 π/2-BPSK symbols with the following mapping (similar to that of PL Header in reference [B2]).

Assuming that the Frame Header binary sequence is denoted as ($x_1\ x_2\ \ldots\ x_{320}$), the In-phase ($I$) and Quadrature ($Q$) components of 320 π/2-BPSK modulated symbols are determined according the following rule:

$$\begin{aligned} I_{2i-1} &= Q_{2i-1} = \frac{1}{\sqrt{2}}(1-2x_{2i-1}) \\ I_{2i} &= -Q_{2i} = \frac{-1}{\sqrt{2}}(1-2x_{2i}) \end{aligned} \quad \text{for } i = 1,2,\ldots,320 \qquad (5\text{-}2)$$

## 5.3 PILOTS INSERTION

The use of distributed pilot symbols in codeword sections is considered to be an option to facilitate carrier and phase synchronization.

Figure 5-5 illustrates the proposed format for insertion of distributed pilots. The presence or absence of pilot symbols can be changed on a frame-by-frame basis using one bit ($b_6$) in the Frame Descriptor field (see table 5-1). Each pilot is an unmodulated symbol, with equal In-phase and Quadrature components: $I$=(1√2), $Q$=(1√2).

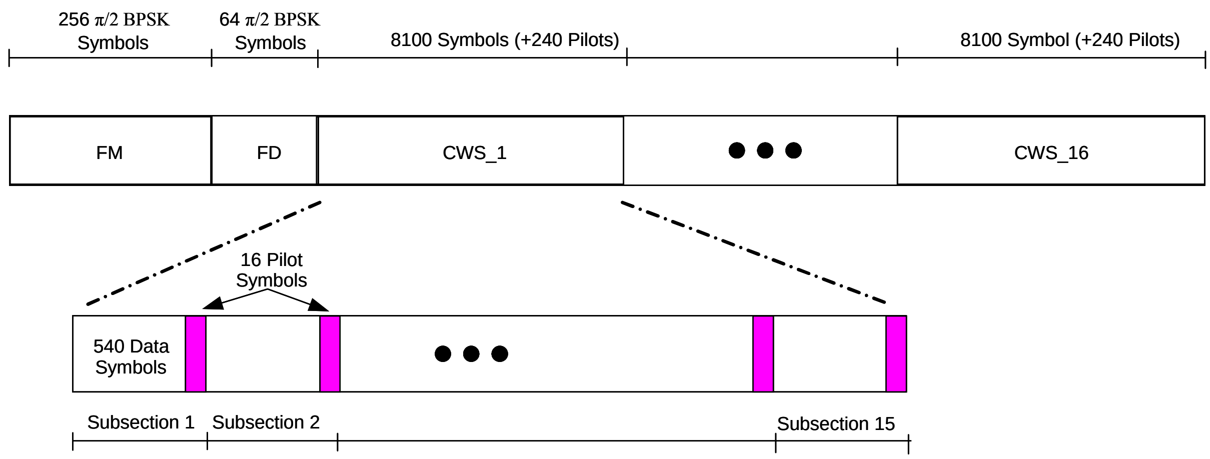



**Figure 5-5: Distributed Pilot Pattern**

Required parameters to specify the pilot distribution pattern within each PL frame are presented in table 5-2. The total overhead due to pilot insertion is around three percent.

**Table 5-2: Frame Parameters Related to Pilot Distribution**

| Parameter | Value |
|---|---|
| Codeword Section Length | 8100 symbols |
| Number of Codeword Section per frame | 16 Sections |
| Number of sub-sections | 15 sub-sections |
| Number of Data Symbols per sub-section | 540 Symbols |
| Number pilots per subsection | 16 Symbols |
| Total Number of pilots per section | 240 Symbols |
| Total Section length including pilot symbols | 8340 Symbols |

## 5.4 PHYSICAL LAYER I/Q PSEUDO-RANDOMIZATION (OPTIONAL)

Physical layer randomization of codeword sections, including the data symbols as well as the pilots, is considered to be an option but not configurable during operation. The Physical layer randomization is used to disperse the signal energy in order to avoid any spectral spur due to repetitive data or pilot patterns. The proposed Physical layer pseudo-randomizer is similar to that in DVB-S2 standard (reference [B2]). For completeness, the PL pseudo-randomizer is described in annex C.

## 5.5 BASEBAND FILTERING

The baseband pulse shaping filter applied to In-phase and Quadrature signals is a square-root raised cosine filter:

$$H(f)=\begin{cases}1 & |f|<f_N(1-\alpha)\\ \left\{\dfrac{1}{2}+\dfrac{1}{2}\sin\dfrac{\pi}{2f_N}\left(\dfrac{f_N-|f|}{\alpha}\right)\right\}^{1/2} & f_N(1-\alpha)<|f|<f_N(1+\alpha)\\ 0 & |f|>f_N(1+\alpha)\end{cases} \qquad (5\text{-}3)$$

where $f_N=\dfrac{1}{2T_s}=\dfrac{R_s}{2}$ is the Nyquist frequency and α is the roll-off factor.

The roll-off factor is fixed per operation and is selected from one of the following values: α=0.2, 0.25, 0.30, or 0.35.

# 6 ENCODER IMPLEMENTATION FOR HIGH BIT RATE DATA TRANSFER

In order to achieve a net data rate as high as 1 Gbits/sec, the encoder architecture (as well as the decoder which will not be described here) must be designed with some degree of parallelism. The trivial solution based on using *n* duplicated encoders (as shown in figure 6-1), each working at a reduced speed of $R_S/n$, has the drawback of requiring a memory *n* times larger than that of a single encoder. This amount of extra memory that is required for *n* parallel operations is significantly large in the case of large codeword sizes.

There is no obvious scheme to generate a parallel encoder without a full functional replication (e.g., acting on a single working memory). In fact, due to the inherent sequential nature of the encoding process, if the information block is split into *n* segments, the encoding of each segment will depend on the final state reached by the trellis in the previous one. However, there exists a solution by exploiting the properties of a linear system and encoding twice the information bits contained in each segment.

The first encoding procedure is used to evaluate the final states of each segment in which an information block is split, starting each encoder from the zero state. Next, by using the mathematical computation of the final states exploiting the linear properties of the encoder, the same data is re-encode with correct initial states obtained by a simple calculation.

The proposed scheme requires a modest increase in memory requirement, but it needs 2*n* encoder processors for *n* degree of parallelism. The additional cost of the encoders is quite marginal (two registers per encoder plus a limited combinatorial logic). This solution does not impose any constraint on the decoder.

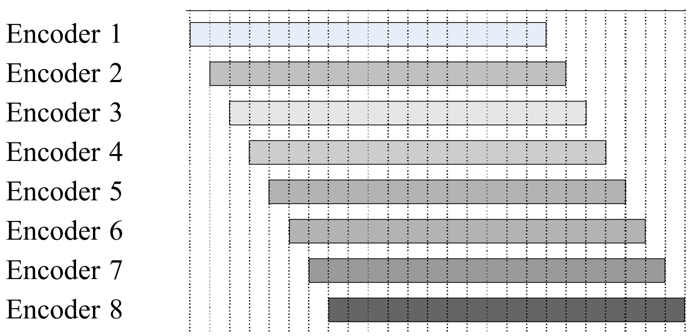



**Figure 6-1: Encoder Functional Partitioning**

The convolutional encoder described in 4.2 can be expressed using state equations:

$$\begin{cases} x(n+1) = A \bullet x(n) + B \bullet u(n) \\ y(n) = C \bullet x(n) + D \bullet u(n) \end{cases} \tag{6-1}$$

where the state, output, and input are respectively denoted as:

$$x(n) = \begin{bmatrix} x_0 \\ x_1 \end{bmatrix}; \qquad y(n) = \begin{bmatrix} c_0 \\ c_1 \end{bmatrix}; \qquad u(n) = u; \tag{6-2}$$

The dots ($\bullet$) represent matrix product defined over a Galois Field GF(2). Equivalently, the following modulo-2 arithmetic with the corresponding sum and product operators are defined:

$$\begin{bmatrix} a, b \in (0,1) \\ a + b = \mathrm{mod}(a+b, 2) \\ a * b = a \cdot b \end{bmatrix} \tag{6-3}$$

in which mod(.) represents the modulo reduction operator.

The following matrixes describe the particular encoder implementation, in which $A$ is the state transition matrix (with zero input):

$$A = \begin{bmatrix} 0 & 1 \\ 1 & 1 \end{bmatrix}; B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}; C = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}; D = \begin{bmatrix} 1 \\ 1 \end{bmatrix}; \tag{6-4}$$

Equation 6-1 can also be written recursively:

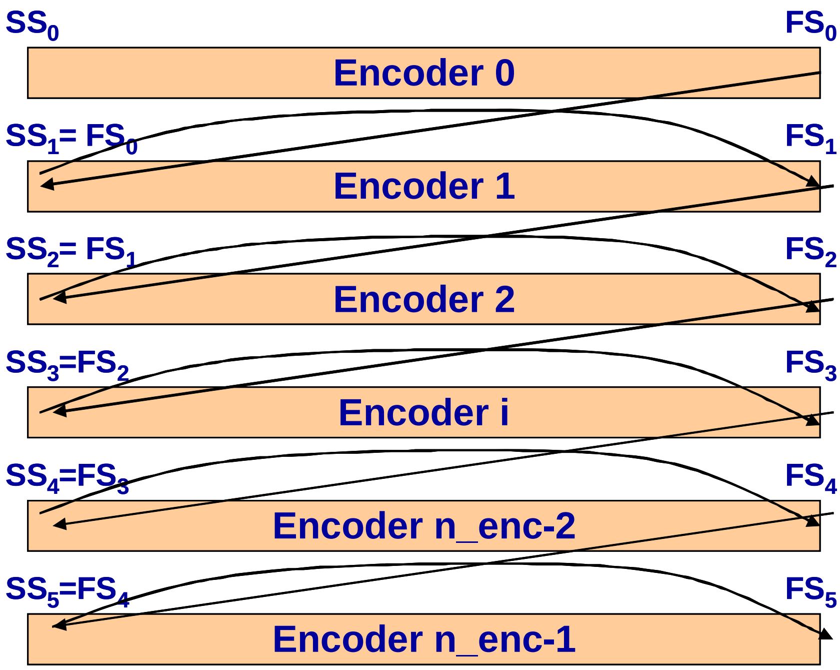
$$\begin{cases} x(n+1) = A \bullet x(n) + B \bullet u(n) = \\ = A^{n+1} \bullet x(0) + A^n B \bullet u(0) + A^{n-1} B \bullet u(1) + \ldots + A^2 B \bullet u(n-2) + AB \bullet u(n-1) + B \bullet u(n) \\ \\ y(n) = C \bullet \left( A \bullet x(n-1) + B \bullet u(n-1) \right) + D \bullet u(n) = \\ = C \bullet A^n \bullet x(0) + CA^{n-1} B \bullet u(0) + \ldots + CAB \bullet u(n-2) + CB \bullet u(n-1) + D \bullet u(n) \end{cases} \tag{6-5}$$

In equation 6-5 one can identify a component of the state that depends only on previous states and another component that depends only on the input. The same applies to the output. Starting from the zero state, equation 6-5 can be turned to the following set of equations, defining the intermediate initial starting states (see also figure 6-2):

$$\begin{aligned}
&x_0(0) = \begin{bmatrix} 0 \\ 0 \end{bmatrix}; \\
&x_1(0) = FS_0; \\
&x_2(0) = FS_1^* = A^n \bullet FS_0 + FS_1; \\
&x_3(0) = FS_2^* = A^n \bullet FS_1^* + FS_2 = A^{2n} \bullet FS_0 + A^n \bullet FS_1 + FS_2; \\
&x_4(0) = FS_3^* = A^n \bullet FS_2^* + FS_3 = A^{3n} \bullet FS_0 + A^{2n} \bullet FS_1 + A^n \bullet FS_2 + FS_3; \\
&x_5(0) = FS_4^* = A^n \bullet FS_3^* + FS_4 = A^{4n} \bullet FS_0 + A^{3n} \bullet FS_1 + A^{2n} \bullet FS_2 + A^n \bullet FS_3 + FS_4;
\end{aligned} \tag{6-6}$$

Equation 6-6 constitutes the rule underneath the suggested encoder parallel operation, obtained with no memory expansion, compared with the traditional single encoder structure. The resulting architecture is shown in figure 6-3.

In equation 6-6 FS denotes the Final State and the indexes refer to the codeword partitioning shown in figure 6-2. Hence, a component of the final states, the one depending on input data only (and zero input state), is obtained by the pre-encoding process (first encoder operation); the second component of the final state is obtained by matrix exponentiation. The latter turns out to be very simple, due to the particular properties of the matrix *A* (see equation 6-7). Next, the final states are used as starting states of the following blocks (see diagonal arrows).




**The Starting State and the Final State of encoder *i* is indicated with $SS_i$ and $FS_i$, respectively. The total number of encoders is n_enc.**

**Figure 6-2: State Propagation Diagram**

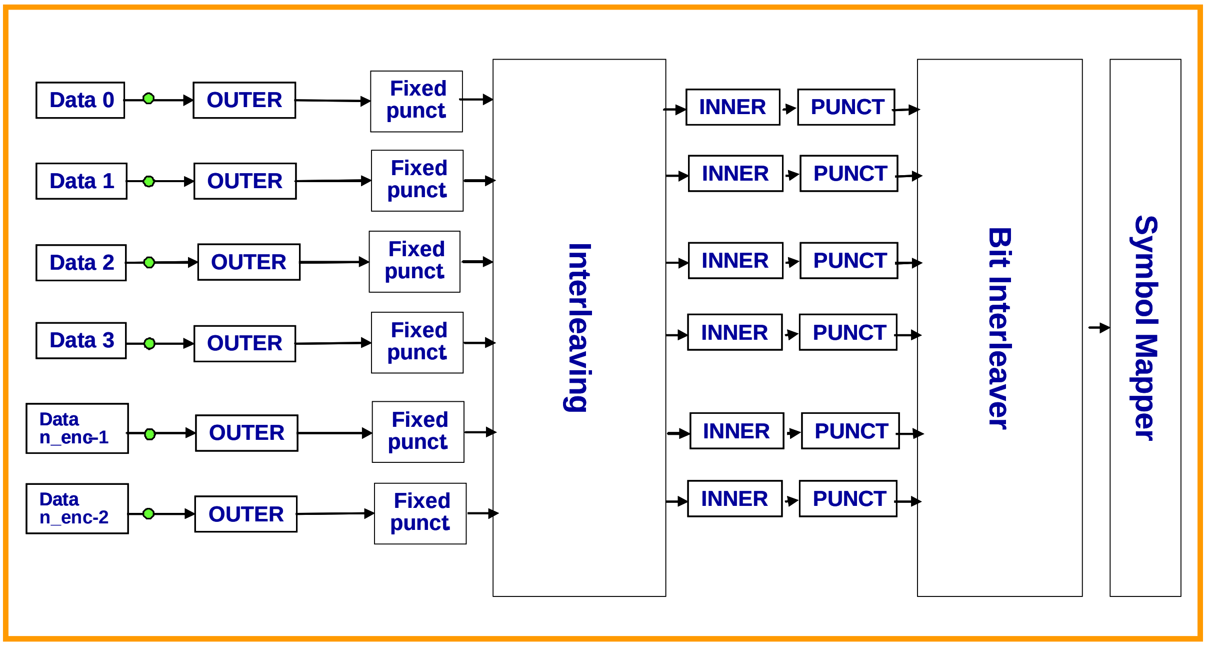



**Figure 6-3: Parallelized Encoder Structure**

The cyclic properties of the matrix $A$ that can be exploited in the calculations are:

$$\begin{aligned}
A &= \begin{bmatrix} 0 & 1 \\ 1 & 1 \end{bmatrix}; \\
A^2 &= \begin{bmatrix} 0 & 1 \\ 1 & 1 \end{bmatrix} \bullet \begin{bmatrix} 0 & 1 \\ 1 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}; \\
A^3 &= A^2 \bullet A = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix} \bullet \begin{bmatrix} 0 & 1 \\ 1 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = I; \\
A^4 &= A^3 \bullet A = I \bullet A = A;
\end{aligned} \tag{6-7}$$

To obtain a parallel SCCC encoder, we need a parallelism order equal to twice that normally necessary since we have to encode the same data twice. The maximum data rate at the inner encoder is 1.5 Gb/sec; hence, considering as an example the maximum speed of the encoder processor (in trellis steps/sec) equal to, $F_{ck}$ = 250 MHz the number of parallel encoders, n_enc, can be calculated as:

$$n\_enc = \frac{3 \text{ Gbit}}{250 \text{ MHz}} = 12;$$

Alternatively, if the clock frequency is set to $F_{ck}$ = 250 MHz, the number of parallel encoders.

$$n\_enc = \frac{3 \text{ Gbit}}{200 \text{ MHz}} = 15.$$

# 7 PERFORMANCE RESULTS

The performance results measured in terms of Bit Error Ratio (BER) and Frame Error Ratio (FER) for 27 selected combinations of coding and modulation schemes in AWGN channel are presented in figures 7-1 and 7-2, respectively.

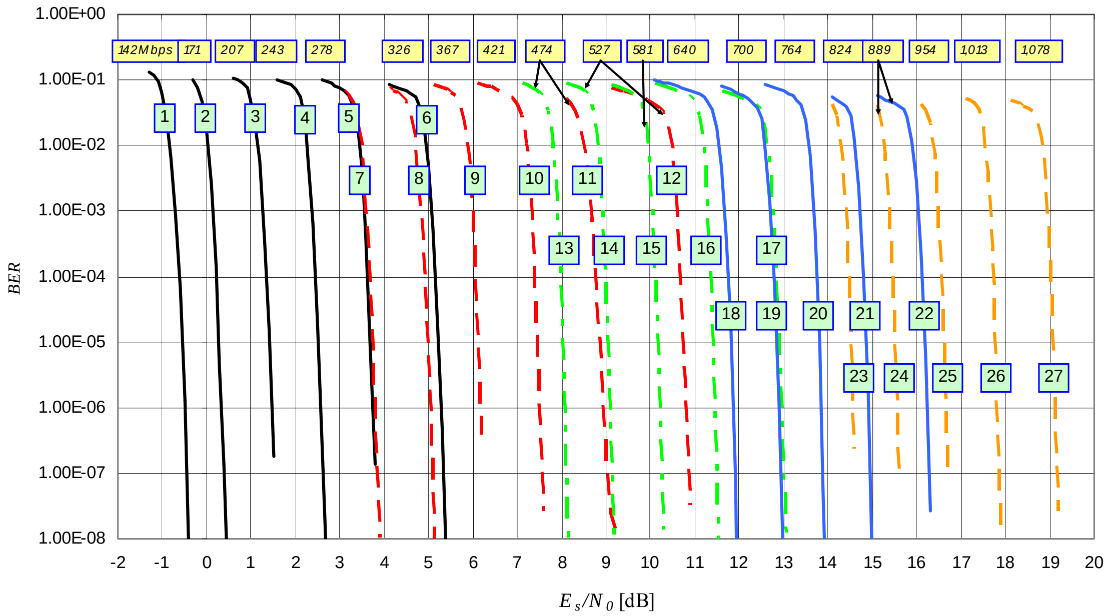



**Figure 7-1: Simulated BER Performance of the 27 ACM Formats**

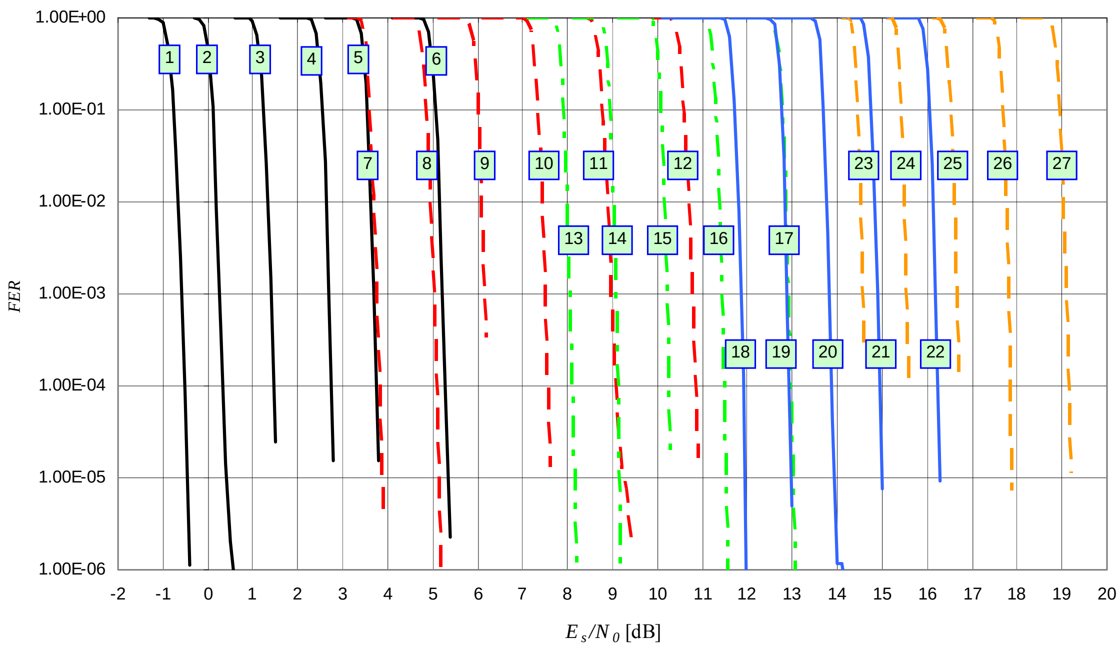



**Figure 7-2: Simulated Frame Error Ratio of the 27 ACM Formats**

The coding rates corresponding to 27 ACM formats can be determined based on the information block size *K* and the encoded block sizes *N*, as specified in table 4-3. As an example, for the ACM format No. 6 with (*K,N*)=(13198,16200) and QPSK modulation, the required *Es*/*No* to achieve a BER of $10^{-8}$ is 5.4 dB. The corresponding Frame Error Ratio in this case is around $10^{-6}$.

It should be noted that the computed Frame Error Ratio in figure 7-2 refers to the probability of occurrence of at least one erroneous bit in a decoded information block. The structure of the information block is illustrated in figure 2-2. As shown, there is no one-to-one mapping between the information blocks and the input Transfer Frames.

The information data rate labelling the curves in figure 7-1 corresponds to a symbol rate of 200 Ms/sec.

In order to provide more insight into the performance of the supported modulation and coding schemes in figure 7-3, simulated performance results are compared with channel capacities. The big solid blue curve is the unconstrained AWGN capacity from which the design of the desired set of spectral efficiencies has been started.

On the same plot, beside the performance results of the schemes (i.e., the required $E_s/N_0$ to achieve the target performance of BER=$10^{-6}$), which are reported with long dashed lines, two other theoretical limits are also reported. The solid curves are the *modulation-constrained capacities*, i.e., the theoretical limits over AWGN with the specific modulation schemes. Short dashed curves are the theoretical limits obtained using the Pragmatic approach, Bit Interleaved Code Modulation (BICM). This approach leads to a performance degradation that can be minimized using Gray labelling, but cannot be eliminated. The two theoretical limits are obtained in the limit of infinite codeword sizes. For a description of the methods used to derive these limits see references [B9] and [B10], and reference therein.

Comparing the performances of proposed schemes against the true limits (short dashed lines), one can observe that the loss of the coding schemes is uniform for all ACM formats and around one dB. Hence, the non-perfectly uniform spacing of curves in figure 7-1 is partly due to the choice of the modulation schemes, which have a variable loss against unconstrained capacity, and partly to the variable loss of the BICM approach. In particular, 8PSK and 32APSK have in general a bigger modulation loss, while the BICM approach, which gives almost negligible losses for 8PSK, 16APSK, and 64APSK gives a non-negligible loss for 32APSK modulation, which in fact does not admit Gray labelling.

Finally, although the performance curves are not uniformly spaced, the high density of the curves, and the partial overlapping between adjacent modulations, guarantees that the best trade-off can be found in all channel types and conditions, including the variable and non-linear satellite channel. In this latter case, in fact, the relative losses of the modulations are different so that curve of figure 7-1, relevant to the AWGN channel, will no longer be valid.

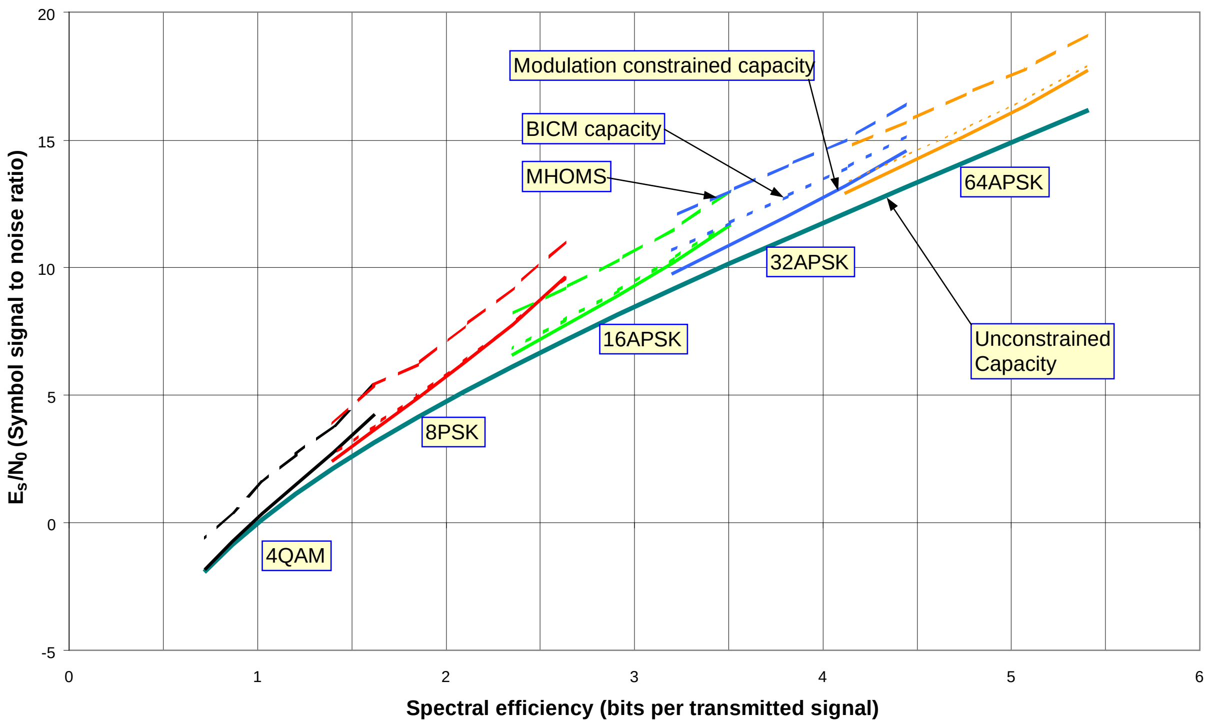



**Figure 7-3: Comparison of the SCCC Achievable Performance versus Theoretical Bounds**

# ANNEX A

# ACRONYMS

| | |
|---|---|
| **ACM** | Adaptive Coding and Modulation |
| **ASM** | Attached SYNC Marker |
| **AOS** | Advanced Orbiting Systems |
| **AWGN** | Additive White Gaussian Noise |
| **BER** | Bit Error Ratio |
| **CCSDS** | Consultative Committee For Space Data Systems |
| **FD** | Frame Descriptor |
| **FER** | Frame Error Ratio |
| **FM** | Frame Marker |
| **PL** | Physical Layer |
| **TC** | Telecommand |
| **TM** | Telemetry |
| **SCCC** | Serially Concatenated Convolutional (Turbo) Code |
| **VCM** | Variable Coding and Modulation |

# ANNEX B

# INFORMATIVE REFERENCES


[B1] S. Benedetto and G. Montorsi. "Serial Concatenation of Block and Convolutional Codes." *Electronics Letters* 32, no. 10 (9 May 1996): 887-888.

[B2] *Digital Video Broadcasting (DVB); Second Generation Framing Structure, Channel Coding and Modulation Systems for Broadcasting, Interactive Services, News Gathering and other Broadband Satellite Applications*. ETSI EN 302 307 V1.1.2 (2006-06). Sophia-Antipolis: ETSI, 2006.

[B3] *TM Synchronization and Channel Coding*. Recommendation for Space Data System Standards, CCSDS 131.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

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[B5] *AOS Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 732.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, July 2006.

[B6] R. De Gaudenzi, A. Guillen i Fabregas, and A. Martinez. "Performance Analysis of Turbo-Coded APSK Modulations over Nonlinear Satellite Channels." *IEEE Transactions on Wireless Communications* 5, no. 9 (September 2006): 2396-2407.

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[B8] G. Caire, G. Taricco, and E. Biglieri. "Bit-Interleaved Coded Modulation." *IEEE Transactions on Information Theory* 44, no. 3 (May 1998): 927-946.

[B9] D.M. Arnold, et al. "Simulation-Based Computation of Information Rates for Channels with Memory." *IEEE Transactions on Information Theory* 52, no. 8 (August 2006): 3498-3508.

[B10] D. Arnold, et al. "Simulation-Based Computation of Information Rates: Upper and Lower Bounds." In *Proceedings of IEEE International Symposium on Information Theory*, 2003 (Kanagawa, Japan), 119-. Piscataway, NJ: IEEE, 2003.

# ANNEX C

# INTERLEAVER DESCRIPTIONS

In order to support 27 distinct ACM formats, it is necessary to design only 19 permutations that allow a parallel implementation of the decoder with a degree of parallelism, *M*=120. Thus, the sizes of all 19 interleavers are integer multiples of 120. The outer encoder writes/reads its data in the memory in natural order. As for the inner encoder, the design of the permutations permits description of them in a simpler way than just giving the 19 series of integers from 0 to *I*.

The inner encoder writes/reads data according to the following relationship, which gives the writing/reading address at time *i:*

$$\pi(i) = W \times \left(i / W + \beta(i_W)\right)_M + \alpha(i_W) \quad i = 0,\ldots,I \qquad \text{(A-1)}$$

where $\alpha$ and $\beta$ are two vectors of length equal to *W*=*I*/120, and

$$i_W \equiv i \bmod W \qquad \text{(A-2)}$$

The elements of $\alpha$ (addresses of macrodata) range in [0,W-1] and the elements of $\beta$ (cyclic shifts of macrodata) range in [0,119].

Beyond yielding a more compact description of the interleaver, the previous permutation relationship allows for efficient implementation of a parallel decoder with parallelism 120 as shown in figure C-1.

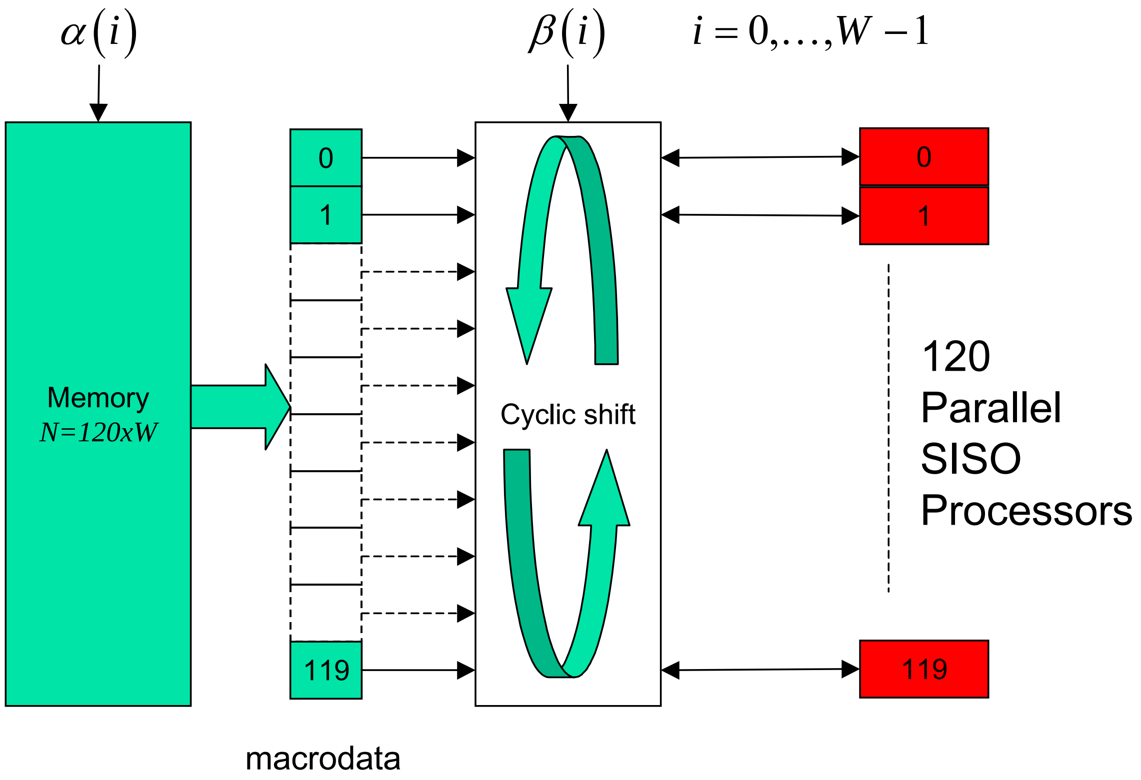


**Figure C-1: Structure of the Simplified Interleaver**

## Table C-1: Interleaver Parameters (1-10)

| | 1<br>N=8640<br>W=72<br>S1=84<br>S2=84 | | 2<br>N=10440<br>W=87<br>S1=90<br>S2=90 | | 3<br>N=12600<br>W=105<br>S1=102<br>S2=102 | | 4<br>N=14760<br>W=123<br>S1=110<br>S2=110 | | 5<br>N=16920<br>W=141<br>S1=109<br>S2=109 | | 6<br>N=19800<br>W=165<br>S1=127<br>S2=127 | | 7<br>N=22320<br>W=186<br>S1=135<br>S2=135 | | 8<br>N=25560<br>W=213<br>S1=144<br>S2=144 | | 9<br>N=28800<br>W=240<br>S1=153<br>S2=153 | | 10<br>N=32040<br>W=267<br>S1=161<br>S2=161 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ |
| 0 | 63 | 116 | 70 | 82 | 85 | 97 | 106 | 1 | 60 | 14 | 116 | 87 | 18 | 114 | 50 | 32 | 109 | 98 | 63 | 93 |
| 1 | 33 | 69 | 53 | 27 | 91 | 27 | 82 | 89 | 107 | 55 | 42 | 34 | 95 | 1 | 134 | 71 | 179 | 66 | 238 | 10 |
| 2 | 64 | 103 | 63 | 101 | 1 | 47 | 115 | 49 | 4 | 31 | 66 | 36 | 68 | 116 | 200 | 47 | 129 | 13 | 92 | 78 |
| 3 | 56 | 92 | 67 | 106 | 0 | 69 | 17 | 43 | 102 | 68 | 77 | 47 | 108 | 72 | 68 | 89 | 214 | 109 | 189 | 72 |
| 4 | 59 | 77 | 10 | 59 | 35 | 104 | 58 | 20 | 87 | 53 | 13 | 38 | 11 | 119 | 74 | 15 | 186 | 45 | 73 | 25 |
| 5 | 5 | 73 | 29 | 22 | 3 | 90 | 81 | 24 | 89 | 76 | 99 | 25 | 104 | 61 | 1 | 18 | 128 | 72 | 172 | 68 |
| 6 | 58 | 58 | 47 | 105 | 77 | 66 | 113 | 41 | 117 | 42 | 84 | 69 | 118 | 108 | 32 | 40 | 60 | 8 | 94 | 96 |
| 7 | 52 | 46 | 52 | 49 | 98 | 57 | 28 | 3 | 68 | 19 | 123 | 8 | 172 | 20 | 102 | 69 | 112 | 91 | 49 | 14 |
| 8 | 61 | 107 | 82 | 33 | 51 | 50 | 12 | 78 | 67 | 113 | 1 | 80 | 181 | 84 | 33 | 79 | 8 | 93 | 228 | 6 |
| 9 | 47 | 1 | 58 | 15 | 13 | 29 | 2 | 111 | 96 | 58 | 102 | 60 | 19 | 95 | 154 | 119 | 183 | 117 | 219 | 5 |
| 10 | 57 | 52 | 65 | 111 | 63 | 60 | 76 | 107 | 15 | 110 | 73 | 101 | 121 | 92 | 21 | 29 | 170 | 64 | 197 | 46 |
| 11 | 35 | 90 | 72 | 7 | 97 | 86 | 10 | 67 | 140 | 105 | 109 | 82 | 106 | 93 | 22 | 111 | 225 | 114 | 173 | 47 |
| 12 | 29 | 32 | 2 | 74 | 78 | 35 | 40 | 10 | 114 | 44 | 21 | 77 | 75 | 88 | 103 | 61 | 35 | 15 | 232 | 111 |
| 13 | 60 | 119 | 40 | 86 | 49 | 37 | 108 | 117 | 112 | 17 | 48 | 89 | 73 | 60 | 162 | 108 | 97 | 77 | 195 | 108 |
| 14 | 36 | 3 | 4 | 70 | 68 | 25 | 9 | 38 | 22 | 28 | 6 | 30 | 109 | 16 | 130 | 54 | 87 | 35 | 144 | 42 |
| 15 | 24 | 68 | 31 | 71 | 7 | 84 | 74 | 51 | 9 | 109 | 47 | 57 | 142 | 101 | 83 | 16 | 88 | 85 | 21 | 80 |
| 16 | 10 | 60 | 36 | 100 | 103 | 117 | 64 | 74 | 34 | 16 | 142 | 52 | 69 | 32 | 38 | 99 | 188 | 6 | 134 | 102 |
| 17 | 20 | 30 | 7 | 31 | 96 | 53 | 92 | 40 | 21 | 34 | 124 | 93 | 117 | 100 | 190 | 105 | 47 | 99 | 161 | 104 |
| 18 | 66 | 83 | 23 | 13 | 57 | 72 | 31 | 87 | 116 | 11 | 150 | 73 | 103 | 80 | 180 | 55 | 165 | 107 | 135 | 19 |
| 19 | 17 | 63 | 77 | 62 | 75 | 115 | 35 | 94 | 62 | 24 | 104 | 112 | 116 | 70 | 61 | 116 | 156 | 88 | 102 | 67 |
| 20 | 31 | 41 | 45 | 39 | 67 | 59 | 101 | 14 | 28 | 79 | 72 | 19 | 113 | 62 | 104 | 75 | 52 | 55 | 259 | 31 |
| 21 | 16 | 50 | 17 | 1 | 58 | 106 | 26 | 63 | 105 | 95 | 4 | 118 | 83 | 87 | 167 | 114 | 233 | 15 | 101 | 97 |
| 22 | 67 | 6 | 79 | 80 | 25 | 7 | 27 | 44 | 79 | 35 | 119 | 10 | 78 | 118 | 168 | 21 | 151 | 95 | 200 | 43 |
| 23 | 28 | 24 | 35 | 104 | 59 | 52 | 69 | 64 | 121 | 20 | 135 | 78 | 138 | 0 | 100 | 101 | 0 | 20 | 3 | 72 |
| 24 | 18 | 22 | 56 | 56 | 65 | 119 | 70 | 104 | 5 | 47 | 43 | 50 | 147 | 58 | 191 | 81 | 17 | 17 | 7 | 53 |
| 25 | 9 | 101 | 33 | 48 | 60 | 23 | 68 | 8 | 6 | 29 | 10 | 1 | 85 | 102 | 26 | 19 | 235 | 115 | 115 | 50 |
| 26 | 6 | 62 | 78 | 19 | 14 | 65 | 34 | 16 | 125 | 39 | 3 | 65 | 59 | 91 | 142 | 67 | 157 | 71 | 114 | 49 |
| 27 | 62 | 57 | 38 | 64 | 74 | 32 | 112 | 54 | 50 | 70 | 156 | 38 | 97 | 98 | 10 | 43 | 70 | 22 | 31 | 65 |
| 28 | 2 | 18 | 37 | 38 | 22 | 13 | 1 | 119 | 41 | 54 | 118 | 17 | 91 | 66 | 178 | 91 | 191 | 67 | 9 | 89 |
| 29 | 27 | 66 | 60 | 35 | 42 | 40 | 55 | 53 | 78 | 93 | 138 | 110 | 46 | 56 | 140 | 33 | 44 | 94 | 255 | 65 |
| 30 | 71 | 9 | 39 | 25 | 87 | 14 | 105 | 106 | 77 | 89 | 163 | 31 | 145 | 52 | 87 | 63 | 50 | 11 | 2 | 76 |
| 31 | 34 | 37 | 30 | 45 | 95 | 102 | 20 | 59 | 53 | 84 | 2 | 84 | 136 | 77 | 158 | 13 | 83 | 48 | 22 | 57 |
| 32 | 14 | 81 | 19 | 37 | 29 | 91 | 18 | 21 | 54 | 63 | 31 | 67 | 22 | 55 | 45 | 90 | 223 | 28 | 89 | 37 |
| 33 | 39 | 114 | 8 | 69 | 10 | 79 | 41 | 97 | 33 | 105 | 159 | 41 | 169 | 57 | 145 | 95 | 155 | 87 | 90 | 60 |
| 34 | 68 | 115 | 6 | 24 | 104 | 18 | 61 | 70 | 106 | 117 | 88 | 26 | 111 | 27 | 207 | 46 | 216 | 111 | 240 | 87 |
| 35 | 51 | 82 | 21 | 58 | 24 | 39 | 91 | 65 | 82 | 43 | 68 | 43 | 105 | 85 | 64 | 3 | 192 | 79 | 50 | 70 |
| 36 | 21 | 26 | 80 | 94 | 31 | 11 | 36 | 90 | 31 | 103 | 63 | 35 | 158 | 22 | 184 | 24 | 30 | 28 | 74 | 12 |
| 37 | 13 | 29 | 9 | 99 | 30 | 43 | 84 | 22 | 132 | 10 | 117 | 4 | 2 | 52 | 4 | 66 | 160 | 49 | 20 | 36 |
| 38 | 37 | 94 | 57 | 6 | 76 | 95 | 14 | 26 | 80 | 37 | 103 | 28 | 53 | 26 | 56 | 4 | 54 | 57 | 236 | 89 |
| 39 | 23 | 39 | 1 | 98 | 52 | 88 | 109 | 60 | 11 | 22 | 97 | 107 | 119 | 4 | 173 | 52 | 146 | 32 | 98 | 17 |
| 40 | 40 | 48 | 55 | 53 | 61 | 110 | 48 | 27 | 63 | 25 | 155 | 84 | 41 | 43 | 101 | 50 | 69 | 41 | 239 | 90 |
| 41 | 41 | 98 | 83 | 40 | 99 | 0 | 83 | 35 | 38 | 73 | 8 | 49 | 16 | 112 | 8 | 112 | 26 | 6 | 1 | 99 |
| 42 | 30 | 76 | 15 | 90 | 66 | 77 | 23 | 72 | 26 | 87 | 113 | 33 | 153 | 75 | 85 | 5 | 136 | 102 | 251 | 103 |
| 43 | 44 | 5 | 62 | 92 | 5 | 117 | 25 | 49 | 108 | 118 | 129 | 3 | 152 | 78 | 201 | 58 | 126 | 60 | 155 | 28 |
| 44 | 25 | 112 | 51 | 88 | 4 | 83 | 57 | 45 | 27 | 88 | 143 | 9 | 149 | 119 | 29 | 17 | 195 | 100 | 160 | 94 |
| 45 | 65 | 35 | 20 | 29 | 83 | 63 | 73 | 76 | 39 | 91 | 80 | 75 | 173 | 106 | 41 | 105 | 41 | 23 | 150 | 27 |
| 46 | 48 | 71 | 14 | 79 | 17 | 22 | 111 | 114 | 8 | 42 | 128 | 77 | 144 | 44 | 42 | 100 | 182 | 74 | 153 | 15 |
| 47 | 69 | 20 | 25 | 91 | 88 | 30 | 77 | 82 | 90 | 13 | 96 | 18 | 139 | 69 | 170 | 34 | 49 | 84 | 80 | 35 |
| 48 | 26 | 96 | 66 | 117 | 48 | 94 | 7 | 14 | 18 | 99 | 162 | 90 | 4 | 100 | 43 | 62 | 190 | 18 | 108 | 101 |
| 49 | 43 | 85 | 28 | 113 | 2 | 81 | 95 | 112 | 131 | 80 | 151 | 16 | 185 | 2 | 115 | 74 | 27 | 34 | 86 | 58 |
| 50 | 55 | 110 | 86 | 77 | 86 | 16 | 62 | 46 | 119 | 57 | 141 | 2 | 157 | 35 | 138 | 76 | 10 | 47 | 165 | 92 |
| 51 | 0 | 52 | 0 | 66 | 38 | 100 | 86 | 36 | 32 | 51 | 115 | 58 | 29 | 13 | 199 | 1 | 33 | 62 | 167 | 113 |
| 52 | 45 | 19 | 12 | 33 | 102 | 2 | 80 | 17 | 135 | 5 | 76 | 13 | 180 | 48 | 108 | 86 | 237 | 113 | 196 | 45 |
| 53 | 50 | 102 | 11 | 111 | 82 | 31 | 5 | 12 | 17 | 114 | 148 | 106 | 34 | 117 | 88 | 117 | 217 | 59 | 67 | 110 |
| 54 | 70 | 55 | 26 | 61 | 72 | 41 | 8 | 95 | 100 | 40 | 25 | 37 | 127 | 95 | 105 | 39 | 100 | 4 | 262 | 38 |
| 55 | 7 | 14 | 27 | 51 | 21 | 10 | 4 | 33 | 71 | 97 | 27 | 99 | 115 | 31 | 90 | 30 | 4 | 37 | 29 | 40 |
| 56 | 32 | 44 | 5 | 18 | 37 | 75 | 54 | 62 | 51 | 2 | 110 | 68 | 129 | 71 | 179 | 92 | 80 | 46 | 104 | 21 |
| 57 | 12 | 9 | 68 | 52 | 6 | 5 | 29 | 56 | 137 | 75 | 30 | 44 | 79 | 53 | 76 | 22 | 196 | 34 | 48 | 61 |
| 58 | 42 | 15 | 75 | 11 | 11 | 62 | 97 | 88 | 76 | 69 | 78 | 11 | 86 | 8 | 204 | 82 | 187 | 11 | 43 | 1 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | 11 | 80 | 84 | 55 | 23 | 46 | 56 | 99 | 99 | 47 | 38 | 6 | 25 | 108 | 121 | 51 | 75 | 83 | 65 | 41 |
| 60 | 46 | 89 | 69 | 3 | 47 | 93 | 67 | 23 | 37 | 10 | 11 | 20 | 32 | 11 | 106 | 23 | 145 | 82 | 61 | 38 |
| 61 | 1 | 106 | 74 | 26 | 36 | 108 | 38 | 105 | 111 | 94 | 95 | 39 | 3 | 44 | 30 | 38 | 43 | 25 | 166 | 77 |
| 62 | 8 | 119 | 59 | 103 | 93 | 81 | 100 | 69 | 133 | 59 | 71 | 81 | 58 | 65 | 54 | 60 | 102 | 92 | 143 | 107 |
| 63 | 15 | 100 | 85 | 46 | 81 | 113 | 93 | 102 | 13 | 8 | 149 | 15 | 93 | 38 | 17 | 54 | 68 | 10 | 202 | 20 |
| 64 | 53 | 45 | 71 | 109 | 69 | 101 | 72 | 101 | 57 | 18 | 106 | 65 | 88 | 37 | 70 | 11 | 22 | 30 | 19 | 69 |
| 65 | 3 | 17 | 43 | 73 | 100 | 24 | 32 | 108 | 61 | 4 | 60 | 116 | 168 | 29 | 37 | 97 | 103 | 1 | 129 | 11 |
| 66 | 19 | 43 | 49 | 114 | 90 | 48 | 43 | 81 | 74 | 86 | 87 | 30 | 33 | 20 | 165 | 41 | 116 | 97 | 33 | 29 |
| 67 | 4 | 87 | 41 | 42 | 45 | 6 | 37 | 0 | 84 | 111 | 51 | 96 | 43 | 25 | 176 | 6 | 117 | 53 | 188 | 84 |
| 68 | 22 | 88 | 48 | 21 | 18 | 21 | 22 | 80 | 120 | 82 | 86 | 95 | 38 | 9 | 156 | 0 | 154 | 105 | 132 | 56 |
| 69 | 49 | 34 | 32 | 96 | 56 | 27 | 0 | 30 | 72 | 67 | 70 | 63 | 36 | 12 | 98 | 9 | 193 | 47 | 53 | 100 |
| 70 | 54 | 11 | 44 | 10 | 20 | 35 | 102 | 109 | 35 | 38 | 85 | 71 | 87 | 17 | 125 | 80 | 99 | 31 | 229 | 4 |
| 71 | 38 | 107 | 61 | 84 | 79 | 70 | 51 | 117 | 66 | 85 | 112 | 55 | 150 | 68 | 92 | 107 | 236 | 20 | 258 | 118 |
| 72 | | | 50 | 43 | 39 | 56 | 75 | 93 | 127 | 65 | 5 | 62 | 14 | 35 | 120 | 35 | 73 | 81 | 209 | 59 |
| 73 | | | 73 | 116 | 46 | 86 | 122 | 91 | 98 | 74 | 0 | 41 | 27 | 7 | 133 | 20 | 161 | 96 | 263 | 119 |
| 74 | | | 34 | 68 | 53 | 84 | 118 | 39 | 95 | 78 | 23 | 97 | 167 | 13 | 65 | 87 | 42 | 67 | 201 | 74 |
| 75 | | | 46 | 5 | 54 | 112 | 47 | 15 | 29 | 115 | 90 | 103 | 133 | 82 | 122 | 110 | 105 | 70 | 51 | 82 |
| 76 | | | 64 | 108 | 32 | 97 | 39 | 66 | 55 | 101 | 69 | 52 | 0 | 87 | 110 | 7 | 141 | 63 | 23 | 118 |
| 77 | | | 13 | 94 | 19 | 116 | 114 | 84 | 92 | 81 | 37 | 86 | 100 | 64 | 151 | 78 | 231 | 39 | 32 | 24 |
| 78 | | | 18 | 15 | 15 | 76 | 19 | 86 | 86 | 107 | 18 | 60 | 184 | 108 | 149 | 83 | 140 | 2 | 235 | 97 |
| 79 | | | 54 | 82 | 28 | 9 | 65 | 73 | 93 | 31 | 14 | 8 | 7 | 103 | 71 | 114 | 162 | 94 | 124 | 54 |
| 80 | | | 76 | 85 | 73 | 109 | 98 | 4 | 139 | 32 | 154 | 100 | 12 | 57 | 212 | 36 | 177 | 12 | 193 | 44 |
| 81 | | | 42 | 0 | 33 | 96 | 6 | 54 | 123 | 15 | 49 | 83 | 28 | 22 | 117 | 73 | 72 | 101 | 91 | 106 |
| 82 | | | 24 | 77 | 16 | 115 | 121 | 74 | 113 | 16 | 130 | 54 | 57 | 18 | 3 | 55 | 57 | 79 | 46 | 64 |
| 83 | | | 16 | 55 | 12 | 18 | 45 | 77 | 85 | 106 | 26 | 15 | 82 | 42 | 19 | 98 | 32 | 58 | 88 | 30 |
| 84 | | | 22 | 119 | 44 | 42 | 46 | 83 | 2 | 52 | 35 | 46 | 128 | 45 | 6 | 88 | 206 | 75 | 106 | 114 |
| 85 | | | 3 | 3 | 9 | 106 | 94 | 34 | 1 | 27 | 121 | 67 | 84 | 111 | 114 | 27 | 29 | 45 | 24 | 51 |
| 86 | | | 81 | 75 | 55 | 68 | 42 | 19 | 14 | 71 | 59 | 78 | 60 | 75 | 75 | 81 | 3 | 61 | 181 | 93 |
| 87 | | | | | 62 | 74 | 107 | 47 | 16 | 3 | 160 | 105 | 176 | 23 | 52 | 95 | 222 | 118 | 242 | 1 |
| 88 | | | | | 80 | 22 | 50 | 96 | 124 | 19 | 144 | 49 | 51 | 5 | 113 | 43 | 204 | 7 | 146 | 10 |
| 89 | | | | | 8 | 95 | 99 | 7 | 136 | 55 | 7 | 25 | 8 | 4 | 11 | 15 | 58 | 42 | 118 | 89 |
| 90 | | | | | 41 | 102 | 79 | 31 | 45 | 9 | 32 | 29 | 166 | 79 | 188 | 77 | 202 | 104 | 170 | 70 |
| 91 | | | | | 101 | 59 | 53 | 78 | 103 | 91 | 57 | 93 | 10 | 105 | 53 | 103 | 137 | 54 | 127 | 105 |
| 92 | | | | | 71 | 57 | 60 | 116 | 104 | 112 | 114 | 50 | 124 | 84 | 57 | 70 | 45 | 52 | 257 | 8 |
| 93 | | | | | 92 | 46 | 33 | 13 | 25 | 68 | 61 | 79 | 74 | 54 | 109 | 42 | 135 | 93 | 156 | 3 |
| 94 | | | | | 89 | 44 | 16 | 1 | 10 | 65 | 75 | 104 | 24 | 10 | 128 | 118 | 15 | 88 | 205 | 110 |
| 95 | | | | | 94 | 66 | 117 | 86 | 118 | 33 | 67 | 111 | 131 | 49 | 157 | 116 | 31 | 39 | 55 | 16 |
| 96 | | | | | 40 | 4 | 88 | 58 | 75 | 110 | 158 | 57 | 17 | 88 | 127 | 85 | 2 | 103 | 47 | 52 |
| 97 | | | | | 43 | 19 | 119 | 28 | 91 | 102 | 92 | 64 | 80 | 114 | 195 | 11 | 11 | 65 | 151 | 62 |
| 98 | | | | | 27 | 50 | 85 | 68 | 49 | 116 | 33 | 14 | 6 | 47 | 152 | 12 | 48 | 98 | 221 | 101 |
| 99 | | | | | 64 | 39 | 30 | 20 | 128 | 83 | 134 | 72 | 177 | 96 | 96 | 104 | 62 | 118 | 119 | 57 |
| 100 | | | | | 84 | 99 | 87 | 33 | 81 | 23 | 41 | 53 | 21 | 68 | 160 | 3 | 178 | 116 | 16 | 115 |
| 101 | | | | | 50 | 34 | 13 | 114 | 7 | 50 | 40 | 98 | 130 | 113 | 47 | 53 | 1 | 5 | 26 | 18 |
| 102 | | | | | 70 | 11 | 90 | 6 | 36 | 93 | 54 | 94 | 90 | 50 | 51 | 96 | 94 | 68 | 95 | 6 |
| 103 | | | | | 26 | 64 | 3 | 47 | 59 | 75 | 132 | 66 | 71 | 63 | 58 | 68 | 23 | 96 | 82 | 47 |
| 104 | | | | | 34 | 17 | 71 | 110 | 110 | 66 | 126 | 23 | 120 | 116 | 196 | 4 | 198 | 30 | 249 | 66 |
| 105 | | | | | | | 15 | 36 | 0 | 5 | 105 | 99 | 56 | 72 | 171 | 100 | 111 | 115 | 122 | 108 |
| 106 | | | | | | | 103 | 98 | 40 | 14 | 146 | 37 | 154 | 110 | 209 | 68 | 166 | 103 | 241 | 55 |
| 107 | | | | | | | 120 | 62 | 138 | 71 | 55 | 77 | 107 | 30 | 60 | 106 | 215 | 42 | 111 | 7 |
| 108 | | | | | | | 59 | 89 | 101 | 103 | 53 | 47 | 65 | 77 | 46 | 8 | 91 | 17 | 176 | 33 |
| 109 | | | | | | | 21 | 37 | 23 | 90 | 131 | 69 | 102 | 115 | 182 | 29 | 127 | 0 | 208 | 25 |
| 110 | | | | | | | 78 | 57 | 122 | 63 | 19 | 5 | 182 | 15 | 169 | 61 | 158 | 110 | 260 | 22 |
| 111 | | | | | | | 116 | 100 | 3 | 69 | 45 | 105 | 52 | 48 | 63 | 113 | 171 | 27 | 213 | 21 |
| 112 | | | | | | | 89 | 27 | 70 | 22 | 153 | 119 | 170 | 89 | 135 | 64 | 229 | 81 | 190 | 32 |
| 113 | | | | | | | 24 | 113 | 48 | 108 | 93 | 73 | 171 | 25 | 194 | 70 | 159 | 23 | 131 | 13 |
| 114 | | | | | | | 49 | 10 | 52 | 119 | 34 | 82 | 89 | 39 | 192 | 32 | 221 | 1 | 72 | 48 |
| 115 | | | | | | | 66 | 32 | 109 | 35 | 20 | 19 | 55 | 46 | 118 | 58 | 67 | 49 | 149 | 80 |
| 116 | | | | | | | 44 | 103 | 88 | 88 | 12 | 36 | 114 | 97 | 69 | 77 | 85 | 109 | 18 | 84 |
| 117 | | | | | | | 63 | 5 | 44 | 28 | 74 | 114 | 81 | 21 | 111 | 10 | 194 | 73 | 35 | 4 |
| 118 | | | | | | | 11 | 97 | 69 | 117 | 111 | 41 | 26 | 28 | 7 | 116 | 77 | 72 | 252 | 82 |
| 119 | | | | | | | 104 | 81 | 24 | 0 | 157 | 75 | 92 | 14 | 147 | 59 | 65 | 38 | 10 | 55 |
| 120 | | | | | | | 52 | 59 | 46 | 82 | 36 | 110 | 183 | 105 | 153 | 40 | 150 | 21 | 139 | 39 |
| 121 | | | | | | | 96 | 56 | 126 | 1 | 62 | 45 | 1 | 29 | 136 | 45 | 153 | 119 | 141 | 53 |
| 122 | | | | | | | 110 | 99 | 19 | 21 | 17 | 109 | 49 | 74 | 2 | 3 | 142 | 33 | 110 | 65 |
| 123 | | | | | | | | | 115 | 113 | 120 | 86 | 35 | 110 | 187 | 30 | 9 | 59 | 158 | 75 |
| 124 | | | | | | | | | 47 | 53 | 98 | 117 | 63 | 34 | 25 | 52 | 149 | 45 | 100 | 103 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125 | | | | | | | | | 20 | 86 | 140 | 0 | 163 | 40 | 210 | 90 | 181 | 61 | 168 | 87 |
| 126 | | | | | | | | | 42 | 7 | 91 | 84 | 9 | 99 | 163 | 28 | 180 | 56 | 223 | 100 |
| 127 | | | | | | | | | 65 | 73 | 15 | 28 | 179 | 90 | 23 | 115 | 19 | 66 | 217 | 26 |
| 128 | | | | | | | | | 83 | 46 | 58 | 112 | 143 | 66 | 80 | 49 | 173 | 40 | 198 | 71 |
| 129 | | | | | | | | | 64 | 95 | 122 | 31 | 50 | 93 | 12 | 16 | 56 | 7 | 222 | 64 |
| 130 | | | | | | | | | 56 | 47 | 56 | 80 | 137 | 19 | 112 | 1 | 20 | 73 | 99 | 81 |
| 131 | | | | | | | | | 134 | 93 | 83 | 91 | 125 | 20 | 91 | 119 | 95 | 47 | 17 | 112 |
| 132 | | | | | | | | | 130 | 39 | 94 | 6 | 135 | 118 | 131 | 82 | 40 | 89 | 133 | 79 |
| 133 | | | | | | | | | 73 | 100 | 127 | 21 | 20 | 82 | 84 | 111 | 234 | 86 | 145 | 96 |
| 134 | | | | | | | | | 129 | 86 | 152 | 22 | 62 | 76 | 155 | 60 | 197 | 50 | 59 | 104 |
| 135 | | | | | | | | | 58 | 105 | 145 | 12 | 40 | 23 | 185 | 62 | 218 | 3 | 112 | 5 |
| 136 | | | | | | | | | 30 | 79 | 161 | 25 | 31 | 83 | 132 | 44 | 81 | 69 | 116 | 90 |
| 137 | | | | | | | | | 94 | 2 | 89 | 118 | 72 | 107 | 97 | 79 | 219 | 85 | 44 | 45 |
| 138 | | | | | | | | | 43 | 61 | 137 | 98 | 174 | 31 | 20 | 39 | 139 | 19 | 246 | 42 |
| 139 | | | | | | | | | 12 | 98 | 65 | 24 | 148 | 10 | 144 | 71 | 205 | 91 | 37 | 25 |
| 140 | | | | | | | | | 97 | 99 | 64 | 56 | 175 | 77 | 16 | 56 | 106 | 113 | 70 | 19 |
| 141 | | | | | | | | | | | 24 | 65 | 98 | 55 | 77 | 109 | 213 | 13 | 187 | 12 |
| 142 | | | | | | | | | | | 108 | 8 | 162 | 65 | 86 | 26 | 118 | 24 | 45 | 113 |
| 143 | | | | | | | | | | | 164 | 68 | 47 | 95 | 175 | 9 | 133 | 6 | 120 | 63 |
| 144 | | | | | | | | | | | 82 | 89 | 156 | 91 | 119 | 99 | 209 | 32 | 140 | 29 |
| 145 | | | | | | | | | | | 79 | 42 | 64 | 1 | 0 | 9 | 119 | 90 | 206 | 36 |
| 146 | | | | | | | | | | | 100 | 97 | 110 | 12 | 148 | 105 | 189 | 52 | 138 | 14 |
| 147 | | | | | | | | | | | 101 | 2 | 30 | 52 | 55 | 0 | 55 | 29 | 66 | 59 |
| 148 | | | | | | | | | | | 29 | 103 | 101 | 26 | 164 | 107 | 13 | 110 | 137 | 8 |
| 149 | | | | | | | | | | | 22 | 59 | 132 | 43 | 39 | 34 | 59 | 107 | 211 | 99 |
| 150 | | | | | | | | | | | 133 | 82 | 48 | 15 | 139 | 108 | 207 | 22 | 233 | 91 |
| 151 | | | | | | | | | | | 107 | 46 | 178 | 37 | 49 | 66 | 64 | 37 | 41 | 34 |
| 152 | | | | | | | | | | | 136 | 115 | 5 | 17 | 67 | 57 | 122 | 84 | 256 | 104 |
| 153 | | | | | | | | | | | 52 | 107 | 77 | 36 | 31 | 47 | 152 | 15 | 162 | 51 |
| 154 | | | | | | | | | | | 81 | 106 | 141 | 7 | 211 | 74 | 28 | 93 | 216 | 30 |
| 155 | | | | | | | | | | | 147 | 95 | 155 | 42 | 161 | 23 | 132 | 64 | 38 | 86 |
| 156 | | | | | | | | | | | 39 | 55 | 122 | 6 | 28 | 25 | 174 | 111 | 56 | 74 |
| 157 | | | | | | | | | | | 139 | 33 | 37 | 112 | 78 | 32 | 210 | 9 | 34 | 107 |
| 158 | | | | | | | | | | | 50 | 17 | 23 | 51 | 197 | 50 | 92 | 44 | 36 | 85 |
| 159 | | | | | | | | | | | 44 | 71 | 13 | 116 | 14 | 102 | 232 | 0 | 185 | 116 |
| 160 | | | | | | | | | | | 16 | 72 | 42 | 49 | 198 | 104 | 208 | 14 | 182 | 9 |
| 161 | | | | | | | | | | | 125 | 60 | 44 | 98 | 141 | 112 | 224 | 70 | 234 | 78 |
| 162 | | | | | | | | | | | 9 | 64 | 70 | 79 | 206 | 42 | 96 | 95 | 212 | 2 |
| 163 | | | | | | | | | | | 28 | 74 | 126 | 108 | 40 | 28 | 61 | 80 | 93 | 119 |
| 164 | | | | | | | | | | | 46 | 101 | 96 | 106 | 66 | 83 | 79 | 114 | 175 | 67 |
| 165 | | | | | | | | | | | | | 151 | 54 | 193 | 69 | 125 | 25 | 54 | 42 |
| 166 | | | | | | | | | | | | | 39 | 40 | 15 | 27 | 114 | 48 | 107 | 76 |
| 167 | | | | | | | | | | | | | 140 | 8 | 35 | 94 | 101 | 112 | 226 | 31 |
| 168 | | | | | | | | | | | | | 76 | 90 | 183 | 95 | 76 | 62 | 220 | 95 |
| 169 | | | | | | | | | | | | | 165 | 38 | 82 | 97 | 86 | 3 | 87 | 44 |
| 170 | | | | | | | | | | | | | 61 | 35 | 166 | 91 | 203 | 78 | 64 | 17 |
| 171 | | | | | | | | | | | | | 45 | 64 | 73 | 29 | 108 | 16 | 97 | 109 |
| 172 | | | | | | | | | | | | | 123 | 13 | 205 | 5 | 238 | 53 | 142 | 55 |
| 173 | | | | | | | | | | | | | 54 | 31 | 202 | 21 | 84 | 63 | 79 | 49 |
| 174 | | | | | | | | | | | | | 164 | 47 | 48 | 50 | 147 | 8 | 245 | 37 |
| 175 | | | | | | | | | | | | | 94 | 80 | 189 | 113 | 134 | 57 | 25 | 35 |
| 176 | | | | | | | | | | | | | 67 | 24 | 79 | 15 | 25 | 102 | 121 | 115 |
| 177 | | | | | | | | | | | | | 134 | 74 | 174 | 37 | 63 | 22 | 125 | 83 |
| 178 | | | | | | | | | | | | | 99 | 11 | 24 | 35 | 14 | 75 | 148 | 58 |
| 179 | | | | | | | | | | | | | 146 | 57 | 34 | 59 | 37 | 0 | 126 | 118 |
| 180 | | | | | | | | | | | | | 112 | 60 | 36 | 42 | 201 | 38 | 244 | 98 |
| 181 | | | | | | | | | | | | | 66 | 69 | 181 | 63 | 124 | 106 | 207 | 0 |
| 182 | | | | | | | | | | | | | 160 | 9 | 159 | 103 | 239 | 89 | 230 | 68 |
| 183 | | | | | | | | | | | | | 15 | 85 | 59 | 14 | 212 | 105 | 40 | 78 |
| 184 | | | | | | | | | | | | | 159 | 18 | 13 | 40 | 74 | 13 | 0 | 28 |
| 185 | | | | | | | | | | | | | 161 | 75 | 186 | 73 | 16 | 20 | 8 | 57 |
| 186 | | | | | | | | | | | | | | | 129 | 89 | 228 | 18 | 250 | 20 |
| 187 | | | | | | | | | | | | | | | 123 | 38 | 36 | 91 | 210 | 35 |
| 188 | | | | | | | | | | | | | | | 94 | 93 | 167 | 66 | 11 | 61 |
| 189 | | | | | | | | | | | | | | | 124 | 65 | 143 | 34 | 62 | 22 |
| 190 | | | | | | | | | | | | | | | 203 | 86 | 89 | 26 | 83 | 77 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 191 | | | | | | | | | | | | | | | 99 | 2 | 5 | 50 | 224 | 18 |
| 192 | | | | | | | | | | | | | | | 9 | 21 | 121 | 11 | 194 | 52 |
| 193 | | | | | | | | | | | | | | | 126 | 67 | 184 | 69 | 237 | 93 |
| 194 | | | | | | | | | | | | | | | 89 | 13 | 138 | 100 | 27 | 116 |
| 195 | | | | | | | | | | | | | | | 95 | 54 | 211 | 97 | 58 | 80 |
| 196 | | | | | | | | | | | | | | | 93 | 116 | 164 | 77 | 5 | 47 |
| 197 | | | | | | | | | | | | | | | 172 | 31 | 144 | 58 | 171 | 106 |
| 198 | | | | | | | | | | | | | | | 208 | 85 | 110 | 79 | 179 | 117 |
| 199 | | | | | | | | | | | | | | | 107 | 46 | 104 | 104 | 261 | 49 |
| 200 | | | | | | | | | | | | | | | 27 | 85 | 226 | 98 | 57 | 0 |
| 201 | | | | | | | | | | | | | | | 18 | 81 | 24 | 6 | 77 | 73 |
| 202 | | | | | | | | | | | | | | | 72 | 7 | 131 | 43 | 6 | 82 |
| 203 | | | | | | | | | | | | | | | 5 | 11 | 38 | 76 | 113 | 112 |
| 204 | | | | | | | | | | | | | | | 150 | 98 | 168 | 71 | 105 | 84 |
| 205 | | | | | | | | | | | | | | | 81 | 84 | 34 | 60 | 183 | 89 |
| 206 | | | | | | | | | | | | | | | 116 | 3 | 230 | 45 | 85 | 101 |
| 207 | | | | | | | | | | | | | | | 177 | 119 | 51 | 74 | 96 | 95 |
| 208 | | | | | | | | | | | | | | | 143 | 114 | 71 | 28 | 227 | 45 |
| 209 | | | | | | | | | | | | | | | 146 | 110 | 18 | 32 | 84 | 27 |
| 210 | | | | | | | | | | | | | | | 62 | 58 | 113 | 117 | 253 | 15 |
| 211 | | | | | | | | | | | | | | | 137 | 27 | 123 | 59 | 204 | 10 |
| 212 | | | | | | | | | | | | | | | 44 | 45 | 200 | 44 | 218 | 113 |
| 213 | | | | | | | | | | | | | | | | | 21 | 55 | 109 | 110 |
| 214 | | | | | | | | | | | | | | | | | 227 | 83 | 254 | 59 |
| 215 | | | | | | | | | | | | | | | | | 53 | 81 | 117 | 4 |
| 216 | | | | | | | | | | | | | | | | | 148 | 4 | 248 | 28 |
| 217 | | | | | | | | | | | | | | | | | 172 | 51 | 152 | 72 |
| 218 | | | | | | | | | | | | | | | | | 199 | 113 | 71 | 91 |
| 219 | | | | | | | | | | | | | | | | | 107 | 40 | 69 | 3 |
| 220 | | | | | | | | | | | | | | | | | 115 | 41 | 68 | 32 |
| 221 | | | | | | | | | | | | | | | | | 82 | 97 | 78 | 75 |
| 222 | | | | | | | | | | | | | | | | | 185 | 10 | 215 | 94 |
| 223 | | | | | | | | | | | | | | | | | 93 | 1 | 12 | 103 |
| 224 | | | | | | | | | | | | | | | | | 130 | 17 | 184 | 17 |
| 225 | | | | | | | | | | | | | | | | | 120 | 31 | 178 | 24 |
| 226 | | | | | | | | | | | | | | | | | 46 | 64 | 225 | 40 |
| 227 | | | | | | | | | | | | | | | | | 12 | 27 | 180 | 41 |
| 228 | | | | | | | | | | | | | | | | | 163 | 30 | 266 | 71 |
| 229 | | | | | | | | | | | | | | | | | 176 | 102 | 186 | 61 |
| 230 | | | | | | | | | | | | | | | | | 169 | 107 | 264 | 13 |
| 231 | | | | | | | | | | | | | | | | | 98 | 39 | 199 | 65 |
| 232 | | | | | | | | | | | | | | | | | 7 | 25 | 265 | 86 |
| 233 | | | | | | | | | | | | | | | | | 39 | 77 | 164 | 107 |
| 234 | | | | | | | | | | | | | | | | | 66 | 105 | 174 | 54 |
| 235 | | | | | | | | | | | | | | | | | 175 | 87 | 76 | 23 |
| 236 | | | | | | | | | | | | | | | | | 90 | 52 | 13 | 5 |
| 237 | | | | | | | | | | | | | | | | | 6 | 57 | 14 | 102 |
| 238 | | | | | | | | | | | | | | | | | 78 | 15 | 28 | 9 |
| 239 | | | | | | | | | | | | | | | | | 220 | 64 | 243 | 108 |
| 240 | | | | | | | | | | | | | | | | | | | 191 | 19 |
| 241 | | | | | | | | | | | | | | | | | | | 136 | 60 |
| 242 | | | | | | | | | | | | | | | | | | | 231 | 33 |
| 243 | | | | | | | | | | | | | | | | | | | 30 | 63 |
| 244 | | | | | | | | | | | | | | | | | | | 130 | 92 |
| 245 | | | | | | | | | | | | | | | | | | | 128 | 30 |
| 246 | | | | | | | | | | | | | | | | | | | 60 | 56 |
| 247 | | | | | | | | | | | | | | | | | | | 39 | 106 |
| 248 | | | | | | | | | | | | | | | | | | | 103 | 45 |
| 249 | | | | | | | | | | | | | | | | | | | 214 | 63 |
| 250 | | | | | | | | | | | | | | | | | | | 81 | 6 |
| 251 | | | | | | | | | | | | | | | | | | | 123 | 64 |
| 252 | | | | | | | | | | | | | | | | | | | 15 | 117 |
| 253 | | | | | | | | | | | | | | | | | | | 154 | 1 |
| 254 | | | | | | | | | | | | | | | | | | | 75 | 11 |
| 255 | | | | | | | | | | | | | | | | | | | 192 | 74 |
| 256 | | | | | | | | | | | | | | | | | | | 159 | 25 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 257 | | | | | | | | | | | | | | | | | | | 163 | 119 |
| 258 | | | | | | | | | | | | | | | | | | | 247 | 3 |
| 259 | | | | | | | | | | | | | | | | | | | 52 | 88 |
| 260 | | | | | | | | | | | | | | | | | | | 147 | 37 |
| 261 | | | | | | | | | | | | | | | | | | | 203 | 42 |
| 262 | | | | | | | | | | | | | | | | | | | 169 | 70 |
| 263 | | | | | | | | | | | | | | | | | | | 157 | 82 |
| 264 | | | | | | | | | | | | | | | | | | | 177 | 100 |
| 265 | | | | | | | | | | | | | | | | | | | 42 | 118 |
| 266 | | | | | | | | | | | | | | | | | | | 4 | 31 |

## Table C-2: Interleaver Parameters (11 to 19)

| | 11 | | 12 | | 13 | | 14 | | 15 | | 16 | | 17 | | 18 | | 19 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N=35280 W=294 S1=158 S2=158 | | N=38880 W=324 S1=166 S2=166 | | N=42480 W=354 S1=174 S2=174 | | N=46440 W=387 S1=193 S2=193 | | N=50040 W=417 S1=189 S2=189 | | N=54000 W=450 S1=208 S2=208 | | N=57960 W=483 S1=215 S2=215 | | N=61560 W=513 S1=222 S2=222 | | N=65520 W=546 S1=216 S2=216 | |
| | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ |
| 0 | 30 | 28 | 193 | 72 | 238 | 48 | 374 | 11 | 147 | 48 | 211 | 24 | 153 | 110 | 380 | 92 | 282 | 83 |
| 1 | 165 | 81 | 208 | 10 | 260 | 88 | 269 | 31 | 76 | 100 | 353 | 68 | 307 | 101 | 415 | 60 | 437 | 63 |
| 2 | 156 | 103 | 3 | 107 | 253 | 11 | 21 | 35 | 22 | 84 | 430 | 37 | 274 | 42 | 81 | 60 | 397 | 89 |
| 3 | 235 | 46 | 254 | 13 | 208 | 43 | 84 | 46 | 64 | 92 | 56 | 55 | 291 | 45 | 327 | 41 | 471 | 115 |
| 4 | 15 | 75 | 165 | 59 | 130 | 102 | 6 | 45 | 53 | 64 | 242 | 50 | 158 | 50 | 60 | 21 | 218 | 29 |
| 5 | 126 | 82 | 81 | 50 | 190 | 79 | 91 | 85 | 50 | 39 | 440 | 76 | 141 | 75 | 289 | 28 | 62 | 79 |
| 6 | 203 | 34 | 154 | 42 | 193 | 2 | 81 | 33 | 219 | 63 | 111 | 67 | 241 | 112 | 341 | 16 | 65 | 0 |
| 7 | 270 | 112 | 38 | 77 | 122 | 73 | 227 | 115 | 134 | 16 | 354 | 11 | 80 | 62 | 162 | 31 | 396 | 88 |
| 8 | 189 | 71 | 104 | 83 | 118 | 47 | 324 | 49 | 406 | 0 | 123 | 96 | 310 | 1 | 409 | 104 | 172 | 93 |
| 9 | 103 | 85 | 216 | 52 | 317 | 95 | 367 | 36 | 315 | 118 | 109 | 89 | 83 | 66 | 95 | 116 | 182 | 49 |
| 10 | 145 | 1 | 63 | 68 | 177 | 42 | 225 | 64 | 416 | 62 | 80 | 23 | 110 | 82 | 159 | 29 | 84 | 88 |
| 11 | 186 | 92 | 68 | 109 | 224 | 111 | 294 | 108 | 187 | 79 | 126 | 63 | 433 | 105 | 330 | 105 | 116 | 48 |
| 12 | 264 | 7 | 116 | 4 | 143 | 89 | 159 | 28 | 307 | 1 | 396 | 51 | 17 | 47 | 262 | 57 | 120 | 98 |
| 13 | 218 | 109 | 292 | 44 | 181 | 100 | 277 | 110 | 252 | 85 | 51 | 106 | 386 | 18 | 157 | 9 | 224 | 39 |
| 14 | 52 | 57 | 31 | 13 | 178 | 86 | 265 | 27 | 373 | 106 | 34 | 2 | 298 | 38 | 223 | 115 | 0 | 41 |
| 15 | 265 | 55 | 167 | 57 | 29 | 30 | 87 | 34 | 146 | 104 | 302 | 73 | 89 | 59 | 170 | 63 | 174 | 107 |
| 16 | 141 | 24 | 322 | 114 | 64 | 40 | 193 | 53 | 115 | 87 | 386 | 25 | 478 | 54 | 34 | 118 | 424 | 0 |
| 17 | 181 | 106 | 94 | 65 | 173 | 81 | 258 | 15 | 293 | 29 | 161 | 94 | 40 | 105 | 137 | 44 | 362 | 105 |
| 18 | 208 | 108 | 122 | 67 | 315 | 50 | 8 | 56 | 291 | 10 | 292 | 79 | 279 | 63 | 411 | 25 | 247 | 52 |
| 19 | 9 | 51 | 21 | 19 | 198 | 3 | 141 | 48 | 33 | 97 | 30 | 16 | 361 | 60 | 269 | 13 | 511 | 82 |
| 20 | 88 | 76 | 201 | 90 | 46 | 7 | 210 | 61 | 257 | 75 | 267 | 8 | 130 | 41 | 174 | 110 | 343 | 95 |
| 21 | 196 | 100 | 86 | 0 | 258 | 0 | 89 | 4 | 399 | 90 | 163 | 21 | 230 | 99 | 197 | 103 | 245 | 59 |
| 22 | 32 | 19 | 23 | 24 | 108 | 98 | 205 | 23 | 213 | 94 | 337 | 6 | 425 | 12 | 4 | 64 | 15 | 105 |
| 23 | 78 | 40 | 270 | 15 | 106 | 69 | 195 | 67 | 4 | 46 | 202 | 5 | 35 | 22 | 202 | 37 | 262 | 96 |
| 24 | 130 | 17 | 236 | 78 | 7 | 50 | 279 | 33 | 207 | 43 | 147 | 54 | 19 | 95 | 110 | 49 | 300 | 60 |
| 25 | 162 | 29 | 7 | 36 | 167 | 101 | 338 | 118 | 233 | 70 | 232 | 49 | 280 | 102 | 437 | 58 | 207 | 11 |
| 26 | 269 | 83 | 227 | 43 | 308 | 51 | 82 | 98 | 266 | 6 | 420 | 2 | 166 | 37 | 180 | 7 | 26 | 31 |
| 27 | 42 | 118 | 307 | 87 | 139 | 105 | 151 | 59 | 39 | 25 | 426 | 14 | 49 | 76 | 375 | 94 | 130 | 35 |
| 28 | 99 | 26 | 316 | 63 | 68 | 85 | 202 | 10 | 249 | 116 | 221 | 110 | 248 | 25 | 368 | 3 | 539 | 46 |
| 29 | 22 | 74 | 44 | 78 | 262 | 96 | 40 | 40 | 405 | 51 | 28 | 83 | 119 | 17 | 337 | 55 | 230 | 45 |
| 30 | 192 | 31 | 27 | 21 | 125 | 19 | 63 | 69 | 226 | 66 | 437 | 115 | 71 | 38 | 475 | 42 | 136 | 85 |
| 31 | 147 | 80 | 297 | 32 | 246 | 91 | 90 | 78 | 341 | 17 | 262 | 77 | 170 | 13 | 303 | 81 | 305 | 33 |
| 32 | 221 | 3 | 285 | 85 | 129 | 114 | 358 | 94 | 203 | 98 | 324 | 40 | 466 | 76 | 176 | 23 | 281 | 36 |
| 33 | 16 | 38 | 279 | 21 | 295 | 30 | 10 | 80 | 73 | 73 | 20 | 43 | 387 | 95 | 320 | 79 | 285 | 64 |
| 34 | 182 | 77 | 175 | 119 | 87 | 119 | 121 | 94 | 110 | 34 | 307 | 69 | 123 | 6 | 397 | 36 | 485 | 108 |
| 35 | 188 | 107 | 192 | 70 | 72 | 17 | 85 | 5 | 62 | 26 | 1 | 85 | 327 | 36 | 169 | 62 | 209 | 28 |
| 36 | 73 | 11 | 37 | 103 | 332 | 9 | 158 | 79 | 89 | 10 | 37 | 111 | 200 | 51 | 447 | 73 | 145 | 110 |
| 37 | 159 | 10 | 293 | 92 | 226 | 1 | 318 | 76 | 359 | 15 | 77 | 105 | 4 | 34 | 372 | 77 | 500 | 27 |
| 38 | 256 | 48 | 239 | 80 | 232 | 113 | 16 | 73 | 204 | 81 | 359 | 38 | 333 | 16 | 291 | 84 | 67 | 34 |
| 39 | 21 | 2 | 32 | 96 | 94 | 13 | 167 | 50 | 58 | 15 | 3 | 32 | 464 | 13 | 134 | 38 | 2 | 53 |
| 40 | 10 | 63 | 162 | 118 | 307 | 22 | 322 | 88 | 124 | 93 | 264 | 112 | 103 | 46 | 84 | 66 | 436 | 15 |
| 41 | 72 | 102 | 30 | 114 | 67 | 109 | 68 | 1 | 358 | 18 | 412 | 94 | 142 | 39 | 443 | 96 | 491 | 56 |
| 42 | 61 | 59 | 310 | 38 | 329 | 24 | 168 | 24 | 247 | 102 | 410 | 52 | 470 | 112 | 154 | 34 | 512 | 48 |
| 43 | 169 | 52 | 218 | 30 | 98 | 6 | 119 | 114 | 104 | 50 | 435 | 108 | 108 | 71 | 385 | 26 | 277 | 61 |
| 44 | 232 | 41 | 209 | 49 | 282 | 94 | 303 | 1 | 250 | 88 | 185 | 88 | 67 | 70 | 190 | 111 | 232 | 4 |
| 45 | 283 | 54 | 146 | 94 | 303 | 70 | 263 | 37 | 116 | 76 | 261 | 7 | 93 | 24 | 51 | 81 | 259 | 23 |
| 46 | 271 | 85 | 315 | 68 | 142 | 67 | 28 | 31 | 323 | 119 | 79 | 99 | 253 | 111 | 423 | 102 | 355 | 67 |
| 47 | 6 | 66 | 2 | 82 | 55 | 32 | 350 | 20 | 152 | 65 | 220 | 27 | 315 | 52 | 500 | 47 | 310 | 118 |
| 48 | 171 | 86 | 206 | 12 | 1 | 79 | 172 | 2 | 170 | 19 | 206 | 70 | 451 | 83 | 165 | 19 | 384 | 98 |
| 49 | 29 | 12 | 265 | 62 | 250 | 90 | 382 | 19 | 362 | 50 | 175 | 117 | 105 | 56 | 501 | 0 | 261 | 10 |
| 50 | 279 | 12 | 281 | 110 | 10 | 86 | 174 | 18 | 156 | 71 | 168 | 20 | 269 | 84 | 357 | 29 | 265 | 40 |
| 51 | 115 | 61 | 191 | 31 | 318 | 80 | 293 | 47 | 237 | 11 | 186 | 48 | 442 | 42 | 469 | 71 | 367 | 69 |
| 52 | 199 | 8 | 184 | 54 | 274 | 23 | 114 | 118 | 121 | 30 | 263 | 111 | 175 | 97 | 226 | 70 | 513 | 94 |
| 53 | 285 | 93 | 282 | 6 | 306 | 99 | 30 | 27 | 238 | 27 | 394 | 66 | 155 | 68 | 377 | 65 | 475 | 80 |
| 54 | 231 | 67 | 305 | 99 | 233 | 52 | 234 | 91 | 285 | 23 | 280 | 72 | 51 | 73 | 151 | 22 | 228 | 94 |
| 55 | 272 | 114 | 9 | 97 | 284 | 89 | 333 | 112 | 385 | 76 | 38 | 31 | 33 | 74 | 482 | 53 | 184 | 5 |
| 56 | 194 | 5 | 140 | 34 | 21 | 29 | 96 | 102 | 240 | 73 | 49 | 104 | 216 | 80 | 358 | 5 | 323 | 76 |
| 57 | 129 | 27 | 214 | 48 | 255 | 110 | 247 | 51 | 65 | 9 | 289 | 96 | 271 | 64 | 206 | 39 | 44 | 73 |
| 58 | 210 | 98 | 158 | 60 | 289 | 69 | 215 | 14 | 95 | 21 | 407 | 45 | 2 | 45 | 12 | 86 | 398 | 50 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | 19 | 89 | 109 | 85 | 163 | 18 | 189 | 72 | 175 | 53 | 365 | 19 | 357 | 90 | 294 | 15 | 258 | 111 |
| 60 | 253 | 115 | 278 | 103 | 6 | 58 | 380 | 8 | 316 | 41 | 245 | 107 | 448 | 77 | 192 | 71 | 221 | 1 |
| 61 | 163 | 64 | 289 | 8 | 343 | 107 | 252 | 45 | 348 | 99 | 447 | 119 | 101 | 9 | 381 | 9 | 446 | 24 |
| 62 | 263 | 69 | 42 | 12 | 144 | 118 | 297 | 70 | 374 | 78 | 23 | 37 | 403 | 82 | 346 | 113 | 141 | 114 |
| 63 | 255 | 113 | 126 | 40 | 124 | 27 | 307 | 92 | 44 | 6 | 223 | 51 | 432 | 79 | 8 | 2 | 444 | 1 |
| 64 | 259 | 99 | 55 | 95 | 96 | 72 | 329 | 98 | 93 | 119 | 103 | 42 | 370 | 43 | 384 | 40 | 201 | 37 |
| 65 | 275 | 45 | 74 | 58 | 221 | 87 | 117 | 101 | 60 | 116 | 290 | 46 | 356 | 47 | 243 | 12 | 216 | 31 |
| 66 | 282 | 87 | 274 | 22 | 188 | 46 | 102 | 25 | 300 | 47 | 443 | 93 | 203 | 23 | 379 | 23 | 39 | 20 |
| 67 | 175 | 96 | 242 | 29 | 111 | 38 | 154 | 107 | 334 | 22 | 296 | 99 | 339 | 22 | 394 | 112 | 45 | 15 |
| 68 | 83 | 117 | 13 | 42 | 323 | 20 | 250 | 5 | 310 | 44 | 224 | 9 | 249 | 21 | 344 | 98 | 492 | 2 |
| 69 | 227 | 47 | 58 | 117 | 172 | 107 | 136 | 54 | 88 | 60 | 266 | 10 | 435 | 10 | 237 | 4 | 203 | 19 |
| 70 | 288 | 19 | 129 | 26 | 214 | 65 | 238 | 17 | 162 | 108 | 73 | 114 | 106 | 3 | 486 | 86 | 168 | 18 |
| 71 | 164 | 53 | 143 | 84 | 169 | 84 | 330 | 32 | 212 | 28 | 201 | 17 | 380 | 7 | 251 | 72 | 227 | 47 |
| 72 | 108 | 42 | 323 | 4 | 89 | 15 | 199 | 3 | 41 | 72 | 193 | 44 | 383 | 0 | 147 | 117 | 1 | 23 |
| 73 | 202 | 104 | 114 | 110 | 247 | 93 | 50 | 70 | 21 | 82 | 130 | 97 | 56 | 107 | 193 | 27 | 284 | 113 |
| 74 | 82 | 25 | 34 | 41 | 297 | 62 | 363 | 52 | 28 | 49 | 284 | 22 | 346 | 29 | 326 | 80 | 64 | 27 |
| 75 | 55 | 101 | 69 | 27 | 342 | 4 | 266 | 9 | 264 | 58 | 120 | 41 | 382 | 34 | 119 | 107 | 135 | 91 |
| 76 | 3 | 93 | 204 | 36 | 270 | 64 | 161 | 77 | 57 | 47 | 195 | 2 | 300 | 30 | 462 | 51 | 211 | 112 |
| 77 | 26 | 36 | 59 | 15 | 286 | 103 | 45 | 63 | 317 | 49 | 214 | 36 | 469 | 4 | 488 | 111 | 435 | 4 |
| 78 | 89 | 41 | 43 | 66 | 335 | 102 | 245 | 34 | 254 | 4 | 327 | 18 | 254 | 14 | 200 | 100 | 17 | 10 |
| 79 | 140 | 51 | 229 | 20 | 9 | 37 | 133 | 74 | 392 | 56 | 100 | 118 | 364 | 89 | 400 | 24 | 443 | 102 |
| 80 | 20 | 39 | 77 | 37 | 325 | 115 | 126 | 44 | 10 | 55 | 136 | 56 | 94 | 86 | 124 | 91 | 179 | 51 |
| 81 | 178 | 30 | 33 | 10 | 346 | 111 | 83 | 19 | 137 | 20 | 87 | 86 | 456 | 31 | 1 | 101 | 322 | 14 |
| 82 | 40 | 37 | 179 | 86 | 191 | 45 | 116 | 49 | 239 | 87 | 196 | 87 | 95 | 104 | 455 | 6 | 369 | 72 |
| 83 | 291 | 29 | 148 | 45 | 293 | 10 | 185 | 22 | 286 | 7 | 275 | 60 | 330 | 94 | 481 | 62 | 522 | 8 |
| 84 | 53 | 23 | 159 | 79 | 34 | 44 | 286 | 40 | 2 | 81 | 346 | 24 | 338 | 20 | 338 | 97 | 479 | 45 |
| 85 | 293 | 15 | 117 | 106 | 121 | 94 | 346 | 64 | 26 | 12 | 338 | 26 | 304 | 110 | 145 | 82 | 393 | 70 |
| 86 | 17 | 106 | 212 | 98 | 99 | 0 | 152 | 7 | 382 | 114 | 349 | 90 | 471 | 32 | 207 | 53 | 417 | 92 |
| 87 | 28 | 6 | 152 | 97 | 264 | 14 | 53 | 62 | 377 | 108 | 167 | 82 | 181 | 114 | 29 | 85 | 473 | 101 |
| 88 | 209 | 58 | 98 | 25 | 334 | 47 | 64 | 83 | 283 | 39 | 425 | 91 | 266 | 115 | 86 | 56 | 504 | 25 |
| 89 | 251 | 84 | 151 | 24 | 86 | 113 | 7 | 92 | 190 | 1 | 155 | 101 | 440 | 96 | 205 | 54 | 478 | 107 |
| 90 | 176 | 22 | 160 | 64 | 185 | 7 | 244 | 68 | 282 | 83 | 105 | 115 | 388 | 71 | 94 | 93 | 53 | 54 |
| 91 | 289 | 68 | 182 | 100 | 136 | 80 | 135 | 55 | 172 | 67 | 119 | 69 | 452 | 1 | 487 | 8 | 123 | 17 |
| 92 | 134 | 7 | 103 | 61 | 338 | 104 | 257 | 116 | 353 | 32 | 41 | 61 | 135 | 8 | 21 | 57 | 332 | 32 |
| 93 | 65 | 0 | 48 | 98 | 14 | 92 | 148 | 60 | 183 | 2 | 241 | 113 | 384 | 3 | 26 | 5 | 453 | 119 |
| 94 | 243 | 28 | 120 | 23 | 39 | 33 | 26 | 17 | 159 | 14 | 95 | 71 | 428 | 5 | 224 | 99 | 195 | 9 |
| 95 | 206 | 63 | 238 | 17 | 339 | 40 | 97 | 26 | 9 | 98 | 306 | 64 | 404 | 55 | 39 | 84 | 337 | 77 |
| 96 | 154 | 19 | 28 | 91 | 107 | 25 | 22 | 115 | 389 | 116 | 422 | 59 | 447 | 98 | 97 | 14 | 92 | 63 |
| 97 | 56 | 77 | 180 | 87 | 61 | 59 | 315 | 93 | 206 | 17 | 371 | 0 | 190 | 35 | 58 | 24 | 423 | 73 |
| 98 | 27 | 110 | 121 | 72 | 160 | 48 | 345 | 28 | 67 | 112 | 279 | 34 | 154 | 42 | 234 | 60 | 271 | 34 |
| 99 | 184 | 111 | 221 | 75 | 90 | 70 | 253 | 85 | 265 | 89 | 125 | 95 | 294 | 2 | 214 | 76 | 374 | 3 |
| 100 | 94 | 73 | 101 | 33 | 187 | 32 | 232 | 111 | 274 | 5 | 234 | 76 | 245 | 109 | 222 | 87 | 421 | 74 |
| 101 | 75 | 3 | 64 | 71 | 78 | 31 | 184 | 104 | 378 | 86 | 117 | 80 | 399 | 117 | 392 | 110 | 304 | 44 |
| 102 | 119 | 13 | 147 | 63 | 230 | 33 | 77 | 66 | 325 | 110 | 364 | 62 | 368 | 92 | 416 | 114 | 335 | 93 |
| 103 | 69 | 91 | 135 | 55 | 73 | 36 | 143 | 88 | 98 | 68 | 21 | 30 | 134 | 26 | 72 | 26 | 5 | 19 |
| 104 | 35 | 81 | 72 | 74 | 352 | 2 | 251 | 11 | 78 | 43 | 377 | 78 | 431 | 108 | 188 | 18 | 406 | 49 |
| 105 | 284 | 118 | 115 | 99 | 104 | 78 | 98 | 6 | 227 | 109 | 177 | 57 | 244 | 48 | 14 | 31 | 353 | 115 |
| 106 | 127 | 90 | 138 | 82 | 305 | 16 | 260 | 96 | 102 | 114 | 332 | 13 | 11 | 27 | 257 | 51 | 75 | 22 |
| 107 | 250 | 97 | 269 | 1 | 340 | 105 | 4 | 76 | 281 | 52 | 392 | 74 | 136 | 31 | 454 | 39 | 484 | 23 |
| 108 | 123 | 46 | 12 | 73 | 197 | 53 | 275 | 58 | 410 | 12 | 169 | 53 | 29 | 111 | 352 | 19 | 52 | 64 |
| 109 | 260 | 9 | 82 | 52 | 265 | 17 | 278 | 39 | 109 | 78 | 331 | 16 | 179 | 54 | 2 | 39 | 292 | 7 |
| 110 | 143 | 44 | 52 | 108 | 84 | 64 | 49 | 75 | 267 | 115 | 151 | 58 | 343 | 65 | 178 | 58 | 103 | 62 |
| 111 | 240 | 116 | 210 | 101 | 174 | 63 | 353 | 53 | 368 | 91 | 311 | 75 | 208 | 95 | 85 | 98 | 100 | 92 |
| 112 | 204 | 74 | 19 | 50 | 299 | 8 | 372 | 71 | 355 | 36 | 29 | 51 | 233 | 116 | 458 | 115 | 541 | 68 |
| 113 | 85 | 114 | 166 | 35 | 80 | 95 | 366 | 106 | 143 | 91 | 384 | 61 | 221 | 49 | 493 | 7 | 450 | 55 |
| 114 | 225 | 0 | 189 | 18 | 312 | 15 | 180 | 73 | 14 | 62 | 129 | 14 | 446 | 111 | 351 | 31 | 291 | 116 |
| 115 | 274 | 101 | 57 | 92 | 37 | 102 | 240 | 90 | 361 | 38 | 446 | 27 | 318 | 44 | 32 | 102 | 153 | 89 |
| 116 | 70 | 82 | 0 | 87 | 202 | 119 | 370 | 3 | 222 | 34 | 181 | 15 | 402 | 100 | 184 | 108 | 386 | 26 |
| 117 | 36 | 22 | 222 | 112 | 320 | 75 | 343 | 113 | 196 | 106 | 165 | 90 | 250 | 33 | 264 | 75 | 339 | 35 |
| 118 | 0 | 35 | 290 | 53 | 278 | 25 | 273 | 80 | 356 | 105 | 428 | 21 | 441 | 80 | 343 | 107 | 41 | 118 |
| 119 | 38 | 31 | 257 | 83 | 152 | 116 | 37 | 52 | 241 | 48 | 256 | 105 | 31 | 79 | 23 | 45 | 519 | 64 |
| 120 | 112 | 50 | 194 | 116 | 47 | 34 | 298 | 97 | 129 | 99 | 191 | 29 | 415 | 39 | 417 | 59 | 48 | 4 |
| 121 | 290 | 42 | 157 | 22 | 182 | 22 | 368 | 57 | 184 | 35 | 237 | 109 | 129 | 103 | 201 | 65 | 505 | 28 |
| 122 | 179 | 76 | 237 | 46 | 231 | 44 | 235 | 12 | 108 | 74 | 114 | 18 | 389 | 99 | 229 | 68 | 21 | 111 |
| 123 | 233 | 94 | 235 | 28 | 313 | 59 | 111 | 43 | 42 | 95 | 131 | 32 | 211 | 76 | 474 | 119 | 390 | 104 |
| 124 | 128 | 21 | 111 | 53 | 341 | 86 | 128 | 103 | 197 | 55 | 27 | 40 | 240 | 87 | 24 | 89 | 464 | 66 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125 | 8 | 27 | 168 | 91 | 162 | 106 | 147 | 37 | 100 | 105 | 313 | 4 | 287 | 67 | 16 | 51 | 415 | 10 |
| 126 | 247 | 70 | 299 | 5 | 301 | 67 | 213 | 109 | 105 | 61 | 116 | 52 | 68 | 108 | 426 | 89 | 410 | 11 |
| 127 | 139 | 15 | 61 | 30 | 123 | 115 | 268 | 100 | 302 | 117 | 198 | 68 | 82 | 93 | 102 | 92 | 447 | 6 |
| 128 | 193 | 39 | 173 | 68 | 281 | 13 | 288 | 4 | 23 | 101 | 68 | 78 | 270 | 75 | 50 | 3 | 480 | 96 |
| 129 | 44 | 34 | 131 | 16 | 259 | 97 | 311 | 29 | 371 | 103 | 406 | 8 | 276 | 104 | 203 | 67 | 29 | 76 |
| 130 | 220 | 55 | 1 | 14 | 175 | 20 | 103 | 56 | 133 | 46 | 411 | 63 | 24 | 18 | 150 | 77 | 77 | 58 |
| 131 | 216 | 103 | 155 | 41 | 133 | 75 | 108 | 81 | 191 | 107 | 413 | 53 | 138 | 0 | 80 | 25 | 76 | 39 |
| 132 | 60 | 116 | 56 | 115 | 183 | 57 | 59 | 28 | 31 | 83 | 423 | 69 | 302 | 62 | 464 | 18 | 375 | 19 |
| 133 | 183 | 85 | 88 | 77 | 33 | 91 | 57 | 32 | 388 | 26 | 137 | 45 | 457 | 93 | 370 | 64 | 442 | 47 |
| 134 | 80 | 32 | 108 | 62 | 235 | 66 | 226 | 105 | 364 | 13 | 121 | 81 | 354 | 8 | 44 | 73 | 106 | 68 |
| 135 | 180 | 40 | 6 | 38 | 3 | 99 | 149 | 33 | 260 | 111 | 351 | 54 | 413 | 74 | 212 | 8 | 246 | 24 |
| 136 | 239 | 77 | 217 | 96 | 135 | 104 | 187 | 38 | 142 | 102 | 281 | 86 | 234 | 88 | 45 | 11 | 237 | 21 |
| 137 | 168 | 62 | 301 | 34 | 113 | 26 | 46 | 71 | 397 | 31 | 238 | 66 | 482 | 48 | 166 | 33 | 133 | 77 |
| 138 | 114 | 54 | 145 | 88 | 119 | 50 | 386 | 7 | 179 | 31 | 45 | 112 | 422 | 70 | 195 | 6 | 131 | 16 |
| 139 | 14 | 79 | 150 | 10 | 348 | 1 | 352 | 54 | 218 | 77 | 350 | 95 | 267 | 105 | 82 | 47 | 150 | 14 |
| 140 | 120 | 18 | 317 | 30 | 314 | 11 | 373 | 117 | 186 | 45 | 300 | 71 | 220 | 28 | 319 | 50 | 349 | 53 |
| 141 | 205 | 65 | 286 | 117 | 213 | 35 | 204 | 16 | 154 | 118 | 180 | 28 | 20 | 116 | 442 | 82 | 427 | 59 |
| 142 | 131 | 87 | 90 | 81 | 292 | 42 | 337 | 35 | 12 | 80 | 378 | 82 | 437 | 53 | 108 | 61 | 461 | 106 |
| 143 | 117 | 105 | 207 | 76 | 88 | 4 | 203 | 78 | 120 | 69 | 13 | 119 | 151 | 101 | 354 | 2 | 445 | 62 |
| 144 | 190 | 33 | 304 | 77 | 12 | 52 | 101 | 0 | 25 | 48 | 219 | 91 | 353 | 114 | 191 | 81 | 331 | 90 |
| 145 | 93 | 71 | 65 | 107 | 83 | 21 | 179 | 30 | 393 | 85 | 269 | 94 | 14 | 98 | 349 | 34 | 118 | 3 |
| 146 | 261 | 13 | 321 | 118 | 52 | 83 | 312 | 67 | 208 | 93 | 53 | 33 | 10 | 17 | 322 | 78 | 33 | 113 |
| 147 | 62 | 83 | 188 | 69 | 345 | 6 | 134 | 23 | 313 | 57 | 312 | 106 | 303 | 107 | 52 | 95 | 303 | 80 |
| 148 | 174 | 2 | 267 | 60 | 257 | 95 | 376 | 81 | 298 | 0 | 259 | 102 | 187 | 63 | 348 | 14 | 527 | 97 |
| 149 | 170 | 14 | 36 | 67 | 242 | 78 | 281 | 61 | 201 | 24 | 277 | 114 | 150 | 117 | 181 | 21 | 159 | 57 |
| 150 | 172 | 59 | 137 | 11 | 271 | 85 | 296 | 59 | 125 | 66 | 176 | 116 | 157 | 4 | 18 | 62 | 229 | 12 |
| 151 | 34 | 45 | 54 | 104 | 69 | 62 | 310 | 44 | 366 | 87 | 204 | 98 | 472 | 24 | 406 | 48 | 42 | 90 |
| 152 | 2 | 7 | 246 | 93 | 205 | 19 | 201 | 62 | 119 | 4 | 385 | 104 | 137 | 85 | 158 | 52 | 320 | 43 |
| 153 | 276 | 24 | 17 | 101 | 290 | 31 | 61 | 57 | 18 | 54 | 375 | 73 | 149 | 113 | 156 | 36 | 455 | 86 |
| 154 | 64 | 88 | 123 | 39 | 249 | 114 | 264 | 99 | 193 | 97 | 200 | 1 | 113 | 65 | 270 | 104 | 112 | 103 |
| 155 | 74 | 60 | 224 | 40 | 298 | 88 | 160 | 86 | 396 | 88 | 326 | 81 | 460 | 18 | 471 | 103 | 414 | 65 |
| 156 | 107 | 115 | 240 | 47 | 40 | 66 | 130 | 119 | 66 | 84 | 212 | 93 | 410 | 118 | 399 | 54 | 326 | 37 |
| 157 | 213 | 38 | 260 | 119 | 140 | 77 | 236 | 21 | 27 | 100 | 194 | 3 | 121 | 89 | 350 | 106 | 405 | 109 |
| 158 | 102 | 70 | 252 | 7 | 272 | 109 | 347 | 14 | 221 | 104 | 32 | 12 | 90 | 69 | 49 | 106 | 68 | 100 |
| 159 | 101 | 66 | 215 | 95 | 330 | 46 | 70 | 91 | 171 | 18 | 4 | 24 | 237 | 18 | 142 | 35 | 382 | 29 |
| 160 | 155 | 113 | 241 | 50 | 210 | 96 | 218 | 41 | 13 | 35 | 438 | 83 | 391 | 57 | 277 | 17 | 87 | 59 |
| 161 | 201 | 102 | 8 | 32 | 154 | 56 | 359 | 95 | 48 | 67 | 439 | 49 | 263 | 77 | 292 | 92 | 104 | 94 |
| 162 | 76 | 49 | 313 | 18 | 328 | 53 | 267 | 26 | 277 | 21 | 108 | 72 | 193 | 43 | 196 | 105 | 97 | 70 |
| 163 | 158 | 106 | 113 | 51 | 217 | 82 | 207 | 46 | 72 | 41 | 7 | 57 | 374 | 35 | 388 | 46 | 219 | 56 |
| 164 | 110 | 29 | 288 | 36 | 227 | 118 | 357 | 48 | 200 | 23 | 88 | 108 | 50 | 50 | 89 | 15 | 180 | 6 |
| 165 | 13 | 8 | 213 | 73 | 201 | 40 | 76 | 80 | 319 | 30 | 62 | 19 | 88 | 84 | 408 | 95 | 196 | 81 |
| 166 | 226 | 36 | 102 | 111 | 291 | 79 | 65 | 99 | 311 | 74 | 72 | 49 | 183 | 92 | 434 | 15 | 399 | 94 |
| 167 | 195 | 89 | 169 | 102 | 141 | 98 | 290 | 77 | 99 | 8 | 276 | 55 | 225 | 58 | 268 | 30 | 152 | 105 |
| 168 | 258 | 108 | 190 | 78 | 236 | 101 | 93 | 95 | 161 | 26 | 115 | 25 | 224 | 3 | 28 | 114 | 528 | 16 |
| 169 | 161 | 101 | 144 | 9 | 74 | 5 | 384 | 15 | 395 | 43 | 282 | 88 | 202 | 40 | 90 | 79 | 146 | 33 |
| 170 | 48 | 104 | 133 | 66 | 126 | 29 | 29 | 93 | 299 | 25 | 16 | 21 | 449 | 14 | 230 | 109 | 361 | 71 |
| 171 | 79 | 111 | 243 | 94 | 77 | 61 | 239 | 50 | 131 | 40 | 187 | 77 | 81 | 64 | 220 | 20 | 253 | 22 |
| 172 | 71 | 92 | 248 | 23 | 27 | 13 | 14 | 12 | 243 | 16 | 369 | 17 | 73 | 7 | 140 | 48 | 125 | 40 |
| 173 | 25 | 5 | 219 | 104 | 13 | 8 | 78 | 42 | 8 | 103 | 36 | 6 | 63 | 106 | 46 | 94 | 86 | 36 |
| 174 | 121 | 75 | 71 | 86 | 149 | 43 | 274 | 114 | 74 | 90 | 99 | 27 | 406 | 54 | 227 | 28 | 489 | 54 |
| 175 | 217 | 95 | 127 | 44 | 54 | 90 | 115 | 9 | 391 | 107 | 363 | 85 | 275 | 37 | 453 | 43 | 336 | 117 |
| 176 | 24 | 112 | 256 | 2 | 245 | 99 | 328 | 73 | 357 | 96 | 133 | 73 | 296 | 69 | 87 | 1 | 38 | 44 |
| 177 | 167 | 35 | 29 | 60 | 43 | 81 | 80 | 79 | 68 | 51 | 142 | 13 | 344 | 11 | 164 | 118 | 99 | 28 |
| 178 | 135 | 97 | 250 | 63 | 326 | 37 | 15 | 88 | 34 | 20 | 255 | 43 | 436 | 46 | 121 | 86 | 391 | 38 |
| 179 | 207 | 23 | 47 | 100 | 19 | 42 | 35 | 84 | 91 | 38 | 47 | 26 | 308 | 50 | 483 | 5 | 34 | 75 |
| 180 | 54 | 26 | 263 | 55 | 304 | 76 | 378 | 17 | 16 | 0 | 178 | 96 | 18 | 87 | 396 | 27 | 240 | 78 |
| 181 | 238 | 83 | 320 | 87 | 311 | 110 | 336 | 33 | 37 | 28 | 251 | 67 | 377 | 41 | 283 | 90 | 206 | 0 |
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| 184 | 223 | 96 | 262 | 57 | 36 | 65 | 211 | 32 | 69 | 52 | 14 | 7 | 111 | 11 | 309 | 32 | 154 | 61 |
| 185 | 173 | 48 | 309 | 51 | 120 | 71 | 340 | 102 | 232 | 113 | 408 | 105 | 421 | 103 | 37 | 69 | 161 | 73 |
| 186 | 266 | 107 | 273 | 79 | 116 | 55 | 20 | 77 | 407 | 33 | 149 | 22 | 184 | 57 | 221 | 102 | 169 | 97 |
| 187 | 228 | 17 | 302 | 65 | 155 | 34 | 223 | 1 | 415 | 1 | 301 | 12 | 169 | 119 | 61 | 59 | 191 | 26 |
| 188 | 31 | 38 | 70 | 46 | 283 | 21 | 349 | 82 | 97 | 64 | 154 | 39 | 76 | 13 | 422 | 116 | 23 | 91 |
| 189 | 236 | 20 | 67 | 59 | 11 | 69 | 5 | 106 | 169 | 22 | 424 | 68 | 177 | 12 | 248 | 24 | 299 | 99 |
| 190 | 241 | 1 | 76 | 93 | 333 | 29 | 129 | 70 | 176 | 13 | 172 | 60 | 43 | 1 | 361 | 96 | 28 | 119 |

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| 191 | 98 | 37 | 174 | 108 | 23 | 94 | 42 | 3 | 127 | 49 | 401 | 34 | 265 | 55 | 284 | 11 | 408 | 100 |
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| 193 | 23 | 56 | 130 | 117 | 156 | 88 | 19 | 97 | 220 | 95 | 50 | 88 | 78 | 91 | 6 | 42 | 537 | 41 |
| 194 | 224 | 68 | 271 | 113 | 254 | 9 | 71 | 2 | 61 | 111 | 26 | 89 | 236 | 81 | 256 | 69 | 223 | 49 |
| 195 | 90 | 119 | 259 | 84 | 49 | 116 | 316 | 108 | 261 | 61 | 145 | 74 | 331 | 59 | 62 | 23 | 185 | 95 |
| 196 | 292 | 50 | 20 | 112 | 252 | 94 | 332 | 38 | 280 | 90 | 303 | 101 | 272 | 79 | 366 | 38 | 205 | 27 |
| 197 | 214 | 26 | 15 | 40 | 50 | 46 | 56 | 41 | 87 | 75 | 18 | 47 | 195 | 74 | 38 | 18 | 117 | 38 |
| 198 | 142 | 41 | 183 | 106 | 209 | 83 | 191 | 75 | 198 | 110 | 48 | 82 | 334 | 51 | 238 | 93 | 27 | 78 |
| 199 | 104 | 30 | 253 | 70 | 319 | 74 | 27 | 67 | 242 | 71 | 8 | 103 | 222 | 34 | 261 | 41 | 544 | 115 |
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| 201 | 246 | 16 | 223 | 32 | 277 | 0 | 34 | 113 | 303 | 17 | 429 | 79 | 116 | 44 | 508 | 67 | 178 | 46 |
| 202 | 96 | 100 | 296 | 61 | 158 | 93 | 73 | 114 | 130 | 98 | 5 | 101 | 194 | 20 | 198 | 97 | 202 | 48 |
| 203 | 267 | 71 | 284 | 68 | 62 | 20 | 173 | 35 | 335 | 70 | 310 | 51 | 32 | 53 | 17 | 53 | 22 | 72 |
| 204 | 278 | 22 | 153 | 0 | 239 | 117 | 32 | 13 | 333 | 14 | 383 | 103 | 259 | 97 | 78 | 54 | 139 | 45 |
| 205 | 41 | 10 | 303 | 14 | 322 | 71 | 54 | 59 | 258 | 63 | 183 | 64 | 371 | 91 | 359 | 58 | 431 | 95 |
| 206 | 12 | 48 | 89 | 18 | 164 | 59 | 381 | 49 | 70 | 70 | 270 | 58 | 159 | 102 | 40 | 58 | 338 | 15 |
| 207 | 219 | 67 | 99 | 56 | 302 | 57 | 23 | 61 | 312 | 106 | 101 | 44 | 400 | 27 | 209 | 85 | 186 | 50 |
| 208 | 252 | 60 | 40 | 26 | 171 | 12 | 249 | 63 | 49 | 45 | 333 | 36 | 396 | 45 | 304 | 42 | 503 | 12 |
| 209 | 148 | 57 | 318 | 98 | 138 | 100 | 319 | 31 | 210 | 33 | 321 | 37 | 405 | 109 | 213 | 40 | 346 | 42 |
| 210 | 150 | 98 | 187 | 29 | 35 | 108 | 51 | 98 | 188 | 86 | 320 | 33 | 206 | 118 | 100 | 100 | 458 | 114 |
| 211 | 273 | 5 | 125 | 31 | 18 | 23 | 361 | 22 | 367 | 54 | 421 | 44 | 423 | 116 | 436 | 66 | 378 | 9 |
| 212 | 50 | 47 | 25 | 68 | 75 | 103 | 283 | 25 | 287 | 67 | 416 | 97 | 465 | 85 | 274 | 114 | 394 | 79 |
| 213 | 87 | 107 | 308 | 20 | 176 | 68 | 79 | 116 | 324 | 73 | 271 | 56 | 337 | 9 | 280 | 44 | 4 | 21 |
| 214 | 152 | 58 | 276 | 24 | 324 | 27 | 206 | 83 | 177 | 29 | 118 | 59 | 393 | 119 | 175 | 43 | 496 | 88 |
| 215 | 92 | 96 | 26 | 5 | 241 | 69 | 379 | 107 | 400 | 65 | 389 | 117 | 463 | 38 | 98 | 75 | 439 | 82 |
| 216 | 280 | 90 | 170 | 1 | 206 | 47 | 228 | 101 | 338 | 78 | 82 | 94 | 345 | 31 | 329 | 10 | 272 | 107 |
| 217 | 151 | 84 | 171 | 37 | 56 | 57 | 112 | 117 | 19 | 10 | 203 | 84 | 351 | 73 | 296 | 45 | 364 | 5 |
| 218 | 215 | 118 | 272 | 82 | 321 | 49 | 292 | 23 | 36 | 37 | 295 | 89 | 395 | 68 | 115 | 2 | 156 | 66 |
| 219 | 191 | 27 | 93 | 85 | 223 | 1 | 156 | 96 | 151 | 101 | 444 | 7 | 332 | 84 | 66 | 110 | 315 | 1 |
| 220 | 37 | 118 | 78 | 2 | 263 | 63 | 383 | 42 | 81 | 63 | 83 | 34 | 147 | 41 | 129 | 115 | 521 | 4 |
| 221 | 249 | 15 | 247 | 88 | 92 | 111 | 224 | 47 | 174 | 88 | 344 | 57 | 189 | 36 | 92 | 55 | 389 | 84 |
| 222 | 106 | 93 | 91 | 4 | 273 | 38 | 256 | 81 | 163 | 112 | 75 | 67 | 109 | 30 | 218 | 116 | 236 | 76 |
| 223 | 116 | 79 | 60 | 72 | 109 | 18 | 295 | 79 | 383 | 112 | 297 | 65 | 8 | 38 | 339 | 99 | 538 | 33 |
| 224 | 245 | 62 | 203 | 8 | 300 | 77 | 242 | 72 | 269 | 50 | 405 | 31 | 127 | 75 | 143 | 84 | 66 | 104 |
| 225 | 146 | 8 | 228 | 5 | 30 | 97 | 280 | 3 | 387 | 10 | 230 | 41 | 104 | 83 | 69 | 65 | 3 | 32 |
| 226 | 149 | 114 | 181 | 74 | 91 | 33 | 216 | 24 | 215 | 83 | 97 | 20 | 107 | 62 | 74 | 70 | 233 | 102 |
| 227 | 51 | 87 | 39 | 63 | 76 | 112 | 74 | 107 | 106 | 27 | 102 | 4 | 0 | 95 | 278 | 22 | 193 | 41 |
| 228 | 109 | 0 | 255 | 43 | 296 | 81 | 186 | 89 | 123 | 57 | 210 | 10 | 91 | 109 | 318 | 12 | 278 | 30 |
| 229 | 286 | 72 | 142 | 98 | 216 | 51 | 24 | 110 | 290 | 76 | 106 | 70 | 325 | 66 | 313 | 29 | 407 | 13 |
| 230 | 58 | 15 | 14 | 84 | 251 | 104 | 88 | 40 | 209 | 99 | 218 | 16 | 148 | 98 | 460 | 107 | 190 | 82 |
| 231 | 125 | 34 | 97 | 76 | 146 | 45 | 110 | 48 | 262 | 51 | 361 | 29 | 278 | 42 | 266 | 56 | 95 | 79 |
| 232 | 100 | 22 | 4 | 47 | 347 | 72 | 122 | 109 | 332 | 82 | 379 | 92 | 84 | 37 | 267 | 26 | 329 | 106 |
| 233 | 45 | 95 | 176 | 90 | 4 | 114 | 259 | 0 | 0 | 43 | 273 | 115 | 167 | 24 | 127 | 111 | 263 | 70 |
| 234 | 68 | 110 | 110 | 54 | 180 | 60 | 335 | 51 | 394 | 29 | 441 | 109 | 292 | 71 | 428 | 55 | 462 | 27 |
| 235 | 18 | 115 | 124 | 83 | 93 | 37 | 331 | 110 | 107 | 96 | 85 | 107 | 229 | 106 | 105 | 37 | 366 | 17 |
| 236 | 1 | 12 | 112 | 13 | 66 | 22 | 255 | 56 | 347 | 56 | 35 | 109 | 398 | 78 | 103 | 72 | 404 | 48 |
| 237 | 230 | 80 | 51 | 16 | 16 | 35 | 123 | 53 | 29 | 31 | 46 | 63 | 6 | 105 | 63 | 28 | 94 | 2 |
| 238 | 248 | 73 | 95 | 36 | 170 | 73 | 86 | 54 | 273 | 116 | 305 | 116 | 408 | 28 | 68 | 88 | 357 | 108 |
| 239 | 43 | 117 | 132 | 101 | 179 | 23 | 198 | 113 | 211 | 44 | 40 | 1 | 30 | 101 | 449 | 33 | 122 | 55 |
| 240 | 33 | 94 | 107 | 14 | 285 | 48 | 229 | 6 | 45 | 106 | 135 | 30 | 72 | 56 | 387 | 21 | 330 | 119 |
| 241 | 198 | 19 | 275 | 105 | 24 | 85 | 67 | 64 | 253 | 15 | 9 | 76 | 61 | 21 | 323 | 76 | 307 | 67 |
| 242 | 200 | 92 | 258 | 66 | 70 | 40 | 169 | 34 | 86 | 23 | 434 | 45 | 227 | 112 | 31 | 46 | 392 | 14 |
| 243 | 157 | 103 | 83 | 118 | 112 | 84 | 105 | 87 | 158 | 56 | 427 | 16 | 54 | 32 | 300 | 101 | 456 | 57 |
| 244 | 47 | 54 | 156 | 25 | 248 | 4 | 306 | 10 | 5 | 5 | 397 | 52 | 192 | 15 | 504 | 11 | 314 | 31 |
| 245 | 86 | 1 | 196 | 77 | 192 | 26 | 75 | 31 | 292 | 62 | 93 | 54 | 246 | 60 | 302 | 77 | 252 | 32 |
| 246 | 95 | 64 | 85 | 58 | 168 | 58 | 157 | 8 | 413 | 71 | 228 | 42 | 160 | 72 | 503 | 19 | 448 | 35 |
| 247 | 4 | 46 | 149 | 75 | 15 | 59 | 200 | 91 | 330 | 75 | 184 | 69 | 480 | 3 | 93 | 78 | 289 | 86 |
| 248 | 237 | 59 | 312 | 44 | 97 | 117 | 127 | 17 | 234 | 9 | 322 | 23 | 27 | 31 | 41 | 63 | 302 | 83 |
| 249 | 97 | 55 | 198 | 33 | 349 | 43 | 214 | 76 | 320 | 37 | 414 | 26 | 381 | 102 | 245 | 9 | 486 | 37 |
| 250 | 81 | 61 | 294 | 102 | 229 | 108 | 371 | 69 | 136 | 32 | 146 | 92 | 36 | 66 | 363 | 25 | 242 | 59 |
| 251 | 262 | 52 | 41 | 64 | 128 | 107 | 313 | 88 | 122 | 36 | 366 | 72 | 64 | 115 | 287 | 57 | 222 | 39 |
| 252 | 113 | 68 | 75 | 35 | 211 | 90 | 118 | 22 | 52 | 77 | 250 | 87 | 434 | 110 | 232 | 13 | 400 | 69 |
| 253 | 118 | 31 | 277 | 21 | 350 | 15 | 351 | 9 | 351 | 39 | 268 | 19 | 164 | 61 | 473 | 102 | 162 | 63 |
| 254 | 84 | 89 | 84 | 73 | 145 | 8 | 137 | 85 | 217 | 103 | 209 | 26 | 455 | 69 | 83 | 32 | 50 | 109 |
| 255 | 63 | 36 | 199 | 99 | 196 | 14 | 3 | 5 | 379 | 81 | 314 | 112 | 261 | 23 | 478 | 34 | 457 | 51 |
| 256 | 138 | 24 | 53 | 41 | 150 | 109 | 47 | 104 | 343 | 72 | 69 | 48 | 38 | 14 | 459 | 73 | 517 | 98 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 257 | 136 | 39 | 73 | 3 | 151 | 42 | 36 | 14 | 327 | 41 | 395 | 76 | 329 | 64 | 374 | 94 | 269 | 104 |
| 258 | 7 | 66 | 139 | 80 | 65 | 63 | 334 | 98 | 354 | 35 | 246 | 0 | 336 | 19 | 35 | 93 | 248 | 93 |
| 259 | 137 | 51 | 298 | 110 | 131 | 96 | 171 | 12 | 308 | 46 | 319 | 3 | 439 | 43 | 163 | 38 | 24 | 25 |
| 260 | 287 | 112 | 136 | 70 | 115 | 3 | 181 | 102 | 248 | 64 | 182 | 62 | 324 | 21 | 391 | 97 | 143 | 112 |
| 261 | 122 | 5 | 226 | 89 | 25 | 48 | 131 | 20 | 173 | 109 | 10 | 96 | 348 | 7 | 429 | 70 | 465 | 2 |
| 262 | 229 | 40 | 232 | 48 | 215 | 6 | 72 | 101 | 145 | 7 | 225 | 95 | 481 | 22 | 376 | 39 | 110 | 23 |
| 263 | 242 | 41 | 118 | 34 | 161 | 67 | 217 | 55 | 344 | 89 | 153 | 50 | 28 | 51 | 148 | 113 | 301 | 103 |
| 264 | 197 | 44 | 319 | 27 | 195 | 10 | 289 | 78 | 255 | 79 | 402 | 77 | 185 | 90 | 308 | 87 | 148 | 101 |
| 265 | 49 | 33 | 177 | 109 | 101 | 31 | 272 | 36 | 372 | 117 | 104 | 117 | 427 | 89 | 425 | 23 | 509 | 117 |
| 266 | 277 | 87 | 62 | 91 | 48 | 17 | 270 | 60 | 43 | 58 | 94 | 102 | 409 | 107 | 362 | 83 | 251 | 96 |
| 267 | 66 | 59 | 233 | 64 | 17 | 27 | 285 | 106 | 79 | 91 | 404 | 99 | 443 | 25 | 450 | 108 | 30 | 84 |
| 268 | 144 | 46 | 266 | 114 | 51 | 54 | 177 | 52 | 7 | 21 | 134 | 24 | 426 | 67 | 210 | 31 | 20 | 1 |
| 269 | 160 | 71 | 195 | 15 | 316 | 78 | 39 | 66 | 349 | 118 | 373 | 114 | 289 | 70 | 301 | 3 | 370 | 105 |
| 270 | 59 | 21 | 230 | 85 | 186 | 65 | 48 | 65 | 231 | 38 | 387 | 90 | 444 | 60 | 107 | 17 | 372 | 64 |
| 271 | 57 | 17 | 280 | 95 | 219 | 64 | 106 | 21 | 205 | 74 | 64 | 23 | 125 | 76 | 445 | 81 | 8 | 16 |
| 272 | 212 | 76 | 185 | 20 | 71 | 1 | 276 | 118 | 59 | 22 | 139 | 104 | 42 | 96 | 265 | 7 | 510 | 21 |
| 273 | 105 | 38 | 100 | 17 | 280 | 106 | 163 | 57 | 360 | 5 | 358 | 38 | 92 | 10 | 342 | 71 | 363 | 81 |
| 274 | 234 | 0 | 24 | 71 | 165 | 36 | 369 | 34 | 245 | 6 | 442 | 54 | 350 | 52 | 120 | 76 | 126 | 31 |
| 275 | 5 | 30 | 128 | 22 | 184 | 76 | 317 | 62 | 309 | 24 | 316 | 25 | 379 | 72 | 254 | 49 | 296 | 40 |
| 276 | 166 | 91 | 163 | 94 | 189 | 15 | 302 | 7 | 294 | 45 | 150 | 86 | 173 | 107 | 410 | 60 | 514 | 107 |
| 277 | 177 | 50 | 225 | 72 | 327 | 28 | 69 | 92 | 301 | 58 | 388 | 24 | 218 | 39 | 355 | 28 | 347 | 0 |
| 278 | 254 | 97 | 105 | 114 | 132 | 62 | 43 | 105 | 150 | 34 | 12 | 42 | 311 | 82 | 440 | 98 | 12 | 73 |
| 279 | 153 | 70 | 96 | 87 | 294 | 32 | 183 | 45 | 138 | 54 | 362 | 96 | 256 | 93 | 36 | 118 | 469 | 110 |
| 280 | 185 | 88 | 119 | 57 | 85 | 77 | 348 | 74 | 268 | 105 | 158 | 79 | 235 | 45 | 364 | 16 | 467 | 26 |
| 281 | 132 | 111 | 92 | 6 | 105 | 2 | 2 | 19 | 275 | 8 | 156 | 6 | 133 | 80 | 413 | 69 | 55 | 51 |
| 282 | 133 | 10 | 134 | 115 | 269 | 20 | 209 | 112 | 297 | 102 | 86 | 38 | 342 | 26 | 7 | 21 | 516 | 63 |
| 283 | 268 | 23 | 22 | 102 | 38 | 68 | 208 | 108 | 148 | 114 | 61 | 43 | 140 | 49 | 324 | 18 | 93 | 9 |
| 284 | 11 | 106 | 10 | 113 | 127 | 118 | 212 | 43 | 295 | 1 | 70 | 15 | 420 | 6 | 217 | 79 | 220 | 72 |
| 285 | 91 | 63 | 244 | 59 | 22 | 95 | 327 | 116 | 272 | 93 | 173 | 8 | 397 | 90 | 161 | 27 | 19 | 56 |
| 286 | 187 | 69 | 200 | 46 | 275 | 50 | 230 | 107 | 363 | 113 | 57 | 87 | 168 | 48 | 505 | 12 | 102 | 12 |
| 287 | 111 | 7 | 172 | 93 | 288 | 54 | 120 | 69 | 412 | 18 | 144 | 78 | 335 | 12 | 402 | 61 | 268 | 61 |
| 288 | 244 | 14 | 306 | 28 | 204 | 95 | 139 | 97 | 322 | 22 | 170 | 61 | 16 | 78 | 490 | 4 | 238 | 47 |
| 289 | 124 | 90 | 231 | 41 | 81 | 53 | 341 | 40 | 103 | 0 | 376 | 2 | 392 | 80 | 340 | 105 | 508 | 53 |
| 290 | 281 | 21 | 283 | 92 | 28 | 64 | 304 | 30 | 411 | 40 | 160 | 66 | 328 | 40 | 315 | 103 | 309 | 115 |
| 291 | 77 | 6 | 268 | 34 | 279 | 93 | 287 | 35 | 329 | 3 | 294 | 93 | 305 | 29 | 365 | 0 | 147 | 92 |
| 292 | 222 | 61 | 197 | 10 | 2 | 10 | 41 | 26 | 180 | 108 | 229 | 100 | 199 | 94 | 71 | 83 | 542 | 113 |
| 293 | 39 | 44 | 45 | 24 | 117 | 30 | 60 | 24 | 199 | 53 | 74 | 85 | 58 | 54 | 438 | 9 | 274 | 6 |
| 294 | | | 261 | 1 | 134 | 11 | 231 | 117 | 194 | 17 | 299 | 27 | 419 | 81 | 225 | 50 | 526 | 34 |
| 295 | | | 161 | 47 | 218 | 72 | 58 | 100 | 153 | 42 | 391 | 35 | 22 | 119 | 189 | 74 | 166 | 34 |
| 296 | | | 314 | 116 | 344 | 109 | 190 | 33 | 92 | 59 | 244 | 48 | 293 | 100 | 418 | 68 | 57 | 88 |
| 297 | | | 234 | 96 | 26 | 39 | 164 | 18 | 94 | 110 | 132 | 33 | 285 | 35 | 306 | 118 | 498 | 101 |
| 298 | | | 249 | 67 | 44 | 98 | 1 | 42 | 6 | 115 | 143 | 21 | 207 | 65 | 335 | 37 | 502 | 10 |
| 299 | | | 79 | 49 | 267 | 66 | 95 | 44 | 414 | 15 | 390 | 94 | 475 | 113 | 152 | 39 | 254 | 109 |
| 300 | | | 5 | 75 | 53 | 47 | 377 | 55 | 192 | 73 | 179 | 12 | 360 | 56 | 472 | 72 | 422 | 8 |
| 301 | | | 220 | 42 | 148 | 61 | 99 | 74 | 46 | 86 | 59 | 40 | 25 | 22 | 463 | 53 | 108 | 8 |
| 302 | | | 264 | 52 | 237 | 86 | 176 | 67 | 352 | 60 | 298 | 110 | 284 | 8 | 136 | 109 | 85 | 17 |
| 303 | | | 49 | 30 | 79 | 69 | 18 | 72 | 63 | 25 | 315 | 63 | 74 | 28 | 186 | 47 | 81 | 0 |
| 304 | | | 80 | 39 | 82 | 13 | 25 | 78 | 401 | 11 | 207 | 46 | 290 | 114 | 70 | 80 | 226 | 44 |
| 305 | | | 245 | 103 | 337 | 114 | 284 | 21 | 321 | 13 | 409 | 67 | 66 | 20 | 130 | 60 | 35 | 26 |
| 306 | | | 11 | 107 | 309 | 33 | 342 | 114 | 370 | 95 | 197 | 83 | 252 | 96 | 101 | 6 | 160 | 106 |
| 307 | | | 287 | 17 | 244 | 29 | 365 | 16 | 189 | 94 | 431 | 70 | 69 | 47 | 404 | 78 | 80 | 10 |
| 308 | | | 50 | 7 | 45 | 104 | 339 | 47 | 111 | 71 | 357 | 102 | 48 | 104 | 104 | 51 | 194 | 18 |
| 309 | | | 18 | 81 | 225 | 39 | 271 | 53 | 80 | 39 | 54 | 52 | 15 | 42 | 53 | 4 | 385 | 85 |
| 310 | | | 106 | 23 | 110 | 116 | 94 | 68 | 168 | 21 | 248 | 49 | 340 | 44 | 285 | 91 | 381 | 68 |
| 311 | | | 295 | 75 | 157 | 79 | 219 | 103 | 304 | 26 | 215 | 34 | 34 | 71 | 10 | 16 | 105 | 5 |
| 312 | | | 291 | 8 | 31 | 25 | 325 | 90 | 381 | 53 | 89 | 32 | 243 | 53 | 317 | 20 | 351 | 23 |
| 313 | | | 186 | 38 | 220 | 113 | 12 | 29 | 279 | 80 | 335 | 28 | 369 | 86 | 235 | 98 | 7 | 14 |
| 314 | | | 35 | 62 | 234 | 55 | 299 | 84 | 135 | 18 | 60 | 51 | 215 | 2 | 360 | 6 | 215 | 13 |
| 315 | | | 16 | 27 | 41 | 5 | 326 | 97 | 114 | 26 | 113 | 116 | 467 | 59 | 241 | 1 | 452 | 99 |
| 316 | | | 178 | 104 | 351 | 102 | 300 | 39 | 55 | 3 | 342 | 47 | 355 | 1 | 282 | 34 | 317 | 20 |
| 317 | | | 205 | 12 | 268 | 17 | 362 | 83 | 202 | 2 | 334 | 107 | 401 | 55 | 430 | 8 | 9 | 67 |
| 318 | | | 300 | 55 | 0 | 12 | 0 | 55 | 314 | 111 | 417 | 55 | 390 | 17 | 79 | 19 | 234 | 16 |
| 319 | | | 46 | 61 | 203 | 16 | 282 | 80 | 223 | 106 | 356 | 61 | 178 | 68 | 331 | 52 | 192 | 21 |
| 320 | | | 311 | 56 | 95 | 89 | 124 | 13 | 178 | 78 | 84 | 114 | 424 | 49 | 73 | 101 | 138 | 78 |
| 321 | | | 251 | 118 | 212 | 5 | 221 | 58 | 1 | 74 | 24 | 5 | 197 | 103 | 64 | 30 | 295 | 36 |
| 322 | | | 211 | 40 | 222 | 105 | 142 | 98 | 160 | 81 | 287 | 119 | 117 | 43 | 231 | 5 | 214 | 3 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 323 | | | 164 | 97 | 199 | 35 | 132 | 4 | 289 | 59 | 252 | 44 | 347 | 34 | 288 | 73 | 395 | 60 |
| 324 | | | | | 137 | 9 | 140 | 59 | 182 | 104 | 418 | 30 | 376 | 15 | 138 | 117 | 43 | 82 |
| 325 | | | | | 194 | 41 | 166 | 2 | 404 | 6 | 260 | 4 | 306 | 116 | 131 | 68 | 83 | 93 |
| 326 | | | | | 336 | 82 | 291 | 49 | 54 | 97 | 33 | 81 | 39 | 24 | 491 | 40 | 515 | 93 |
| 327 | | | | | 276 | 107 | 66 | 15 | 90 | 95 | 112 | 41 | 186 | 5 | 307 | 95 | 157 | 65 |
| 328 | | | | | 147 | 91 | 197 | 79 | 386 | 48 | 159 | 80 | 373 | 33 | 77 | 71 | 350 | 118 |
| 329 | | | | | 266 | 68 | 144 | 106 | 403 | 27 | 205 | 7 | 60 | 118 | 502 | 101 | 380 | 76 |
| 330 | | | | | 58 | 4 | 375 | 0 | 113 | 62 | 226 | 68 | 239 | 75 | 128 | 106 | 481 | 42 |
| 331 | | | | | 57 | 75 | 301 | 100 | 132 | 85 | 393 | 64 | 65 | 6 | 22 | 107 | 51 | 29 |
| 332 | | | | | 310 | 115 | 62 | 39 | 71 | 30 | 341 | 6 | 171 | 108 | 146 | 108 | 321 | 91 |
| 333 | | | | | 200 | 38 | 17 | 76 | 126 | 119 | 128 | 113 | 385 | 87 | 9 | 31 | 235 | 73 |
| 334 | | | | | 63 | 81 | 55 | 37 | 384 | 12 | 247 | 59 | 316 | 62 | 271 | 33 | 342 | 98 |
| 335 | | | | | 228 | 110 | 246 | 26 | 342 | 109 | 19 | 9 | 323 | 58 | 439 | 46 | 249 | 80 |
| 336 | | | | | 261 | 37 | 385 | 61 | 278 | 4 | 317 | 20 | 44 | 117 | 122 | 99 | 311 | 62 |
| 337 | | | | | 353 | 117 | 309 | 101 | 96 | 24 | 231 | 101 | 77 | 36 | 240 | 36 | 345 | 7 |
| 338 | | | | | 100 | 50 | 107 | 0 | 256 | 31 | 243 | 40 | 118 | 77 | 310 | 59 | 348 | 55 |
| 339 | | | | | 103 | 93 | 38 | 33 | 3 | 117 | 157 | 112 | 26 | 65 | 118 | 81 | 256 | 45 |
| 340 | | | | | 287 | 59 | 323 | 44 | 398 | 0 | 286 | 54 | 257 | 119 | 395 | 115 | 328 | 52 |
| 341 | | | | | 59 | 42 | 178 | 64 | 83 | 68 | 339 | 62 | 21 | 94 | 509 | 35 | 96 | 113 |
| 342 | | | | | 166 | 57 | 170 | 93 | 24 | 46 | 348 | 18 | 98 | 92 | 216 | 53 | 267 | 97 |
| 343 | | | | | 159 | 40 | 308 | 17 | 390 | 83 | 78 | 93 | 213 | 11 | 444 | 75 | 18 | 45 |
| 344 | | | | | 60 | 21 | 146 | 110 | 229 | 75 | 239 | 82 | 359 | 99 | 19 | 45 | 91 | 74 |
| 345 | | | | | 20 | 58 | 145 | 30 | 339 | 43 | 400 | 1 | 231 | 0 | 13 | 77 | 111 | 99 |
| 346 | | | | | 42 | 36 | 11 | 58 | 157 | 70 | 127 | 77 | 309 | 85 | 452 | 84 | 499 | 19 |
| 347 | | | | | 114 | 66 | 233 | 9 | 144 | 45 | 382 | 115 | 99 | 46 | 424 | 74 | 463 | 59 |
| 348 | | | | | 256 | 42 | 222 | 96 | 259 | 20 | 254 | 22 | 47 | 69 | 250 | 89 | 451 | 30 |
| 349 | | | | | 32 | 15 | 153 | 77 | 101 | 29 | 55 | 111 | 242 | 101 | 272 | 65 | 140 | 108 |
| 350 | | | | | 102 | 56 | 237 | 22 | 167 | 92 | 293 | 106 | 299 | 36 | 446 | 114 | 313 | 116 |
| 351 | | | | | 243 | 13 | 248 | 66 | 350 | 17 | 152 | 105 | 161 | 84 | 325 | 85 | 536 | 106 |
| 352 | | | | | 153 | 32 | 182 | 71 | 228 | 118 | 11 | 28 | 212 | 16 | 290 | 72 | 523 | 91 |
| 353 | | | | | 5 | 102 | 100 | 94 | 337 | 87 | 0 | 61 | 12 | 112 | 111 | 64 | 59 | 37 |
| 354 | | | | | | | 92 | 91 | 346 | 74 | 189 | 29 | 37 | 33 | 42 | 3 | 525 | 22 |
| 355 | | | | | | | 354 | 87 | 140 | 47 | 419 | 71 | 286 | 47 | 5 | 27 | 429 | 56 |
| 356 | | | | | | | 165 | 114 | 244 | 10 | 253 | 118 | 358 | 14 | 332 | 15 | 73 | 62 |
| 357 | | | | | | | 364 | 105 | 35 | 52 | 445 | 82 | 407 | 24 | 427 | 1 | 308 | 54 |
| 358 | | | | | | | 243 | 14 | 380 | 68 | 96 | 60 | 461 | 8 | 47 | 87 | 79 | 98 |
| 359 | | | | | | | 320 | 102 | 38 | 90 | 329 | 111 | 75 | 93 | 259 | 2 | 477 | 65 |
| 360 | | | | | | | 175 | 82 | 340 | 104 | 141 | 19 | 468 | 97 | 476 | 99 | 532 | 79 |
| 361 | | | | | | | 356 | 59 | 305 | 36 | 164 | 47 | 70 | 79 | 421 | 109 | 82 | 69 |
| 362 | | | | | | | 44 | 9 | 230 | 40 | 2 | 26 | 283 | 22 | 114 | 44 | 40 | 70 |
| 363 | | | | | | | 261 | 85 | 331 | 47 | 372 | 42 | 214 | 18 | 3 | 15 | 360 | 74 |
| 364 | | | | | | | 321 | 91 | 165 | 41 | 25 | 12 | 100 | 97 | 431 | 17 | 69 | 28 |
| 365 | | | | | | | 355 | 6 | 263 | 35 | 171 | 67 | 3 | 30 | 208 | 70 | 466 | 18 |
| 366 | | | | | | | 196 | 27 | 40 | 103 | 340 | 16 | 262 | 78 | 495 | 47 | 132 | 77 |
| 367 | | | | | | | 31 | 118 | 128 | 60 | 235 | 43 | 219 | 95 | 494 | 77 | 409 | 24 |
| 368 | | | | | | | 241 | 31 | 77 | 43 | 432 | 91 | 87 | 8 | 246 | 86 | 287 | 117 |
| 369 | | | | | | | 305 | 13 | 84 | 15 | 91 | 91 | 301 | 105 | 67 | 40 | 243 | 100 |
| 370 | | | | | | | 188 | 40 | 51 | 116 | 217 | 98 | 41 | 3 | 369 | 82 | 412 | 33 |
| 371 | | | | | | | 314 | 76 | 216 | 48 | 380 | 9 | 1 | 41 | 211 | 42 | 487 | 95 |
| 372 | | | | | | | 113 | 83 | 328 | 25 | 92 | 45 | 363 | 76 | 109 | 14 | 113 | 42 |
| 373 | | | | | | | 104 | 112 | 166 | 61 | 58 | 35 | 445 | 63 | 403 | 50 | 290 | 11 |
| 374 | | | | | | | 9 | 89 | 251 | 77 | 138 | 94 | 462 | 4 | 457 | 7 | 493 | 45 |
| 375 | | | | | | | 262 | 115 | 17 | 66 | 22 | 73 | 126 | 81 | 59 | 66 | 37 | 117 |
| 376 | | | | | | | 33 | 52 | 75 | 14 | 81 | 18 | 201 | 59 | 125 | 90 | 286 | 87 |
| 377 | | | | | | | 192 | 72 | 15 | 111 | 188 | 103 | 319 | 115 | 153 | 67 | 109 | 59 |
| 378 | | | | | | | 360 | 68 | 32 | 79 | 258 | 76 | 416 | 9 | 367 | 117 | 388 | 49 |
| 379 | | | | | | | 13 | 87 | 149 | 84 | 285 | 90 | 238 | 74 | 113 | 62 | 115 | 33 |
| 380 | | | | | | | 138 | 42 | 56 | 32 | 174 | 65 | 411 | 65 | 382 | 100 | 134 | 104 |
| 381 | | | | | | | 52 | 111 | 271 | 115 | 98 | 16 | 375 | 117 | 347 | 24 | 340 | 78 |
| 382 | | | | | | | 125 | 107 | 369 | 94 | 345 | 58 | 418 | 108 | 168 | 55 | 354 | 114 |
| 383 | | | | | | | 194 | 90 | 409 | 80 | 31 | 108 | 55 | 44 | 57 | 7 | 49 | 85 |
| 384 | | | | | | | 162 | 63 | 139 | 38 | 370 | 21 | 268 | 98 | 54 | 92 | 495 | 46 |
| 385 | | | | | | | 155 | 101 | 195 | 58 | 6 | 34 | 430 | 100 | 141 | 26 | 459 | 83 |
| 386 | | | | | | | 109 | 43 | 181 | 8 | 249 | 72 | 321 | 110 | 233 | 43 | 231 | 10 |
| 387 | | | | | | | | | 117 | 50 | 190 | 96 | 313 | 107 | 135 | 49 | 127 | 103 |
| 388 | | | | | | | | | 225 | 22 | 199 | 109 | 477 | 57 | 498 | 22 | 199 | 53 |

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| 389 | | | | | | | | | 118 | 55 | 318 | 117 | 320 | 104 | 468 | 37 | 244 | 2 |
| 390 | | | | | | | | | 112 | 107 | 236 | 32 | 349 | 54 | 456 | 113 | 430 | 47 |
| 391 | | | | | | | | | 336 | 62 | 398 | 87 | 297 | 38 | 295 | 111 | 212 | 57 |
| 392 | | | | | | | | | 375 | 66 | 71 | 89 | 258 | 27 | 65 | 105 | 14 | 13 |
| 393 | | | | | | | | | 284 | 101 | 304 | 13 | 223 | 37 | 311 | 66 | 490 | 14 |
| 394 | | | | | | | | | 288 | 21 | 44 | 46 | 209 | 32 | 467 | 27 | 171 | 75 |
| 395 | | | | | | | | | 236 | 96 | 381 | 104 | 417 | 39 | 11 | 43 | 472 | 119 |
| 396 | | | | | | | | | 296 | 57 | 90 | 37 | 180 | 17 | 255 | 112 | 533 | 29 |
| 397 | | | | | | | | | 82 | 102 | 352 | 89 | 5 | 72 | 297 | 63 | 151 | 110 |
| 398 | | | | | | | | | 224 | 65 | 43 | 104 | 53 | 70 | 182 | 29 | 167 | 32 |
| 399 | | | | | | | | | 276 | 9 | 52 | 69 | 114 | 34 | 386 | 116 | 319 | 35 |
| 400 | | | | | | | | | 11 | 89 | 222 | 36 | 255 | 63 | 263 | 84 | 266 | 38 |
| 401 | | | | | | | | | 345 | 112 | 374 | 48 | 458 | 42 | 126 | 12 | 124 | 25 |
| 402 | | | | | | | | | 270 | 69 | 192 | 38 | 62 | 99 | 393 | 3 | 324 | 39 |
| 403 | | | | | | | | | 30 | 34 | 240 | 84 | 264 | 13 | 286 | 68 | 31 | 44 |
| 404 | | | | | | | | | 47 | 6 | 355 | 66 | 281 | 66 | 479 | 71 | 418 | 111 |
| 405 | | | | | | | | | 376 | 61 | 110 | 99 | 144 | 82 | 215 | 16 | 440 | 36 |
| 406 | | | | | | | | | 306 | 32 | 367 | 5 | 247 | 28 | 465 | 5 | 494 | 80 |
| 407 | | | | | | | | | 365 | 38 | 76 | 50 | 314 | 20 | 497 | 56 | 101 | 41 |
| 408 | | | | | | | | | 214 | 19 | 336 | 105 | 120 | 26 | 461 | 92 | 200 | 115 |
| 409 | | | | | | | | | 155 | 25 | 288 | 30 | 205 | 33 | 252 | 78 | 25 | 58 |
| 410 | | | | | | | | | 185 | 87 | 330 | 81 | 191 | 25 | 253 | 113 | 371 | 31 |
| 411 | | | | | | | | | 235 | 91 | 449 | 79 | 122 | 89 | 27 | 96 | 298 | 4 |
| 412 | | | | | | | | | 408 | 105 | 265 | 92 | 429 | 16 | 492 | 49 | 164 | 95 |
| 413 | | | | | | | | | 20 | 57 | 436 | 78 | 152 | 29 | 484 | 67 | 283 | 50 |
| 414 | | | | | | | | | 164 | 112 | 233 | 33 | 453 | 52 | 334 | 45 | 316 | 72 |
| 415 | | | | | | | | | 85 | 33 | 415 | 112 | 97 | 86 | 477 | 51 | 476 | 71 |
| 416 | | | | | | | | | 326 | 85 | 63 | 30 | 139 | 21 | 312 | 79 | 142 | 79 |
| 417 | | | | | | | | | | | 166 | 31 | 174 | 41 | 407 | 119 | 483 | 73 |
| 418 | | | | | | | | | | | 227 | 116 | 79 | 116 | 236 | 115 | 71 | 27 |
| 419 | | | | | | | | | | | 448 | 118 | 365 | 50 | 194 | 11 | 177 | 48 |
| 420 | | | | | | | | | | | 122 | 63 | 282 | 57 | 96 | 1 | 255 | 119 |
| 421 | | | | | | | | | | | 399 | 10 | 414 | 114 | 106 | 46 | 497 | 52 |
| 422 | | | | | | | | | | | 257 | 102 | 217 | 31 | 139 | 91 | 275 | 0 |
| 423 | | | | | | | | | | | 325 | 24 | 372 | 45 | 405 | 96 | 518 | 76 |
| 424 | | | | | | | | | | | 42 | 58 | 277 | 55 | 242 | 25 | 365 | 67 |
| 425 | | | | | | | | | | | 309 | 0 | 182 | 118 | 75 | 54 | 524 | 48 |
| 426 | | | | | | | | | | | 208 | 17 | 7 | 1 | 398 | 13 | 333 | 29 |
| 427 | | | | | | | | | | | 162 | 20 | 102 | 12 | 390 | 107 | 32 | 97 |
| 428 | | | | | | | | | | | 65 | 59 | 273 | 6 | 299 | 9 | 173 | 26 |
| 429 | | | | | | | | | | | 272 | 75 | 9 | 68 | 25 | 59 | 89 | 101 |
| 430 | | | | | | | | | | | 216 | 15 | 260 | 10 | 371 | 31 | 11 | 40 |
| 431 | | | | | | | | | | | 39 | 74 | 46 | 49 | 412 | 62 | 204 | 51 |
| 432 | | | | | | | | | | | 433 | 14 | 232 | 92 | 480 | 57 | 312 | 5 |
| 433 | | | | | | | | | | | 140 | 48 | 162 | 54 | 496 | 69 | 543 | 114 |
| 434 | | | | | | | | | | | 274 | 85 | 450 | 75 | 219 | 118 | 428 | 102 |
| 435 | | | | | | | | | | | 368 | 40 | 367 | 5 | 33 | 17 | 56 | 38 |
| 436 | | | | | | | | | | | 66 | 66 | 45 | 45 | 247 | 22 | 373 | 32 |
| 437 | | | | | | | | | | | 213 | 86 | 198 | 61 | 507 | 110 | 175 | 102 |
| 438 | | | | | | | | | | | 148 | 1 | 295 | 69 | 239 | 83 | 88 | 22 |
| 439 | | | | | | | | | | | 323 | 34 | 288 | 4 | 30 | 84 | 239 | 23 |
| 440 | | | | | | | | | | | 328 | 45 | 378 | 18 | 144 | 97 | 280 | 64 |
| 441 | | | | | | | | | | | 360 | 93 | 124 | 2 | 356 | 90 | 535 | 108 |
| 442 | | | | | | | | | | | 291 | 57 | 112 | 19 | 204 | 94 | 54 | 52 |
| 443 | | | | | | | | | | | 107 | 7 | 228 | 73 | 249 | 114 | 225 | 1 |
| 444 | | | | | | | | | | | 17 | 103 | 57 | 50 | 345 | 48 | 181 | 68 |
| 445 | | | | | | | | | | | 283 | 99 | 394 | 88 | 353 | 102 | 90 | 100 |
| 446 | | | | | | | | | | | 278 | 94 | 188 | 91 | 485 | 33 | 270 | 92 |
| 447 | | | | | | | | | | | 15 | 14 | 474 | 36 | 160 | 31 | 520 | 89 |
| 448 | | | | | | | | | | | 124 | 5 | 85 | 103 | 56 | 13 | 344 | 40 |
| 449 | | | | | | | | | | | 347 | 49 | 204 | 35 | 373 | 55 | 119 | 46 |
| 450 | | | | | | | | | | | | | 438 | 79 | 172 | 21 | 368 | 43 |
| 451 | | | | | | | | | | | | | 23 | 55 | 88 | 79 | 273 | 81 |
| 452 | | | | | | | | | | | | | 13 | 102 | 48 | 89 | 197 | 62 |
| 453 | | | | | | | | | | | | | 196 | 109 | 273 | 110 | 213 | 98 |
| 454 | | | | | | | | | | | | | 412 | 27 | 20 | 33 | 341 | 110 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 455 | | | | | | | | | | | | | 476 | 60 | 183 | 119 | 293 | 17 |
| 456 | | | | | | | | | | | | | 59 | 90 | 414 | 11 | 257 | 58 |
| 457 | | | | | | | | | | | | | 341 | 94 | 448 | 38 | 441 | 6 |
| 458 | | | | | | | | | | | | | 366 | 82 | 433 | 28 | 189 | 9 |
| 459 | | | | | | | | | | | | | 322 | 70 | 378 | 104 | 401 | 27 |
| 460 | | | | | | | | | | | | | 312 | 97 | 401 | 76 | 488 | 38 |
| 461 | | | | | | | | | | | | | 362 | 25 | 155 | 98 | 188 | 105 |
| 462 | | | | | | | | | | | | | 454 | 51 | 228 | 3 | 61 | 66 |
| 463 | | | | | | | | | | | | | 146 | 20 | 419 | 73 | 6 | 71 |
| 464 | | | | | | | | | | | | | 86 | 95 | 171 | 69 | 356 | 45 |
| 465 | | | | | | | | | | | | | 96 | 16 | 15 | 99 | 47 | 114 |
| 466 | | | | | | | | | | | | | 165 | 88 | 199 | 4 | 288 | 101 |
| 467 | | | | | | | | | | | | | 172 | 62 | 499 | 111 | 379 | 28 |
| 468 | | | | | | | | | | | | | 479 | 26 | 116 | 95 | 10 | 5 |
| 469 | | | | | | | | | | | | | 115 | 65 | 55 | 53 | 36 | 111 |
| 470 | | | | | | | | | | | | | 251 | 87 | 117 | 9 | 506 | 60 |
| 471 | | | | | | | | | | | | | 459 | 10 | 276 | 87 | 534 | 54 |
| 472 | | | | | | | | | | | | | 473 | 31 | 132 | 56 | 264 | 86 |
| 473 | | | | | | | | | | | | | 128 | 101 | 133 | 102 | 352 | 12 |
| 474 | | | | | | | | | | | | | 226 | 1 | 441 | 20 | 128 | 82 |
| 475 | | | | | | | | | | | | | 131 | 0 | 451 | 34 | 16 | 51 |
| 476 | | | | | | | | | | | | | 156 | 30 | 466 | 70 | 416 | 77 |
| 477 | | | | | | | | | | | | | 352 | 119 | 333 | 75 | 425 | 104 |
| 478 | | | | | | | | | | | | | 210 | 8 | 293 | 23 | 468 | 58 |
| 479 | | | | | | | | | | | | | 317 | 86 | 177 | 41 | 433 | 112 |
| 480 | | | | | | | | | | | | | 326 | 7 | 336 | 53 | 129 | 15 |
| 481 | | | | | | | | | | | | | 52 | 31 | 173 | 6 | 529 | 55 |
| 482 | | | | | | | | | | | | | 145 | 53 | 510 | 117 | 217 | 85 |
| 483 | | | | | | | | | | | | | | | 383 | 2 | 279 | 47 |
| 484 | | | | | | | | | | | | | | | 298 | 7 | 58 | 34 |
| 485 | | | | | | | | | | | | | | | 258 | 103 | 155 | 93 |
| 486 | | | | | | | | | | | | | | | 99 | 18 | 297 | 69 |
| 487 | | | | | | | | | | | | | | | 279 | 67 | 318 | 109 |
| 488 | | | | | | | | | | | | | | | 123 | 107 | 501 | 87 |
| 489 | | | | | | | | | | | | | | | 489 | 82 | 411 | 23 |
| 490 | | | | | | | | | | | | | | | 316 | 46 | 470 | 66 |
| 491 | | | | | | | | | | | | | | | 112 | 0 | 144 | 3 |
| 492 | | | | | | | | | | | | | | | 0 | 101 | 13 | 91 |
| 493 | | | | | | | | | | | | | | | 149 | 76 | 74 | 112 |
| 494 | | | | | | | | | | | | | | | 281 | 60 | 474 | 118 |
| 495 | | | | | | | | | | | | | | | 43 | 81 | 530 | 75 |
| 496 | | | | | | | | | | | | | | | 260 | 57 | 545 | 101 |
| 497 | | | | | | | | | | | | | | | 512 | 79 | 531 | 94 |
| 498 | | | | | | | | | | | | | | | 432 | 36 | 107 | 31 |
| 499 | | | | | | | | | | | | | | | 435 | 35 | 137 | 7 |
| 500 | | | | | | | | | | | | | | | 321 | 39 | 165 | 70 |
| 501 | | | | | | | | | | | | | | | 244 | 62 | 60 | 43 |
| 502 | | | | | | | | | | | | | | | 76 | 42 | 208 | 76 |
| 503 | | | | | | | | | | | | | | | 305 | 19 | 359 | 79 |
| 504 | | | | | | | | | | | | | | | 167 | 74 | 98 | 107 |
| 505 | | | | | | | | | | | | | | | 179 | 105 | 78 | 2 |
| 506 | | | | | | | | | | | | | | | 185 | 27 | 121 | 45 |
| 507 | | | | | | | | | | | | | | | 506 | 18 | 187 | 116 |
| 508 | | | | | | | | | | | | | | | 91 | 100 | 482 | 86 |
| 509 | | | | | | | | | | | | | | | 420 | 15 | 358 | 3 |
| 510 | | | | | | | | | | | | | | | 470 | 91 | 426 | 85 |
| 511 | | | | | | | | | | | | | | | 328 | 12 | 72 | 81 |
| 512 | | | | | | | | | | | | | | | 511 | 50 | 210 | 54 |
| 513 | | | | | | | | | | | | | | | | | 46 | 19 |
| 514 | | | | | | | | | | | | | | | | | 250 | 118 |
| 515 | | | | | | | | | | | | | | | | | 507 | 92 |
| 516 | | | | | | | | | | | | | | | | | 454 | 117 |
| 517 | | | | | | | | | | | | | | | | | 438 | 98 |
| 518 | | | | | | | | | | | | | | | | | 540 | 11 |
| 519 | | | | | | | | | | | | | | | | | 376 | 26 |
| 520 | | | | | | | | | | | | | | | | | 325 | 115 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 521 | | | | | | | | | | | | | | | | | 183 | 73 |
| 522 | | | | | | | | | | | | | | | | | 158 | 96 |
| 523 | | | | | | | | | | | | | | | | | 294 | 83 |
| 524 | | | | | | | | | | | | | | | | | 402 | 107 |
| 525 | | | | | | | | | | | | | | | | | 377 | 42 |
| 526 | | | | | | | | | | | | | | | | | 383 | 22 |
| 527 | | | | | | | | | | | | | | | | | 460 | 44 |
| 528 | | | | | | | | | | | | | | | | | 449 | 13 |
| 529 | | | | | | | | | | | | | | | | | 176 | 21 |
| 530 | | | | | | | | | | | | | | | | | 334 | 59 |
| 531 | | | | | | | | | | | | | | | | | 63 | 83 |
| 532 | | | | | | | | | | | | | | | | | 241 | 56 |
| 533 | | | | | | | | | | | | | | | | | 170 | 87 |
| 534 | | | | | | | | | | | | | | | | | 327 | 111 |
| 535 | | | | | | | | | | | | | | | | | 276 | 63 |
| 536 | | | | | | | | | | | | | | | | | 149 | 72 |
| 537 | | | | | | | | | | | | | | | | | 163 | 71 |
| 538 | | | | | | | | | | | | | | | | | 413 | 8 |
| 539 | | | | | | | | | | | | | | | | | 260 | 67 |
| 540 | | | | | | | | | | | | | | | | | 419 | 72 |
| 541 | | | | | | | | | | | | | | | | | 420 | 14 |
| 542 | | | | | | | | | | | | | | | | | 114 | 8 |
| 543 | | | | | | | | | | | | | | | | | 434 | 39 |
| 544 | | | | | | | | | | | | | | | | | 306 | 103 |
| 545 | | | | | | | | | | | | | | | | | 432 | 21 |

# ANNEX D

# PARALLELISED INTERLEAVER DESIGN

The methodology used to design good interleavers is based on the classical approach of random incremental generation of the permutation law and application of spread constraints, as described below:

The spread constraint was the following (linear):

$$\frac{|i-j|}{S_1}+\frac{|\pi(i)-\pi(j)|}{S_2}\geq 1 \qquad \text{(B-1)}$$

The general permutation law π satisfying the parallel access constraints is described through the two vectors β and α describing the shift and macro address permutation as follows:

$$\pi(i)=W\left\{\lfloor i/W\rfloor+\beta(i_W)\right\}_{120}+\alpha(i_W) \quad i=0,\ldots,N-1 \qquad \text{(B-2)}$$

where the notation $\{\}_N$ denotes the remainder or modulus operation, and $W$=$N$/120 is the size of each memory bank.

The algorithm works as follows:

1) Fix the value of the parameters $S_1$=$S_2=\sqrt{N}$, which is the theoretical maximum one. Fix the maximum number of local trials $T_l$ and the maximum number of global trials $T_g$.

2) Sequentially, for each possible *i* ranging from 0 to *W*-1.

3) Generate a new random value of $\beta(i)$ in the range [0,119] and a new random value for the permutation $\alpha(i)$ on *W* elements.

4) The specification of these new values allows to be determined a subset of generally non-contiguous values of the permutation $\tilde{\pi}$.

5) Check the condition (B-1) on all positions *j* for which the permutation is already defined.

6) If the condition is verified continue to next *i* from point 2; otherwise increase the number of local trials.

7) If the number of local trials is smaller than $T_l$ go back to point 3; otherwise increase the number of global trials.

8) If the number of global trials is smaller than $T_g$ restart from point 2, setting *i*=0.

9) Alternatively reduce $S_1$ and $S_2$ by one and restart.

This procedure allows good interleavers to be obtained in an amount of time that can be controlled through the choice of $T_l$ and $T_g$. The upper row of the tables describing the interleavers report the obtained values of $S_1$ and $S_2$.

# ANNEX E

# PHYSICAL LAYER PSEUDO-RANDOMIZATION

The use of Physical layer pseudo-randomization is envisaged as an option for energy dispersal. The PL pseudo-randomization is obtained by multiplying the In-phase and Quadrature samples by a complex randomization sequence ($C_I + jC_Q$):

$I_{\_\text{randomized}} = \{ I \,.\, C_I - Q \,.\, C_Q \}$ $\qquad$ $Q_{\_\text{randomized}} = \{ Q \,.\, C_I + I \,.\, C_Q \}$

The randomization sequence is not applied to the PL header. The randomization sequence is reinitialized at the end of each Physical layer header (FM+FD).

The scrambling code sequences are constructed by combining two real *m*-sequences (generated by means of two generator polynomials of degree 18) into a complex sequence. The resulting sequences thus constitute segments of a set of Gold sequences. Let $x$ and $y$ be the two sequences respectively.

The $x$ sequence is constructed using the primitive polynomial $h(x)=1+x^7+x^{18}$.

The $y$ sequence is constructed using the polynomial: $g(y)=1+ y^5+ y^7+ y^{10}+ y^{18}$.

The sequence depending on the chosen scrambling code number $n$ is denoted $z_n$ in the sequel. Furthermore, let $x(i)$, $y(i)$ and $z_n(i)$ denote the $i^{th}$ symbol of the sequence $x$, $y$, and $z_n$ respectively.

The *m*-sequences $x$ and $y$ are constructed as:

– Initial conditions:
  - $x$ is constructed with $x(0) = 1, x(1) = x(2) = ... = x(16) = x(17) = 0$.
  - $y(0) = y(1) = \ldots = y(16) = y(17) = 1$.
– Recursive definition of subsequent symbols:
  - $x(i+18) = x(i+7) + x(i)$ modulo 2, $i = 0, \ldots, 2^{18} - 20$.
  - $y(i+18) = y(i+10) + y(i+7) + y(i+5) + y(i)$ modulo 2, $i = 0, \ldots, 2^{18} - 20$.
– The n$^{th}$ Gold code sequence $z_n$, $n = 0,1,2,\ldots,2^{18}-2$, is then defined as:
  - $z_n(i) = [x((i+n) \text{ modulo } (2^{18}-1)) + y(i)]$ modulo 2, $i = 0,\ldots, 2^{18}-2$.

These binary sequences are converted to integer valued sequences $R_n$ ($R_n$ assuming values 0, 1, 2, 3) by the following transformation:

$R_n(i) = 2\, z_n((i + 131\,072) \text{ modulo } (2^{18}-1)) + z_n(i)$, $i = 0, 1, \ldots, 133440$.

Finally, the n$^{th}$ complex scrambling code sequence $C_I(i) + jC_Q(i)$ is defined as:

$$C_I(i) + jC_Q(i) = \exp^{(j\,Rn\,(i)\,\pi/2)}$$

| $R_n$ | $\exp^{(j\,Rn\,\pi/2)}$ | $I$_randomized | $Q$_randomized |
|---|---|---|---|
| 0 | 1 | $I$ | $Q$ |
| 1 | $j$ | $-Q$ | $I$ |
| 2 | -1 | $-I$ | $-Q$ |
| 3 | $-j$ | $Q$ | $-I$ |

The figure below gives a possible block diagram for pseudo-randomization sequence generation for $n = 0$.