ATSC-Mobile DTV Standard, Part 2 – RF/Transmission System Characteristics

Document A/153 Part 2:2011, 7 October 2011

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Specifically, ATSC is working to coordinate television standards among different communications media focusing on digital television, interactive systems, and broadband multimedia communications. ATSC is also developing digital television implementation strategies and presenting educational seminars on the ATSC standards.

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ATSC Digital TV Standards include digital high definition television (HDTV), standard definition television (SDTV), data broadcasting, multichannel surround-sound audio, and satellite direct-to-home broadcasting. Contact information is given below.

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A/153 Revision History

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1 SCOPE

This Part includes specific details of the ATSC Mobile DTV (mobile/handheld, or simply "M/H") physical layer transmission system. In addition, it provides a framework for future enhancements or changes.

1.1 Organization

This document is organized as follows:

- **Section 1** – Outlines the scope of this Part and provides a general introduction.
- **Section 2** – Lists references and applicable documents.
- **Section 3** – Provides a definition of terms, acronyms, and abbreviations for this Part.
- **Section 4** – ATSC-M/H system overview.
- **Section 5** – ATSC-M/H transmission system characteristics.
- **Section 6** – Additional system attributes.
- **Annex A** – Group format tables.
- **Annex B** – Method of packet timing and PCR adjustment of main service data

2 REFERENCES

At the time of publication, the editions indicated were valid. All referenced documents are subject to revision, and users of this Standard are encouraged to investigate the possibility of applying the most recent edition of the referenced document.

2.1 Normative References

The following documents, in whole or in part, as referenced in this document, contain specific provisions that are to be followed strictly in order to implement a provision of this Standard.

[1] IEEE: "Use of the International Systems of Units (SI): The Modern Metric System", Doc. IEEE/ASTM SI 10-2002, Institute of Electrical and Electronics Engineers, New York, N.Y.

[2] ATSC: "ATSC Digital Television Standard, Part 2 – RF/Transmission System Characteristics," Doc. A/53 Part 2:2011, Advanced Television Systems Committee, Washington, D.C., 15 December 2011.

[3] ATSC: "ATSC Digital Television Standard, Part 1 – "Digital Television System," Doc. A/53 Part 1:2011, Advanced Television Systems Committee, Washington, D.C., 1 June 2011.

[4] ATSC: "Program and System Information Protocol for Terrestrial Broadcast and Cable," Doc. A/65:2009, Advanced Television Systems Committee, Washington, D.C., 14 April 2009.

[5] ATSC: "Data Broadcast Standard – With Amendment 1 and Corrigendum 1 and 2," Doc. A/90, Advanced Television Systems Committee, Washington, D.C., 26 July 2000 (Amendment 1 dated 14 May 2002; Corrigendum 1 and 2 dated 1 April 2002),

[6] ATSC: "Software Download Data Service," Doc. A/97, Advanced Television Systems Committee, Washington, D.C., 16 November 2004,

[7] ATSC: "Carriage of Legacy TV Data Services," Doc. A/99, Advanced Television Systems Committee, Washington, D.C., 23 July 2008.

[8] ATSC: "Advanced Common Application Platform (ACAP)," Doc. A/101A, Advanced Television Systems Committee, Washington, D.C., 12 February 2009.

[9] ATSC: "Digital Television Standard, Part 3 – Service Multiplex and Transport Subsystem Characteristics," Doc. A/53 Part 3:2009, Advanced Television Systems Committee, Washington, D.C., 7 August 2009.

2.2 Informative References

The following documents contain information that may be helpful in applying this Standard.

[10] ATSC: "ATSC Mobile/Handheld Digital Television Standard, Part 1 – Mobile/Handheld Digital Television System," Doc. A/153 Part 1:2009, Advanced Television Systems Committee, Washington, D.C., 15 October 2009.

[11] ATSC: "ATSC Standard for Transmitter Synchronization," Doc. A/110:2011, Advanced Television Systems Committee, Washington, D.C., 8 April 2011.

[12] ISO: "ISO/IEC IS 13818-1:1 2000 (E), International Standard: Information technology – Generic coding of moving pictures and associated audio information: systems."

[13] ATSC: "ATSC Mobile/Handheld Digital Television Standard, Part 3 – Service Multiplex and Transport Subsystem Characteristics," Doc. A/153 Part 3:2009, Advanced Television Systems Committee, Washington, D.C. 15 October 2009.

[14] Navstar: Navstar Global Positioning System, Interface Specification, "Navstar GPS Space Segment/Navigation User Interfaces," IS-GPS-200, Revision D, 7 March 2006.

3 DEFINITIONS

With respect to definition of terms, abbreviations, and units, the practice of the Institute of Electrical and Electronics Engineers (IEEE) as outlined in the Institute's published standards [1] shall be used. Where an abbreviation is not covered by IEEE practice or industry practice differs from IEEE practice, the abbreviation in question will be described in Section 3.3 of this document.

3.1 Compliance Notation

This section defines compliance terms for use by this document:

shall – This word indicates specific provisions that are to be followed strictly (no deviation is permitted).

shall not – This phrase indicates specific provisions that are absolutely prohibited.

should – This word indicates that a certain course of action is preferred but not necessarily required.

should not – This phrase means a certain possibility or course of action is undesirable but not prohibited.

3.2 Treatment of Syntactic Elements

This document contains symbolic references to syntactic elements used in the audio, video, and transport coding subsystems. These references are typographically distinguished by the use of a different font (e.g., restricted), may contain the underscore character (e.g., sequence_end_code) and may consist of character strings that are not English words (e.g., dynrng).

3.2.1 Reserved Fields

reserved — Fields in this document marked "reserved" are not to be assigned by the user, but are available for future use. Receiving devices are expected to disregard reserved fields for which no definition exists that is known to that unit. Each bit in the fields marked "reserved" is to be set to '1' until such time as it is defined and supported.

3.3 Symbols, Abbreviations, and Mathematical Operators

The symbols, abbreviations, and mathematical operators used herein are as found in Section 3.4 of ATSC A/53 Part 1:2007 [3], with the addition of the following:

ATSC-M/H – ATSC Mobile/Handheld Standard

AT – ATSC Time

B – SCCC output block length in symbols

CRC – Cyclic redundancy check

DTxN – Distributed transmission network

DTxA – Distributed transmission network adaptor

FEC – Forward error correction

FIC – Fast information channel

GF – Galois field

M/H – Mobile/pedestrian/handheld

MHE – M/H encapsulation

N – Number of columns in RS Frame payload

NoG – Number of groups per M/H sub-frame

P – Number of RS parity bytes per RS frame column

PRC – Parade Repetition Cycle

PCCC – Parallel concatenated convolutional code

PL – RS frame portion length

RS – Reed-Solomon

S – Number of padding bytes

SCB1…SCB10 – SCCC (serial concatenated convolutional coding) blocks number 1 through number 10

SCCC – Serial concatenated convolutional code

SGN – Starting group number

SIBL – SCCC input block length in bytes

SOBL – SCCC output block length in bytes

TNoG – Total number of groups per sub-frame

TPC – Transmission parameter channel

TS – Transport Stream

$\lfloor X \rfloor$ – The greatest integer less than or equal to X

3.4 Terms

The following terms are used within this Part:

AT Tick Alignment Point – The starting instant of the first symbol of the first data field sync of the first (odd) 8-VSB data field following the beginning of an M/H frame and/or the corresponding point in the packet domain.

Group Region – See *M/H Group Region.*

M/H Block – A defined series of contiguous transmitted VSB data segments within an M/H Group, containing M/H data or a combination of main (legacy) and M/H data.

M/H Ensemble (or simply "Ensemble") – A collection of consecutive RS Frames with the same FEC codes, wherein each RS Frame encapsulates a collection of packetized data.

M/H Frame – Time period that carries main data and M/H data (encapsulated in MHE packets) equal in duration of exactly 20 VSB data frames (~968ms).

M/H Group – At the MPEG-2 transport stream level, a collection of 118 consecutive MHE transport packets delivering M/H service data; also, the corresponding data symbols in the 8-VSB signal after interleaving and trellis coding.

M/H Parade (or simply "Parade") – A collection of M/H Groups that have the same M/H FEC parameters. A Parade is contained within one M/H Frame. Each M/H Parade carries one or two M/H Ensembles.

M/H Group Region (or simply "Group Region") – A defined set of M/H Blocks, designated as Region A, B, C, or D.

M/H Slot – A portion of an M/H Sub-Frame consisting of 156 consecutive MPEG-2 transport packets. A Slot may consist solely of all TS-M (main) packets or may consist of 118 M/H packets and 38 TS-M packets. There are 16 M/H Slots per M/H Sub-Frame. Note: TS-M is Transport Stream main as defined in A/53 Part 3 [9].

M/H Sub-Frame – One fifth of an M/H Frame; each Sub-Frame is equal in duration to 4 VSB data frames (8 VSB data fields).

Non-systematic – A property of a code in which the code word does not meet the definition of a systematic code, due to either re-ordering or substitution of data.

Number of Groups (NoG) – The number of M/H Groups per M/H Sub-Frame for a particular Ensemble.

Parade Repetition Cycle – A specification of the frequency of transmission of a Parade carrying a particular Ensemble. The Parade containing a particular Ensemble is transmitted in one M/H Frame per *PRC* M/H frames; e.g., PRC = 3 implies transmission in one M/H frame out of every three M/H frames.

Primary Ensemble – An ensemble to be transmitted through a primary RS frame of a Parade.

RS Frame – A 2-dimensional data frame through which an M/H Ensemble is RS-CRC encoded. RS Frames are defined in detail herein.

RS Frame Portion Length – The number of SCCC payload bytes per Group.

Secondary Ensemble – An ensemble to be transmitted through a secondary RS frame of a Parade. Depending on RS Frame Mode, a Parade may or may not have the Secondary Ensemble and associated secondary RS Frame.

Starting Group Number – The Group Number assigned to the first Group in a Parade, which determines placement of the Parade into a particular series of M/H Slots.

Systematic – A property of a code in which the code word is composed of the original data in its sequential order followed by parity data for the codeword.

Total Number of Groups – The number of Groups per M/H Sub-Frame including all M/H Ensembles present in the Sub-Frame.

4 SYSTEM OVERVIEW

Please see ATSC A/153 Part 1 [10] for an overall description of the M/H system. The ATSC Mobile/Handheld service (M/H) shares the same RF channel as a standard ATSC broadcast service described in ATSC A/53 Part 2:2007 [2]. M/H is enabled by using a portion of the total available ~19.4 Mbps bandwidth and utilizing delivery over IP transport. The overall ATSC broadcast system including standard (TS Main) and M/H systems is illustrated in Figure 4.1.

Central to the M/H system are additions to the physical layer of the ATSC transmission system that are easily decodable under high Doppler rate conditions. The requirements for these additions are defined in this Part. Extra training sequences and forward error correction (FEC) are added to assist reception of the enhanced stream(s). Consideration has also been given to the many system details that make such a signal compatible with legacy ATSC receivers, particularly audio decoder buffer constraints; but also such constraints as MPEG transport packet header standards, requirements for legacy PSIP carriage, etc. These changes do not alter the emitted spectral characteristics.

5 M/H TRANSMISSION SYSTEM

The first major subsection hereunder establishes the context in the 8-VSB structures, as defined in A/53, for the M/H system. The following major subsections define the set of mandatory and optional characteristics of the ATSC M/H transmission system.

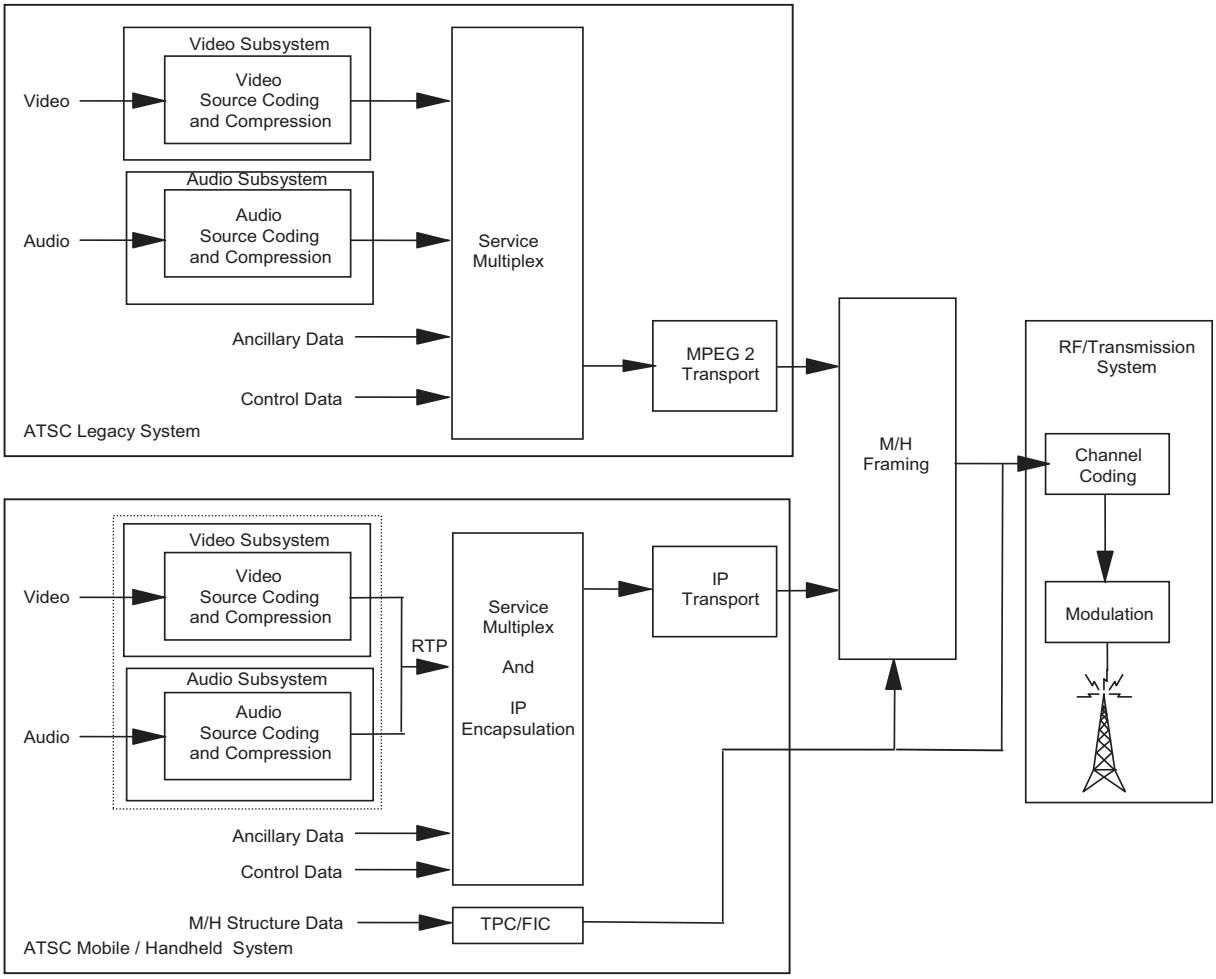

Figure 4.1 ATSC broadcast system with TS Main and M/H services.

The following sections establish normative and optional requirements for the M/H system associated with explicit versioning signaling and control that shall be sent. The value of tpc_protocol_version = '11111' shall mean all aspects of the parameters possible to be signaled therein are as defined in their respective sections of this Part, even though no explicit cross reference is established for this initial version. Other values for tpc_protocol_version are not currently defined.

5.1 Overview of M/H Transmission System

The M/H system provides mobile/pedestrian/handheld broadcasting services using a portion of the ~19.39 Mbps ATSC 8-VSB payload, while the remainder is still available for HD and/or multiple SD television services. The M/H system is a dual-stream system—the ATSC service multiplex for existing digital television services and the M/H service multiplex for one or more mobile, pedestrian, and handheld services.

The presence of this M/H system in the transmission is signaled by use of one the system enhancement bits defined in A/53 Part 2 [2]; the characteristics and position of which is specified

in Section 5.3.2.13.3. This M/H system provides bursted transmission of the M/H data, which allows the M/H receiver to cycle power in the tuner and demodulator for energy saving.

The M/H system's data organization is established by information in the M/H Signaling Channel, which establishes and controls the specific structure of each version. The initial release of the M/H system provides data which is partitioned into *Ensembles*, each of which contains one or more services. Each Ensemble uses an independent *RS Frame* (a forward error correcting (FEC) structure to be explained below), and furthermore, each Ensemble may be coded to a different level of error protection depending on the application.

M/H encoding includes FEC at both the packet and trellis levels, plus the insertion of long and regularly spaced training sequences into the M/H data. Robust and reliable control data is also inserted for use by M/H receivers.

5.2 M/H Signaling Channel

5.2.1 Transmission Parameter Channel

5.2.1.1 Transmission Parameter Channel (TPC) Data

TPC data shall be sent in each Group, as specified in Table 5.1 and Section 5.2.3. The syntax of the TPC shall be per Table 5.1 and the elements of Table 5.1 shall be as described in the succeeding text. Values of TPC data shall describe the M/H Frame and Group as specified in Section 5.2.3.

Table 5.1 Transmission Parameter Channel Data

Syntax	No. of Bits	Format
TPC_data {		
sub-frame_number	3	uimsbf
slot_number	4	uimsbf
parade_id	7	uimsbf
if (sub-frame_number ≤ 1) {		
current_starting_group_number	4	uimsbf
current_number_of_groups_minus_1	3	uimsbf
}		
if (sub-frame_number ≥ 2) {		
next_starting_group_number	4	uimsbf
next_number_of_groups_minus_1	3	uimsbf
}		
parade_repetition_cycle_minus_1	3	uimsbf
If (sub-frame_number ≤ 1) {		
current_ rs_frame_mode	2	bslbf
current_ rs_code_mode_primary	2	bslbf
current_ rs_code_mode_secondary	2	bslbf
current_ sccc_block_mode	2	bslbf
current_ sccc_outer_code_mode_a	2	bslbf

Table 5.1 Transmission Parameter Channel Data

current_ sccc_outer_code_mode_b	2	bslbf
current_ sccc_outer_code_mode_c	2	bslbf
current_ sccc_outer_code_mode_d	2	bslbf
}		
If (sub-frame_number ≥ 2) {		
next_rs_frame_mode	2	bslbf
next_rs_code_mode_primary	2	bslbf
next_rs_code_mode_secondary	2	bslbf
next_sccc_block_mode	2	bslbf
next_sccc_outer_code_mode_a	2	bslbf
next_sccc_outer_code_mode_b	2	bslbf
next_sccc_outer_code_mode_c	2	bslbf
next_sccc_outer_code_mode_d	2	bslbf
}		
fic_version	5	uimsbf
parade_continuity_counter	4	uimsbf
If (sub-frame_number ≤ 1) {		
current_TNoG	5	uimsbf
reserved	5	bslbf
}		
If (sub-frame_number ≥ 2) {		
next_TNoG	5	uimsbf
current_TNoG	5	uimsbf
}		
reserved	16	bslbf
tpc_protocol_version	5	bslbf
}		

sub-frame_number – The value of this field shall be in the range of 0 through 4 inclusive and shall indicate the current Sub-Frame number within the M/H Frame. It is transmitted to aid M/H Frame synchronization in the receiver.

slot_number – The value of this field shall be in the range of 0 through 15 inclusive and shall indicate the current Slot number within the M/H Sub-Frame. It is transmitted to aid M/H Frame synchronization in the receiver.

parade_id – This 7-bit field identifies the Parade to which the current Group belongs, for the current M/H Frame. The value of this field may be any 7-bit value. Each Parade in an M/H transmission shall have a unique Parade_id. Assignment of Parade_id values may occur at a convenient level of the system, usually in the management layer.

current_starting_group_number – The value of this field shall be the first-assigned Group_number for a Parade to which this Group belongs. See Section 5.3.1.4. Groups within a Parade are numbered consecutively.) A Starting Group Number (SGN) is used both for current M/H Frame information and for signaling in advance for the current M/H Frame.

current_number_of_groups_minus_1 – The value of this field shall be the number of Groups in a Sub-Frame assigned to the Parade to which this Group belongs, minus 1, for the current M/H Frame; e.g., number_of_groups_minus_1 = 0 implies that one Group is allocated to this Parade in each Sub-Frame of the current M/H Frame. The value of number_of_groups_minus_1 shall be in the range of 0 through 7 inclusive. number_of_groups_minus_1 is used both for current M/H Frame information and for signaling in advance.

next_starting_group_number (SGN) – The value of this field shall be the first-assigned Group_number for a Parade to which this Group belongs. See Section 5.3.1.4. Groups within a Parade are numbered consecutively for the next M/H Frame.

next_number_of_groups_minus_1 – The value of this field shall be the number of Groups in a Sub-Frame assigned to the Parade to which this Group belongs, minus 1, for the next M/H Frame; e.g., number_of_groups_minus_1 = 0 implies that one Group is allocated to this Parade in each Sub-Frame of the next M/H Frame. The value of number_of_groups_minus_1 shall be in the range of 0 through 7 inclusive.

parade_repetition_cycle_minus_1 – The value of this field shall indicate the number of M/H Frames that do not contain the current parade that are between M/H Frames that contain the current parade, per Table 5.2.

Table 5.2 parade_repetition_cycle_minus_1

Value	Description
000	This Parade is transmitted once every M/H Frame.
001	This Parade is transmitted once every 2 M/H Frames.
010	This Parade is transmitted once every 3 M/H Frames.
011	This Parade is transmitted once every 4 M/H Frames.
100	This Parade is transmitted once every 5 M/H Frames.
101	This Parade is transmitted once every 6 M/H Frames.
110	This Parade is transmitted once every 7 M/H Frames.
111	Reserved

Note: the following eight coding parameter fields (rs_Frame_mode… sccc_outer_code_mode_d) are used both for current M/H Frame information and for signaling in advance.

current_rs_frame_mode – This shall be the RS frame mode of the Parade to which this group belongs, as defined in Table 5.3, for the current M/H Frame.

current_rs_code_mode_primary – This shall be the RS code mode for the primary RS Frame. The RS code mode is defined in Table 5.5.

current_rs_code_mode_secondary – This shall be the RS code mode for the secondary RS Frame of the Parade to which this group belongs, for the current M/H Frame. The RS code mode is defined in Table 5.5.

current_sccc_block_mode – This shall be be the SCCC Block Mode of the Parade to which this group belongs, as defined in Table 5.6.

current_sccc_outer_code_mode_a – This shall be the SCCC outer code mode for Region A of the Parade to which this group belongs, for the current M/H Frame. Note: The SCCC outer code mode is defined in Table 5.7.

current_sccc_outer_code_mode_b – This shall be the SCCC outer code mode for Region B of the Parade to which this group belongs, for the current M/H Frame.

current_sccc_outer_code_mode_c – This shall be the SCCC outer code mode for Region C of the Parade to which this group belongs, for the current M/H Frame.

current_sccc_outer_code_mode_d – This shall be the SCCC outer code mode for Region D of the Parade to which this group belongs, for the current M/H Frame.

next_rs_frame_mode – This shall be the RS frame mode of the Parade to which this group belongs, as defined in Table 5.3, for the next M/H Frame.

next_rs_code_mode_primary – This shall be the RS code mode for the primary RS Frame of the Parade to which this group belongs, for the next M/H Frame. The RS code mode is defined in Table 5.5.

next_rs_code_mode_secondary – This shall be the RS code mode for the secondary RS Frame of the Parade to which this group belongs, for the next M/H Frame. The RS code mode is defined in Table 5.5.

next_sccc_block_mode – This shall be the SCCC Block Mode of the Parade to which this group belongs, as defined in Table 5.6, for the next M/H Frame.

next_sccc_outer_code_mode_a – This shall be the SCCC outer code mode for Region A of the Parade to which this group belongs, for the next M/H Frame. Note: The SCCC outer code mode is defined in Table 5.7.

next_sccc_outer_code_mode_b – This shall be the SCCC outer code mode for Region B of the Parade to which this group belongs, for the next M/H Frame.

next_sccc_outer_code_mode_c – This shall be the SCCC outer code mode for Region C of the Parade to which this group belongs, for the next M/H Frame.

next_sccc_outer_code_mode_d – This shall be the SCCC outer code mode for Region D of the Parade to which this group belongs, for the next M/H Frame.

fic_version – This is a 5-bit field whose value shall indicate change in FIC-Chunk contents. The fic_version shall be incremented by 1 modulo 32 when an FIC-Chunk in the current M/H Frame that describes the current + 1 M/H frame is different from the FIC-Chunk with the same FIC_chunk_major_protocol_version in the current – 1 M/H frame that described the current M/H frame.

parade_continuity_counter – The value of this field shall increment by 1 every (PRC) M/H Frames. The value of this field shall increase from 0 to 15 and then repeat.

Example (refer to Table 5.2): parade_repetition_cycle_minus_1 = 011 (i.e., PRC = 4) implies that parade_continuity_counter increases every fourth M/H frame.

current_TNoG – The value of this field shall be the total number of groups to be transmitted during a Sub-Frame for the current M/H Frame. In other words, it is the sum of NoGs of all Parades within a Sub-Frame of the current M/H Frame. Its value shall be in the range of 0 through 16 inclusive.

next_TNoG – The value of this field shall be the total number of groups to be transmitted during a Sub-Frame, for the next M/H Frame. In other words, it is the sum of NoGs of all Parades within a Sub-Frame of the next M/H Frame. Its value shall be in the range of 0 through 16 inclusive.

tpc_protocol_version – A 5-bit unsigned integer field that represents the version of the structure of the TPC syntax. The 2 most-significant bits are the major version level; the least-significant three bits are the minor version level, to be interpreted as follows: A change in the major version level shall indicate a non-backward-compatible level of change. A change in the minor version level, provided the major version level remains the same, shall indicate a backward-compatible level of change. The initial value for this field shall be '11111'. At least one of the bits shall be changed so as to form a previously unused value of this field each time the TPC structure is changed by a future version of this standard. Other values of the version may be used in future to signal use of the reserved bits or a change in the defined syntax. The first such change shall be to '00' or '000', so that this field increments in the same manner as other fields for later changes.

Note: The last row of this table should be parsed to determine tpc_protocol_version before attempting to parse the other rows.

Since the TPC parameters (except sub-frame_number and slot_number) for each Parade do not change their values during an M/H Frame, the same information is transmitted repeatedly through all M/H Groups belonging to that Parade during an M/H Frame. The repetition increases the robustness and reliability of the TPC data. Because the sub-frame_number and the slot_number are increasing counter values, they also are made more robust, due to the transmission of regularly expected values.

5.2.2 Fast Information Channel

The Fast Information Channel (FIC) carries cross-layer information to enable a fast M/H service acquisition. This information primarily includes channel binding information between M/H Ensembles and M/H services. The FIC data is generated and consumed in the Management layer. The detailed description of the FIC data content shall be per A/153 Part 3 [13]. The carriage of the FIC data is described in this Physical layer document.

Note: Signaling of the parade_id between the physical layer and the management layer is enabled by means of the ensemble_id field in the SMT (defined in Section 6.6.1, Part 3 of this Standard.) As defined there, the parade_id is concatenated with a bit that signals primary/secondary ensemble to create the contents of the ensemble_id field. If the ensemble_id is for the primary M/H Ensemble delivered through this M/H Parade, the MSB of the ensemble_id is set to '0'. If it is for the secondary M/H Ensemble, the MSB of the ensemble_id is set to '1'.

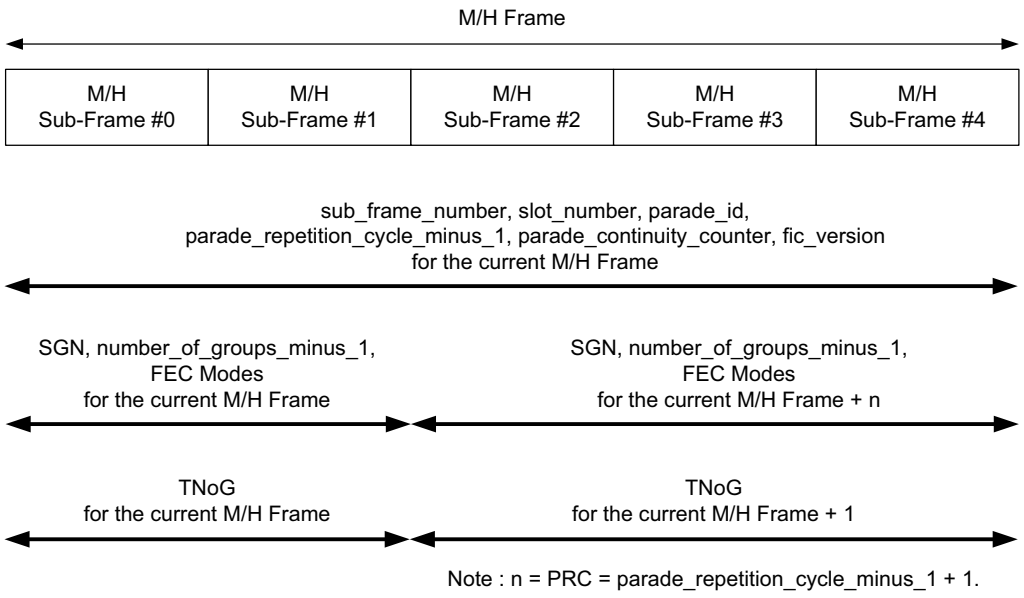

Figure 5.1 Signaling in advance.

5.2.3 Signaling in Advance

Figure 5.1 illustrates the signaling scenario of the TPC data.

The sub-frame_number, slot_number, parade_id, parade_repetition_cycle_minus_1, parade_continuity_counter, and fic_version shall have their values corresponding to the current M/H Frame throughout the 5 Sub-Frames within a particular M/H Frame.

Certain TPC parameters and FIC data are signaled in advance. The applicability to the current Parade or the next Parade is defined in Table 5.1 and described below.

The values of SGN, number_of_groups_minus_1, and all FEC mode parameters (rs_frame_mode, rs_code_mode_primary, rs_code_mode_secondary, sccc_block_mode, sccc_outer_code_mode_a, sccc_outer_code_mode_b, sccc_outer_code_mode_c, sccc_outer_code_mode_d corresponding to the current M/H Frame are given in the first two Sub-Frames of the current M/H Frame. The values of SGN, number_of_groups_minus_1, and all FEC mode parameters corresponding to the M/H Frame in which the Parade next appears are given in the 3rd, 4th, and 5th Sub-Frames of the current M/H Frame.

This repetitive advance signaling is provided to allow M/H receivers to receive the transmission parameters in advance with high reliability.

During the 1st and 2nd subframes, the TPC carries only the current_TNoG field; during the 3rd, 4th, and 5th subframes the TPC carries the current_TNoG and next_TNoG fields.

5.3 Overview of M/H Transmission Processing

Figure 5.2 shows a functional block diagram of the M/H transmission system when the enhancement bit is set in accordance with Section 5.3.2.13.3 and the tpc_protocol_version = '11111.'

The M/H transmission system receives two sets of input streams: one consists of the MPEG transport stream (TS) packets of the main service data, and the other consists of the M/H service data. At a high level, the function of the M/H transmission system is to combine these two types

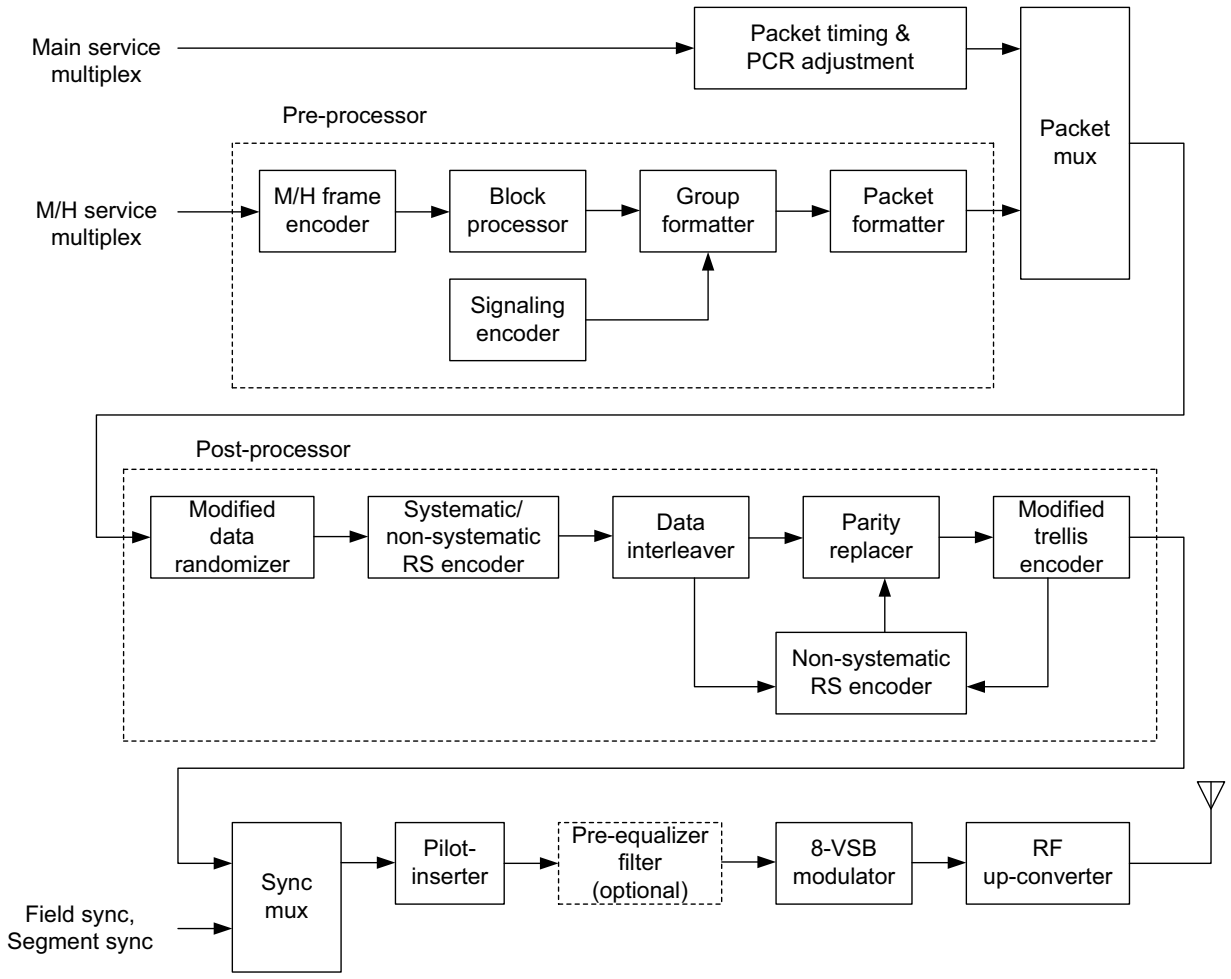

Figure 5.2 M/H transmission system.

of streams into one stream of MPEG TS packets and process and modulate them into the normal ATSC trellis-coded 8-VSB signal, as illustrated in Figure 5.2.

For compatibility with legacy 8-VSB receivers, the M/H service data is encapsulated in special MPEG-2 transport stream packets, designated as M/H Encapsulation (MHE) packets. The M/H transmission system can accommodate encapsulated service data that is in any desired format. For example, services carried in MPEG transport streams such as like MPEG-2 video/ audio, MPEG-4 video/audio, other data, or services carried by IP packets. Any choices of format made in other system layers are not discussed in this Part.

Time-division multiplexing of main and M/H data introduces changes to the time of emission of the main service stream packets compared to the timing that would occur with no M/H stream present. This Part defines the changes necessary to compensate completely for temporal displacements at the combining point so that the emitted signal complies with the MPEG and ATSC standards to protect legacy receivers. These functions are performed by the “Packet Timing & PCR Adjustment” block shown in Figure 5.2.

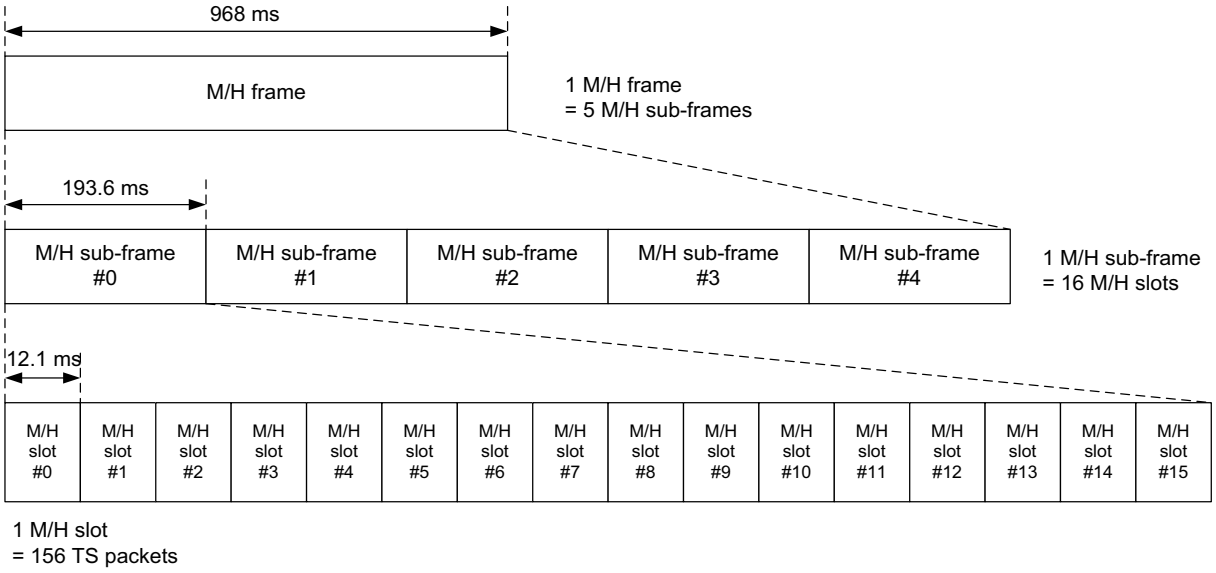

Figure 5.3 M/H frame structure.

The operations of the M/H transmission system on the M/H data are divided into two stages: a pre-processor and a post-processor.

The function of the pre-processor is to rearrange the M/H service data into an M/H data structure, to enhance the robustness of the M/H service data by additional FEC processes, to insert training sequences, and subsequently to encapsulate the processed enhanced data into MHE transport stream packets. The pre-processor operations include M/H Frame encoding, Block processing, Group formatting, packet formatting, and M/H signaling encoding.

The function of the post-processor is to process the main service data by normal 8-VSB encoding and to manipulate the pre-processed M/H service data in the combined stream to ensure compatibility with ATSC 8-VSB receivers. Main service data in the combined stream is processed exactly the same way as for normal 8-VSB transmission: randomizing, RS encoding, interleaving, and trellis encoding. The M/H service data in the combined stream is processed differently from the main service data in that the pre-processed M/H service data bypasses the data randomizer. The pre-processed M/H service data is processed by a non-systematic RS encoder. Additional operations are done on the pre-processed M/H service data to initialize the trellis encoder memories at the start of each training sequence, which has been included in the pre-processed M/H service data. The non-systematic RS encoding allows the insertion of the regularly spaced long training sequences without disrupting reception by legacy receivers.

5.3.1 M/H Data Structure

5.3.1.1 M/H Frame

Figure 5.3 shows an M/H Frame structure for transmission of M/H data and main data. One M/H Frame carries main data and M/H data (encapsulated in MHE packets) equivalent in size to exactly 20 VSB data frames. However, the boundaries of the M/H Frame are offset from VSB Frame boundaries, as explained in the following text.

The M/H Frame shall consist of 5 consecutive *Sub-Frames*, respectively numbered 0, 1, 2, 3, and 4. Thus, each Sub-Frame contains the same amount of data as 4-VSB data frames (8-VSB data fields).

Each Sub-Frame shall consist of 16 consecutive M/H *Slots*, respectively numbered 0, 1, 2, ..., 15.

Each M/H Slot shall consist of 156 TS packets or equivalently 156 data segments (at the symbol level), or equivalently one half of a VSB data field.

Note that when packets from a given M/H Slot are processed into interleaved data segments, the symbols from that Slot are distributed throughout more than 156 data segments. This is explained in detail in later sections.

The duration of an M/H Slot is approximately 12.1 ms, and the duration of an M/H Sub-Frame is approximately 193.6 ms. The duration of a M/H Frame is the same as 20 VSB data frames (i.e., approximately 968 ms), but the M/H Frame boundaries are offset from VSB data frame boundaries.

The M/H Slot is the basic time period for multiplexing of M/H data and main data. After M/H pre-processing, M/H data is formatted as a *Group* of 118 consecutive MHE packets which encapsulate the M/H service data. A particular Slot may contain M/H data, or may consist of only main data.

If an M/H Group is transmitted during an M/H Slot, then the first 118 TS packets in the Slot shall be an M/H Group, and the remaining 38 packets shall be main TS packets.

If there is no M/H Group in an M/H Slot, the M/H Slot shall consist of 156 main TS packets.

> Note: The M/H Slot boundaries are offset from VSB data field boundaries as described below.

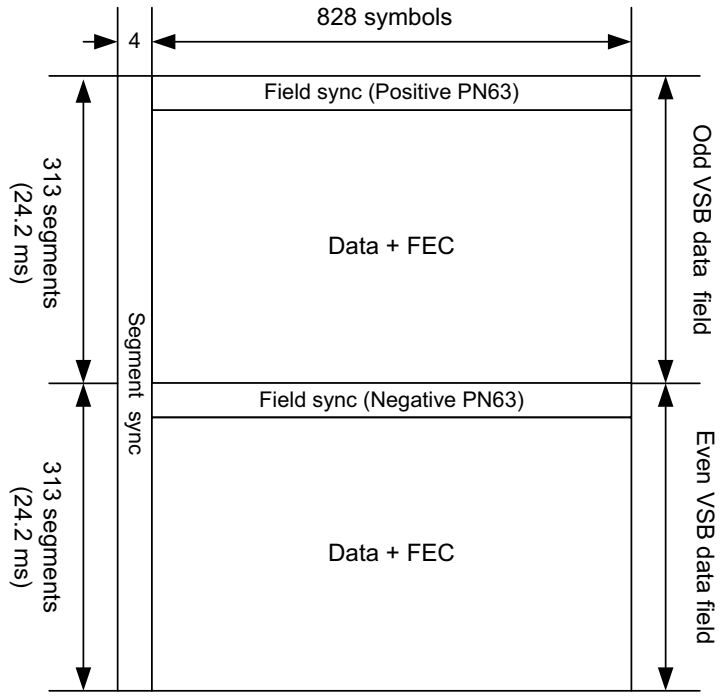

Figure 5.4 VSB data frame.

Figure 5.4 shows the VSB data frame organization. Incorporation of M/H technology does not change the data frame structure. Note that the data frame structure is formed after data byte interleaving, and therefore, while each data segment carries a payload equivalent to one TS packet, each data segment consists of symbols derived from some bytes of the current TS packet and each of the preceding 51 TS packets. Although the data byte interleaver operation is synchronized with the data field structure, the interleaver is of a convolutional type that operates continuously (except during sync insertion). Therefore the data from some TS packets is dispersed into two data fields.

As required in A/53 Part 2 [2], each VSB data frame consists of two VSB data fields, each containing 313 data segments. The first data segment of each VSB data field is a unique synchronizing signal (field sync) and includes the training sequence used by non-M/H as well as M/H receivers. The remaining 312 data segments each carry the equivalent of the data from one 188-byte Transport Stream (TS) packet plus its associated FEC overhead.

The start of the M/H Slot is offset in its position relative to the start of a VSB data frame. Figure 5.5 depicts the positioning of the first 4 M/H Slots of an M/H Sub-Frame with respect to a VSB data frame. Note that this arrangement applies at the transport stream level where M/H data appears as MHE *packets*, the data has not been through the data byte interleaver, and data field sync has not yet been inserted.

Slots shall be numbered from 0 through 15 inclusive.

Consecutive Slots shall map into consecutive portions of 8-VSB data fields.

The position of Slots with respect to data fields shall be as follows:

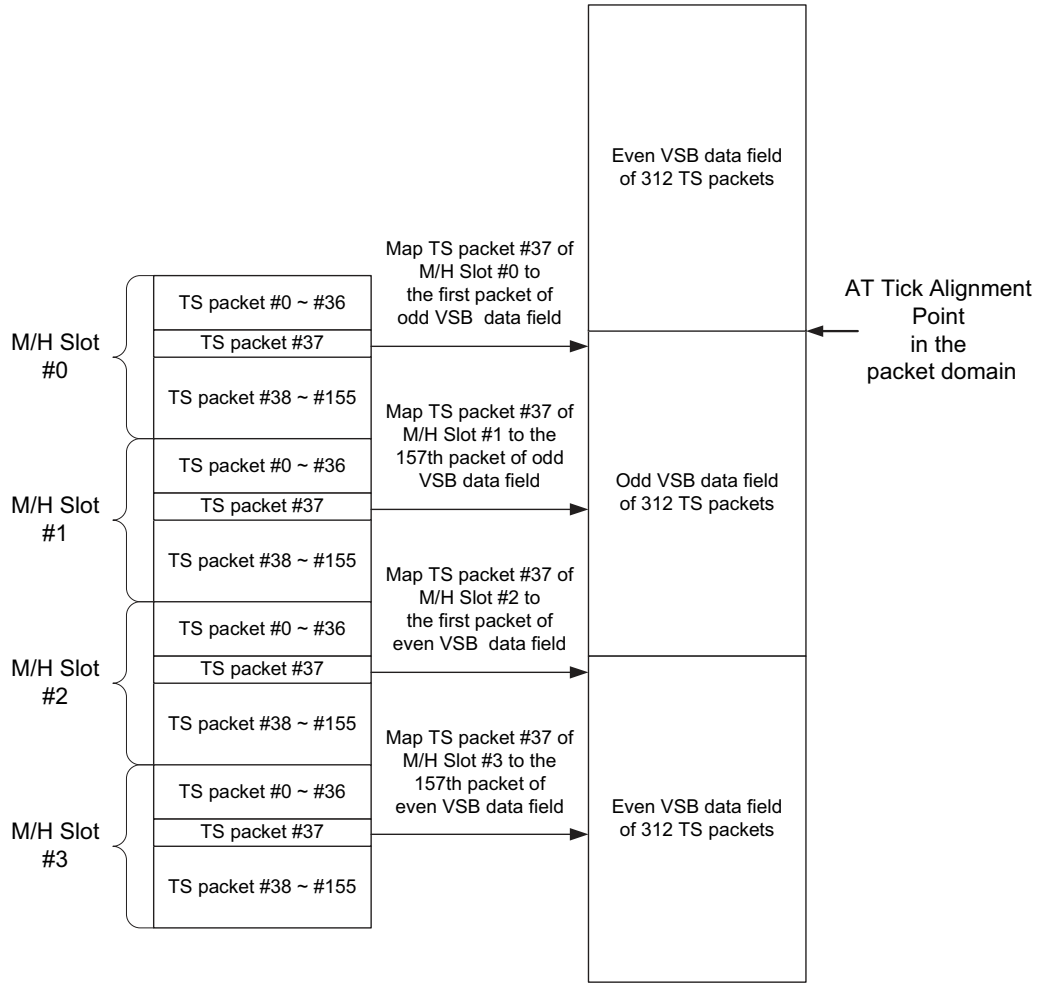

Figure 5.5 M/H slot position with respect to a VSB data frame.
(See Section 5.3.2.13.1 for the definition of AT tick.)

- MHE packets #37 of even-numbered Slots (#0, 2, 4, ... 14) shall map to the initial TS packets of consecutive 8-VSB data fields.
- MHE packets #37 of odd-numbered Slots (#1, 3, ... 15) shall map to the 157th TS packets of consecutive 8-VSB data fields.
- MHE packet #37 of Slot #0 shall map to the initial TS packet of an odd VSB data field

Note that after data byte interleaving and trellis encoding, the data from each packet is dispersed among the corresponding data segment and the following 51 data segments.

5.3.1.2 M/H Group

An M/H Group consists of 118 consecutive TS packets. After MPEG sync byte removal by a modified data randomizer and an addition of 20 parity bytes by a systematic/non-systematic RS encoder, each TS packet is converted to a 207-byte data packet. Figure 5.6 shows the format of the Group just before the ATSC byte interleaver.

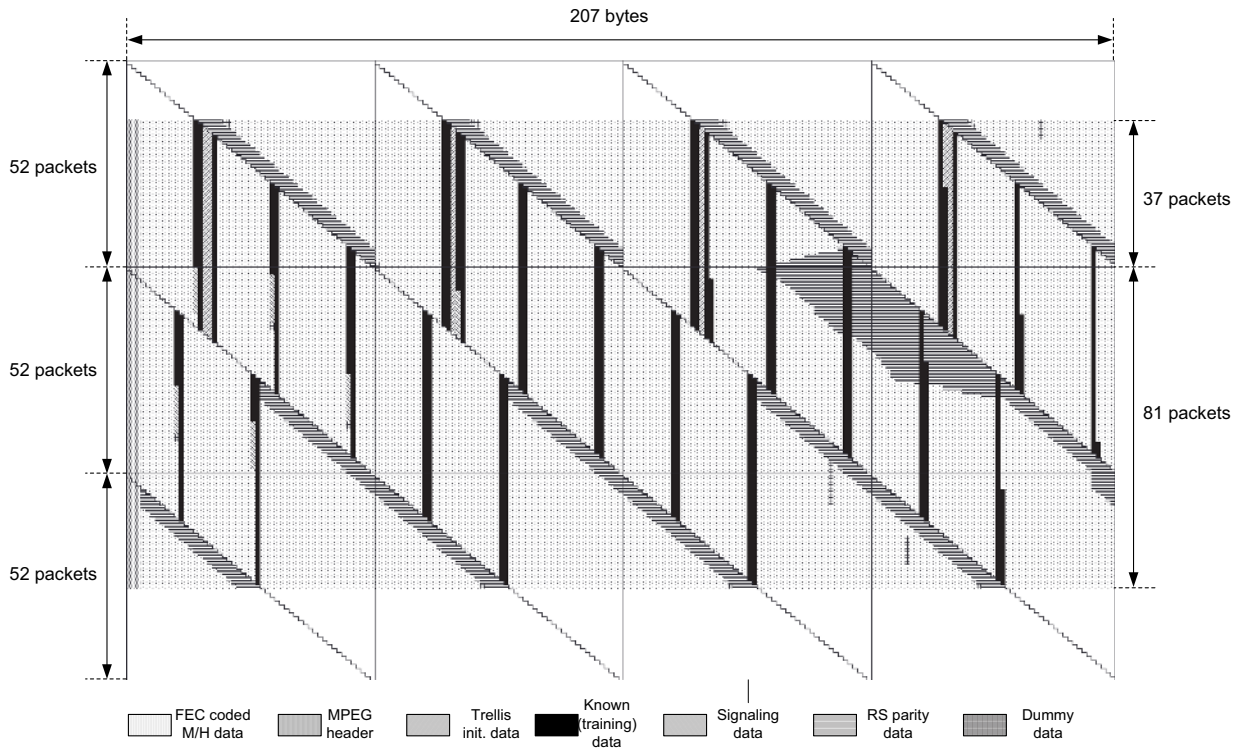

Figure 5.6a Group format before the data interleaver.

All parts of a Group shall be constructed as specified in Annex A. Note that the following Figures (5.6a, 5.6b, 5.7a, and 5.7b) are simplified for illustrative purposes and direct interpretation of the data is per Annex A. (Note Table A1 retains precedence.)

As shown in Figure 5.6, each packet (row) consists of 207 bytes and may include the FEC coded M/H service data, MPEG TS header bytes, trellis initialization bytes, known (training) data bytes, signaling data bytes, non-systematic RS parity bytes and/or "dummy data" bytes. As shown in Figure 5.6, the RS parity bytes for the M/H data packets are not appended at the end of the 187 data bytes.

For the M/H service data packets, the RS parity bytes shall be inserted in pre-determined positions by non-systematic RS encoding as defined in Annex A.

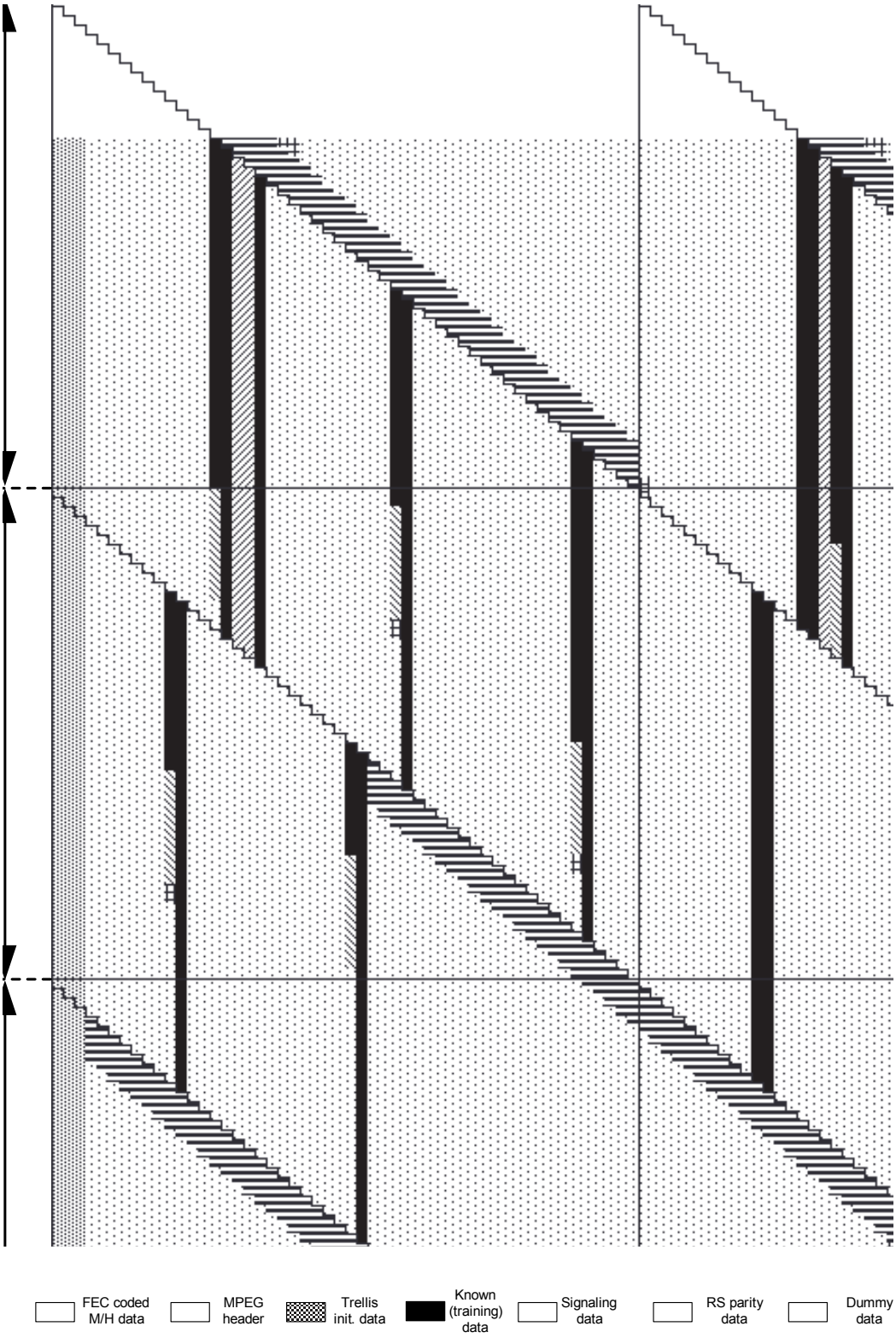

Figure 5.6b Expanded upper left part of Figure 5.6a.

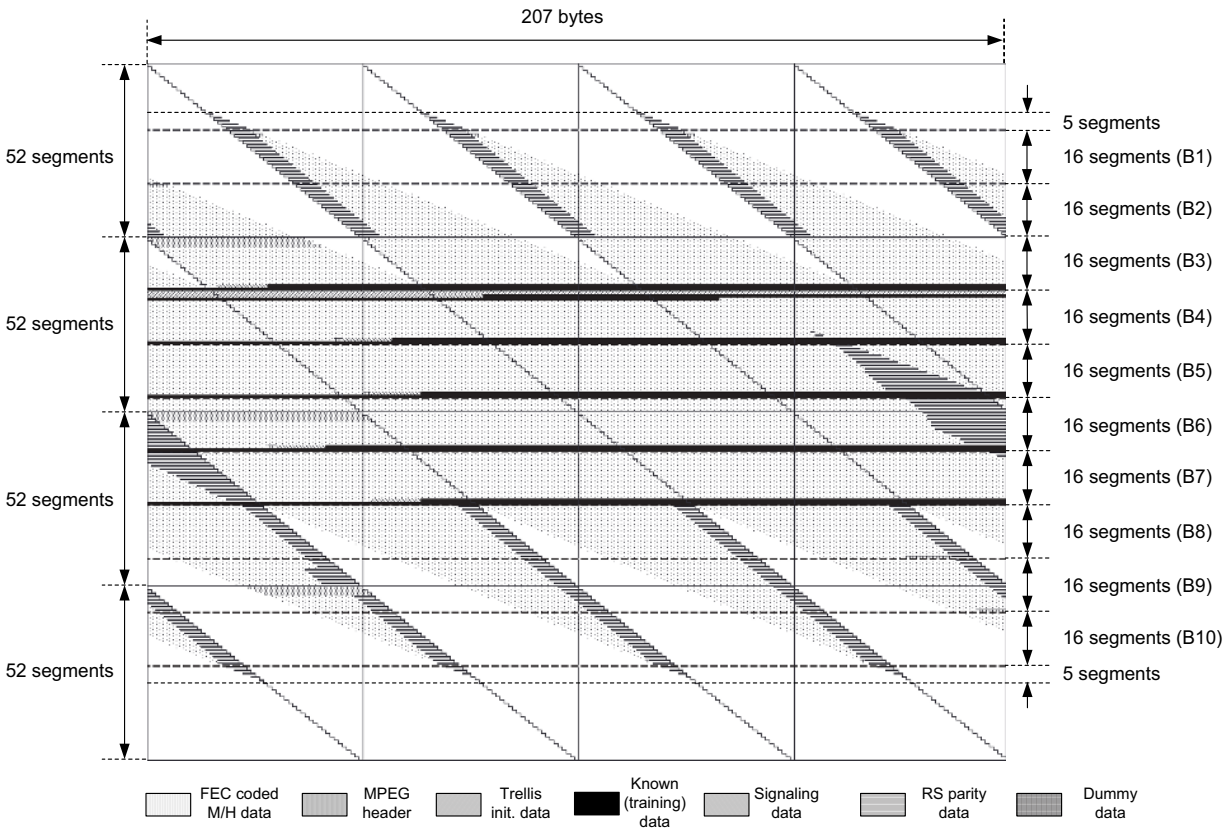

Figure 5.7a Group format after the data interleaver.

The ATSC byte interleaver disperses the M/H Group of 118 packets throughout 170 data segments. Figure 5.7 depicts the M/H Group format after being interleaved by the ATSC byte interleaver. After the ATSC byte interleaving process, the first 5 segments and the last 5 segments have only RS parity data, so they do not carry any FEC coded M/H service data.

After the ATSC byte interleaving, the 160 data segments of an M/H Group excluding the first 5 and last 5 segments shall be divided into 10 M/H Blocks. Each Block shall be 16 segments long. The Blocks are shown in Figure 5.7a as B1 through B10.

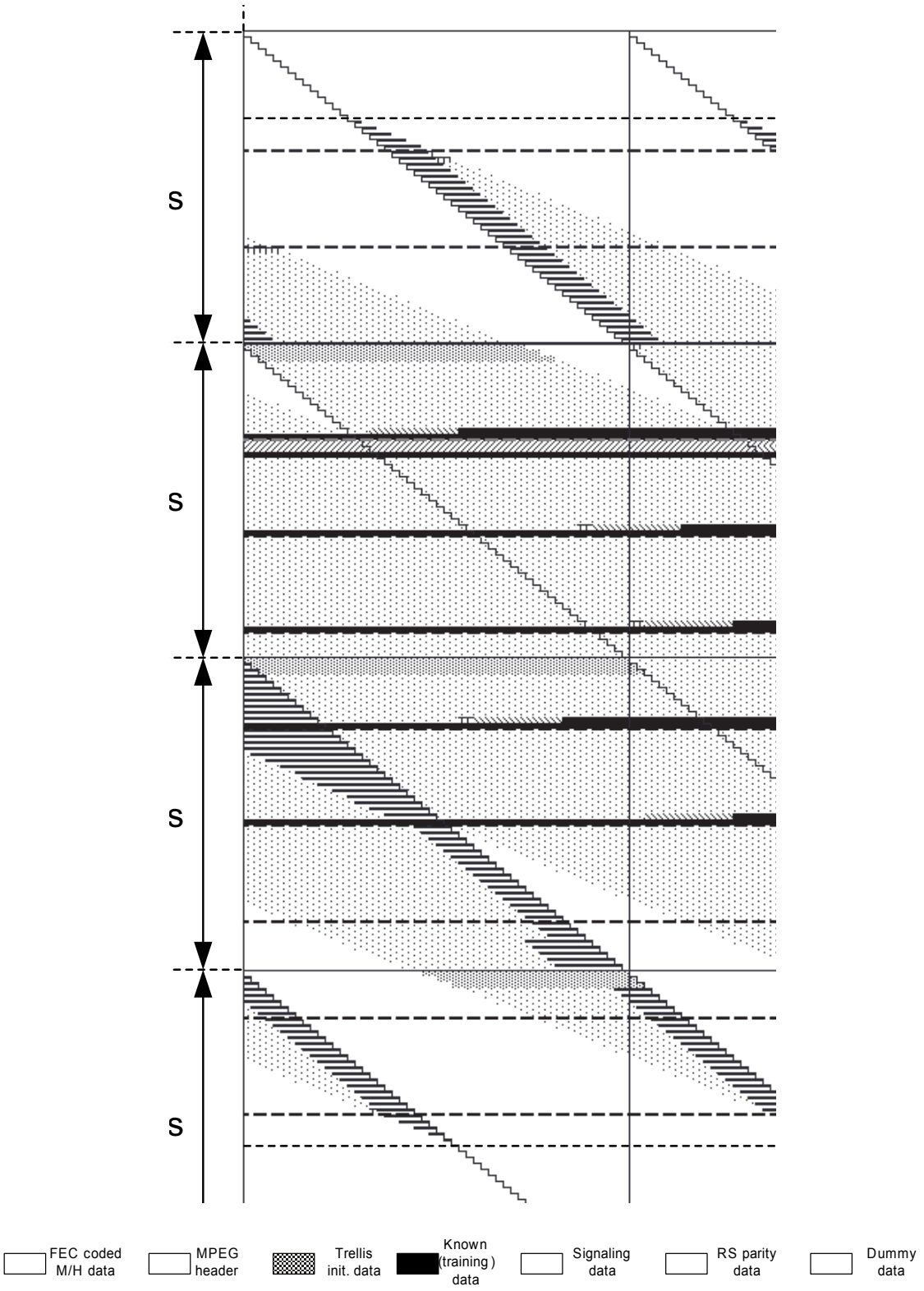

Figure 5.7b Expanded upper left part of Figure 5.7a.

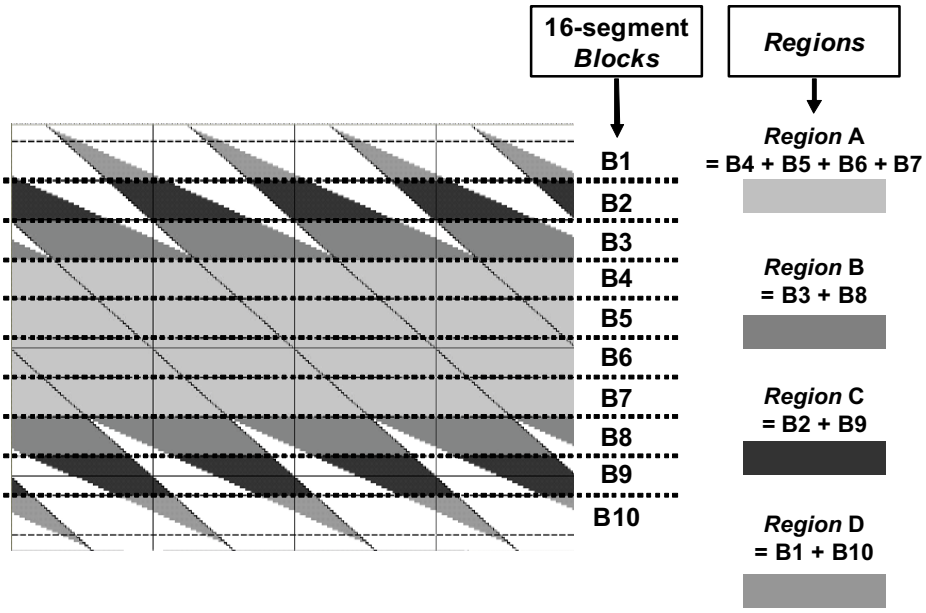

Figure 5.8 M/H group regions.

When there is a field synchronization segment within a Group, it occurs between the 2nd M/H Block (B2) and the 3rd M/H Block (B3); i.e., the M/H Slot position has an offset of 37 packets with respect to the VSB data field (see Section 5.3.1.1).

The 10 M/H Blocks are categorized as four distinct *Regions*:

- Region A shall consist of M/H Blocks B4, B5, B6, and B7
- Region B shall consist of M/H Blocks B3 and B8.
- Region C shall consist of M/H Blocks B2 and B9.
- Region D shall consist of Blocks B1 and B10.

Refer to Figure 5.8, and note that Region A is central, Region B is concentric about Region A, Region C is concentric about Regions A and B, and Region D is concentric about Regions A, B, and C.

Partitioning of M/H data into Blocks is described below in the discussion of the M/H Block encoder. Details of the M/H Group format before and after the data interleaver are shown in Table A.1 and A.2 of Annex A, respectively.

5.3.1.3 Group Assignment in an M/H Frame

Figure 5.9 illustrates the allocation and assignment of M/H Groups in an M/H Frame. Each M/H Frame is composed of 5 M/H Sub-Frames. Each subframe is composed of 16 Slots. A Slot consists of 156 TS packets (before byte interleaving). A slot may consist of only legacy TS packets, or may be assigned to carry a Group of 118 M/H-carrying MHE packets plus 38 legacy TS packets. This section describes the order in which Slots are assigned to carry M/H Groups as the amount of M/H data increases. Once the assignment is made, however, the M/H data is transmitted in time order of available slots, as described in later sections of this document. There

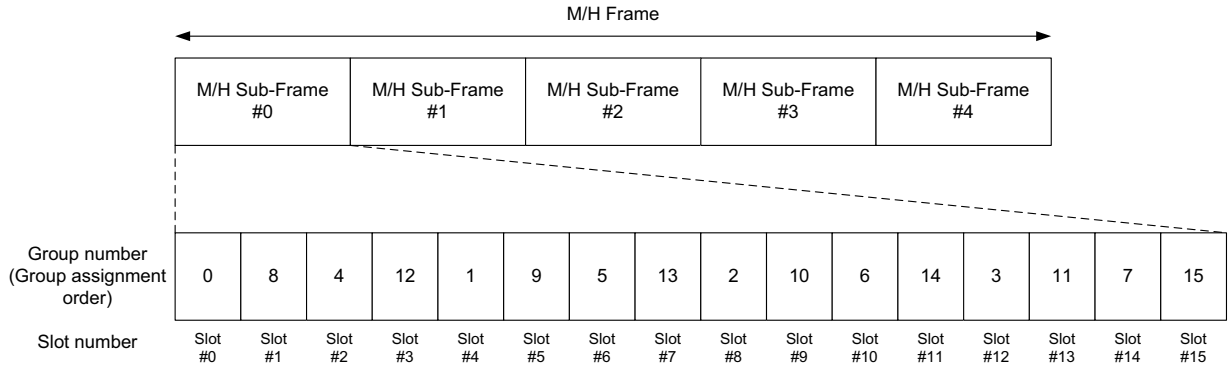

Figure 5.9 Group assignment order in a Sub-Frame.

are further rules for the placement of Groups belonging to single or multiple Ensembles, which are also described in later sections of this document.

The number of Groups allotted per M/H Frame shall be a multiple of 5, and the Group allotment and assignment shall be identical for all M/H Sub-Frames in an M/H Frame.

The lower row of Figure 5.9 illustrates the Group assignment order in an M/H Sub-Frame. For example, if there are 3 Groups per M/H Sub-Frame, then the first Slot (Slot #0), the 5th Slot (Slot #4) and the 9th Slot (Slot #8) will be allocated in each M/H Sub-Frame, shown as Group assignment order numbers 0, 1, and 2.

The assignments start as one-of-four spacing until those possibilities are exhausted, then go to one-of-two, and so on. Equation 5.1 is the formal statement of the Group assignment rule.

For a given Group number i (0~15), the Slot number j (0~15) shall be determined by the equation

$$j = (4i + O) \bmod 16 \quad \text{where } O = 0 \text{ if } i < 4;\ O = 2 \text{ else if } i < 8;\ O = 1 \text{ else if } i < 12;\ O = 3 \text{ else} \tag{5.1}$$

5.3.1.4 M/H Parade

An M/H Parade shall be a collection of M/H Groups, contained within one M/H Frame. The portion of a Parade within a Sub-Frame shall consist of a collection of consectutively numbered Groups. The structure of a Parade in terms of its constituent Group numbers and Slot numbers within a Sub-Frame shall be replicated in all Sub-Frames of an M/H Frame (although the data contents of the Groups differ among the Sub-Frames).

The starting Group number for the first Parade to which Group numbers are assigned shall be zero. The starting Group number of a succeeding Parade shall be the next higher Group number after the Group numbers for all preceding Parades have been assigned. Note that the Slot numbers (locations of Groups in a Sub-Frame) allocated respectively to Groups are calculated from the Group numbers according to Equation 5.1.

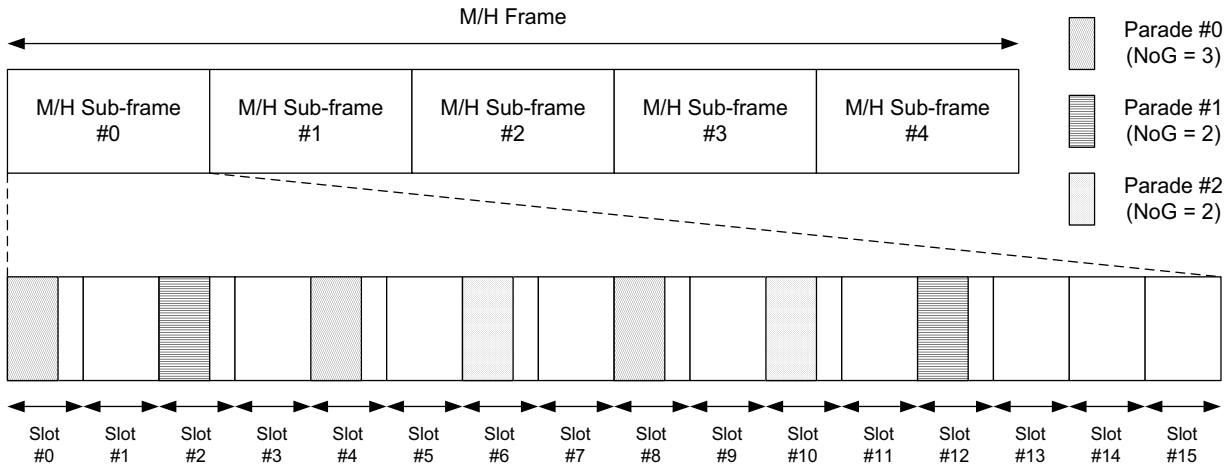

Figure 5.10 Group assignments for multiple Parades.

An M/H Parade carries data from one or two particular RS Frames depending on an RS Frame mode. The RS Frame, which is explained in detail in the next section, is a packet-level FEC structure for the M/H data. Each RS Frame carries, and FEC encodes, an M/H Ensemble, which is a collection of M/H services providing the same quality of service (QoS).

Multiple M/H Parades can be transmitted with main data within an M/H Frame. Figure 5.10 shows an example of multiple-Parade transmission. One Sub-Frame is expanded to show the detailed Parade pattern. All five Sub-Frames follow the same pattern. The example shows three M/H Parades in an M/H Frame. The first Parade has 3 Groups per M/H Sub-Frame and its Group positions are determined by substituting the Group number i from 0 to 2 in Equation (5.1). The second Parade has 2 Groups per M/H Sub-Frame and its allocated Slot numbers are determined by substituting the Group number i from 3 to 4. In a similar manner, the Group positions of the third Parade are obtained by substituting the Group number i from 5 to 6.

Slot allocation for M/H Parades shall be determined by first taking all the Groups of one Parade in sequence as input to Equation 5.1, followed by the Groups of the second Parade, and so forth.

> Note: The M/H Frame organization can be changed M/H Frame by M/H Frame. This allows adjustment of Ensemble data rates on a frequent and flexible basis.

The Number of Groups per M/H Sub-Frame (NoG) for an M/H Parade ranges from 1 to 8 and therefore the number of Groups per an M/H Frame for a Parade ranges from 5 to 40 with a step of 5.

5.3.2 M/H Data Processing

The complete processing diagram including the relationship of the blocks discussed in the following sections is shown in Figure 5.2

5.3.2.1 Packet Timing and PCR Adjustment of Main Service Data

In the M/H system, like any time-division multiplexed system, the positions of the main data packets in the legacy ATSC stream are changed by the insertion of the MHE packets. Standard ATSC Transport Stream decoder buffer models exist, which are intended to constrain these

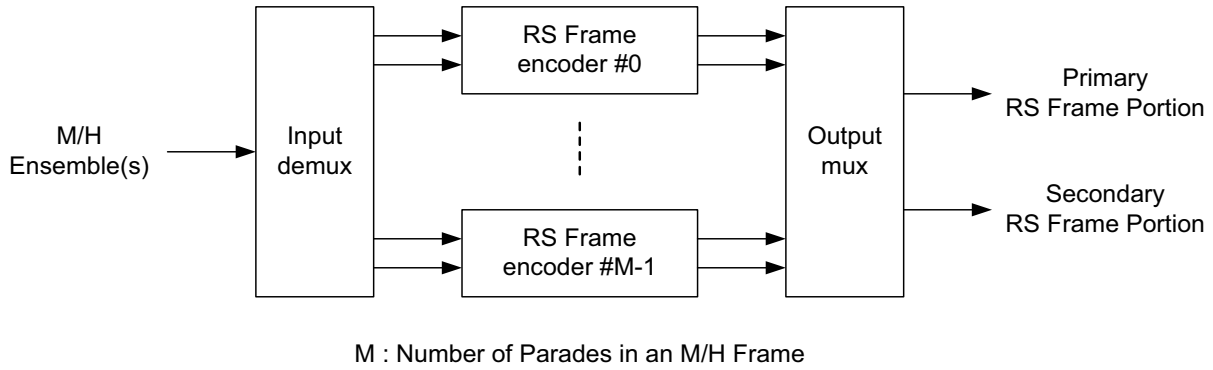

Figure 5.11 M/H Frame encoder.

temporal packet displacements. For example, in ISO 13818-1, the target system decoder includes a transport buffer definition which limits the short term maximum data rate. This is followed by a main or elementary buffer which holds a larger portion of data for processing and essentially defines a minimum data rate burst for a particular stream type. The size of this buffer and the rate at which it is allowed to empty put limits on how much delay may be inserted into the stream and how quickly it may be replenished. Maximum and minimum data rates translate to multiple packet advancement in time and packet delay respectively. As the fullness of the buffer model is in general unknown, even a single TS packet displacement can violate the standard ATSC Transport Stream buffer model. Displacement of larger Groups of packets can be expected to systemically exceed the capability provided in the standard ATSC Transport Stream buffer models. Compensatory adjustments need to be made to avoid violating current ATSC standards to prevent disruption of the main and ancillary services.

The emitted combined main service and M/H multiplex shall be constructed such that the non-M/H portion(s) of the multiplex complies with each ATSC-standard data flow transmitted in the non-M/H portion, including, A/53 Part 3 [9], A/65 [4], A/90 [5], A/97 [6], A/99 [7], and A/101 [8], when such data are transmitted.

Of particular and direct relevance, the buffer models for all TS-M packets, such as defined in A/53 Part 3 [9] Section 6.1.2, contain critical requirements directly addressing the packet-level adjustments required by M/H. A/53 Part 3 [9], A/65 [4], and other ATSC Standards establish other requirements and recommendations for the internal construction of the transport stream,its elements and various defined buffer models that continue to apply. For example, the System Time Table, as defined in A/65 [4], is required to have a defined accuracy and is recommended to be emitted at a certain time with respect to the transition instant of the UTC seconds count.

There are several methods that may be employed to meet the limits imposed by the ATSC Transport Stream buffer models. Annex B provides a detailed discussion and one exemplary method for timing and PCR adjustment of main service packets with special attention to audio packets that have been displaced by their being time-division multiplexed with the M/H data packets.

5.3.2.2 M/H Frame Encoder

The M/H Frame is a basic time period that carries one or more M/H Parades. Each Parade is derived from either one or two RS Frames. Figure 5.11 shows a conceptual block diagram of the

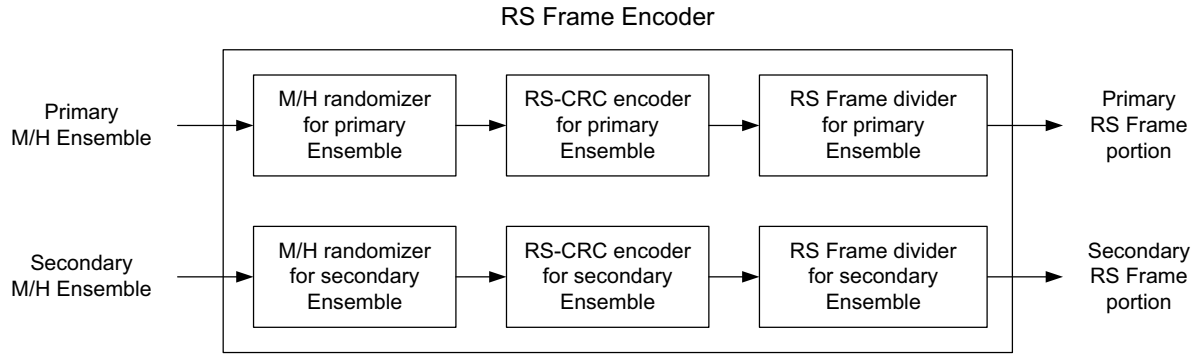

Figure 5.12 RS Frame encoder.

M/H Frame encoder. The input demultiplexer separates the input Ensembles and routes the corresponding Ensemble(s) into each RS Frame encoder. As shown in Figure 5.11, there is the same number of RS Frame encoders as the number of Parades in an M/H Frame. Each RS Frame encoder builds one or two RS Frames for each Parade and separates each RS Frame into several portions. Each segmented portion of the RS Frame corresponds to the amount of data carried by a Group.

The output mux puts the RS frame portions constructed by the RS Frame Encoders into the order required by the Block Processor shown in Figure 5.2 and described in Section 5.3.2.3.

5.3.2.2.1 RS Frame Encoder

An RS Frame encoder operates in one of two modes according to the RS Frame mode assigned to that encoder. In the case of RS Frame mode = '00' (Single Frame), the RS Frame encoder produces one (primary) RS frame, which will be transmitted in Regions A, B, C, and D of M/H Groups. In the case of RS frame mode = '01' (Dual Frame), the RS Frame encoder encodes two RS Frames, a primary RS Frame, which will be transmitted in Regions A and B of M/H Groups and a secondary RS Frame, which will be transmitted in Regions C and D of M/H Groups.

In the case of RS frame mode = '00', an RS Frame encoder builds one RS Frame for each M/H Parade by receiving a primary M/H Ensemble. In the case of RS frame mode = '01', an RS Frame encoder builds two RS Frames for each M/H Parade by receiving a primary and a secondary M/H Ensemble. Each M/H Ensemble is processed through an M/H Randomizer and then is FEC coded using both RS and CRC codes in a cross-interleaved manner to build an RS Frame. Figure 5.12 illustrates the detailed block diagram of the RS Frame encoder.

Each RS Frame encoder shall include an M/H randomizer, an RS-CRC encoder and an RS Frame divider for the primary Ensemble, and a parallel set of these Blocks for the secondary Ensemble, as shown in Figure 5.12.

In the RS Frame encoder, one or two RS Frames are built depending on a RS Frame mode. Table 5.3 indicates how many RS Frames are to be built per a Parade and their Group Region association. One M/H Parade can carry up to two RS Frames.

If the RS Frame mode of a Parade equals '00', there shall be only the primary RS Frame for the Parade (Single Frame mode).

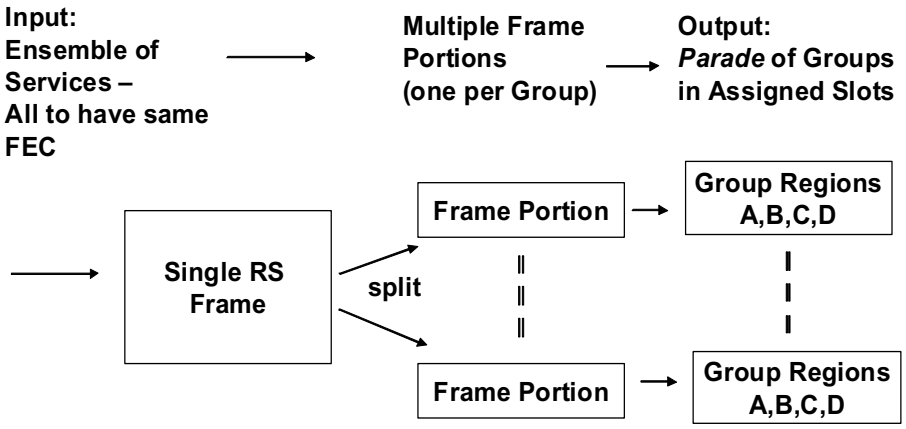

Figure 5.13 Progression from Ensemble to RS Frame to Parade of Groups for Single Frame Mode.

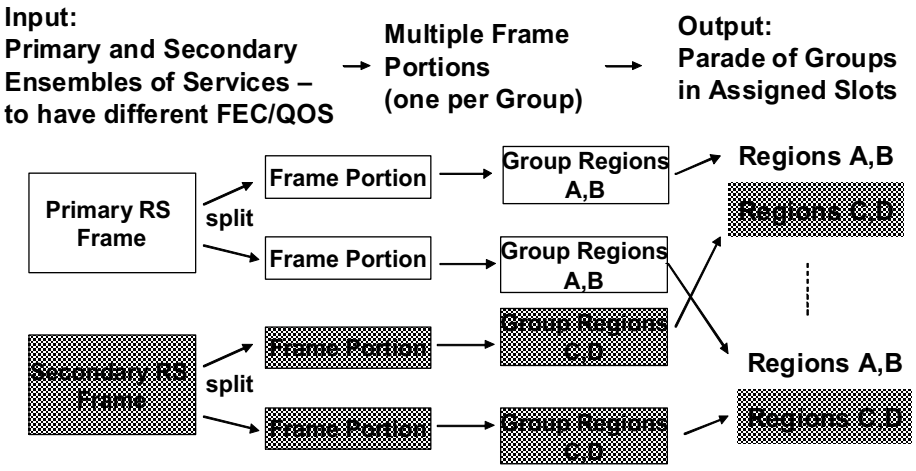

Figure 5.14 Progression from Ensembles to RS Frames to Parade of Groups for Dual Frame Mode.

If the RS Frame mode of a Parade is '01' (Dual Frame mode), there shall be two separate RS Frames, the primary RS Frame and the secondary RS Frame.

If the RS Frame mode of a Parade is '01', the primary RS Frame shall be transmitted in Region A and B of a Group, and the secondary RS Frame shall be transmitted in Region C and D of a Group. This concept is illustrated in Figure 5.13 and Figure 5.14.

Table 5.3 RS Frame Mode

RS Frame mode	Description
00 (Single Frame)	There is only a primary RS Frame for all Group Regions
01 (Dual Frame)	There are two separate RS Frames - Primary RS Frame for Group Region A and B - Secondary RS Frame for Group Region C and D
10	Reserved
11	Reserved

The number of payload bytes of a RS Frame shall be a multiple of 187. Figure 5.15 shows how the RS Frame payload data is organized, with N columns by 187 rows. The number of rows of a RS Frame payload shall be 187.

The payload packets shall be written in sequence row-by-row from left-to-right and top-to-bottom in the RS Frame.

As shown in Figure 5.15 for IP packet transport, the input data shall be written in sequence row-by-row from left-to-right and top-to-bottom in the RS Frame. See A/153 Part 3 [13] for the normative definition of the contents of each row.

The number of columns of a RS Frame payload, N, is a function of the number of Groups per M/H Sub-Frame (NoG), the number of SCCC payload bytes per a Group (PL) and the number of RS parity bytes per RS Frame column (P).

N shall be determined according to equation (5.2).

$$N = \left\lfloor \frac{5 \times NoG \times PL}{187 + P} \right\rfloor - 2 \tag{5.2}$$

Notation: $\lfloor X \rfloor$ indicates the greatest integer less than or equal to X.

In the above equation, PL is a RS Frame Portion *Length* and is equal to the number of SCCC payload bytes per Group. PL depends on the RS Frame mode, a SCCC Block Mode and SCCC

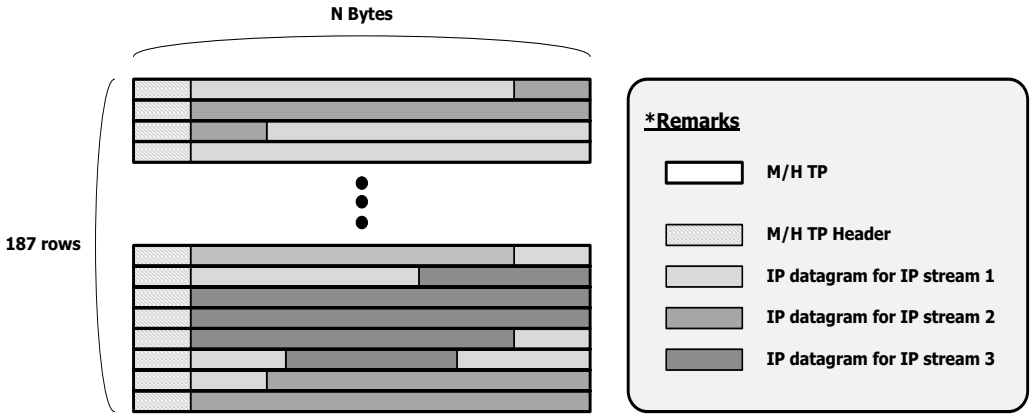

Figure 5.15 RS Frame payload organization.

outer code modes. Tables 5.4a through 5.4d tabulate (PL) according to the RS Frame mode, the SCCC Block Mode and the SCCC outer code mode. Detailed explanation of the SCCC Block Mode and the SCCC outer code mode is given in Section 5.3.2.3.

Table 5.4a PL for the Primary RS Frame when RS Frame Mode = '00' (Single Frame) and SCCC Block Mode = '00' (Separate Block)

SCCC Outer Code Mode Combinations				PL
For Region A	For Region B	For Region C	For Region D	
00	00	00	00	9624
00	00	00	01	9372
00	00	01	00	8886
00	00	01	01	8634
00	01	00	00	8403
00	01	00	01	8151
00	01	01	00	7665
00	01	01	01	7413
01	00	00	00	7023
01	00	00	01	6771
01	00	01	00	6285
01	00	01	01	6033
01	01	00	00	5802
01	01	00	01	5550
01	01	01	00	5064
01	01	01	01	4812
Others				Undefined

Table 5.4b PL for the Primary RS Frame when RS Frame Mode = '00' (Single Frame) and SCCC Block Mode = '01' (Paired Block)

SCCC Outer Code Mode	PL
00	9624
01	4812
Others	Undefined

Table 5.4c PL for the Primary RS Frame when RS Frame Mode = '01' (Dual Frame) and SCCC Block Mode = '00' (Separate Block)

SCCC Outer Code Mode Combinations		PL
For Region A	**For Region B**	
00	00	7644
00	01	6423
01	00	5043
01	01	3822
Others		Undefined

Table 5.4d PL for the Secondary RS Frame when RS Frame Mode = '01' (Dual frame) and SCCC Block Mode = '00' (Separate Block)

SCCC Outer Code Mode Combinations		PL
For Region C	**For Region D**	
00	00	1980
00	01	1728
01	00	1242
01	01	990
Others		Undefined

5.3.2.2.1.1 M/H Randomizer

As shown in Figure 5.12, separate M/H randomizers are used for the primary RS Frame and the secondary RS Frame. The M/H randomizer XORs all the M/H Frame payload data bytes with a 16-bit maximum length pseudo random binary sequence (PRBS), which is initialized at the beginning of each RS Frame.

The PRBS is generated in a 16-stage binary shift register that has 9 feedback taps. Eight of the shift register outputs are permanently selected to form the randomizing byte, generating one randomizing byte per shift. Each bit from this byte is used to individually XOR the corresponding input data bit. The data bits are XORed MSB to MSB ... LSB to LSB.

The randomizer polynomial and initialization is shown in Figure 5.16.

The M/H randomizer generator polynomial shall be:

$$G_{(16)} = X^{16} + X^{13} + X^{12} + X^{11} + X^{7} + X^{6} + X^{3} + X + 1 \tag{5.3}$$

The initialization (pre-load) shall be to 0xF180 (load to 1) and shall occur before starting randomization of the first byte of the RS Frame payload. The first byte shall be randomized using the pre-load condition, followed by the first stepping of the register. The register shall step after each subsequent byte. The randomizing byte taps shall be as shown in Figure 5.16. Each bit from this byte shall be used to individually XOR the corresponding input data bit (MSB to MSB … LSB to LSB).

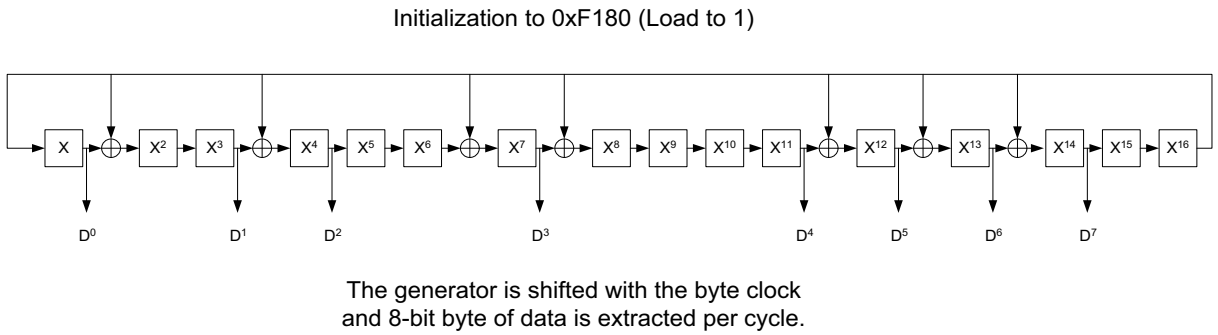

Figure 5.16 Randomizer polynomial.

5.3.2.2.1.2 RS-CRC Encoder

The M/H randomizer output is provided to the RS-CRC encoder.

The RS-CRC encoder shall perform RS encoding for each of the N-columns of bytes of the RS Frame payload and shall add the RS parity bytes at the bottom of each column. See Figure 5.17.

The RS-CRC encoder then shall add CRC syndrome checksum bytes at the right end of each row.

The number of RS payload bytes shall be 187.

The RS code mode shall be set independently for the primary RS Frame and for the secondary RS Frame. The RS Code shall be as shown in Table 5.5 for each RS code mode. The number of RS parity bytes for each RS code mode is shown in Table 5.5.

Table 5.5 RS Code Mode

RS Code Mode	RS Code	Number of Parity Bytes (P)
00	(211,187)	24
01	(223,187)	36
10	(235,187)	48
11	Reserved	Undefined

The RS code parity generator polynomial and the primitive field generator polynomial for the RS Frame shall be:

Parity generator polynomial

$$g(x) = (x+\alpha^0)(x+\alpha^1)(x+\alpha^2)\cdots(x+\alpha^{2t-1}) \tag{5.4}$$

Primitive field generator polynomial

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1 \tag{5.5}$$

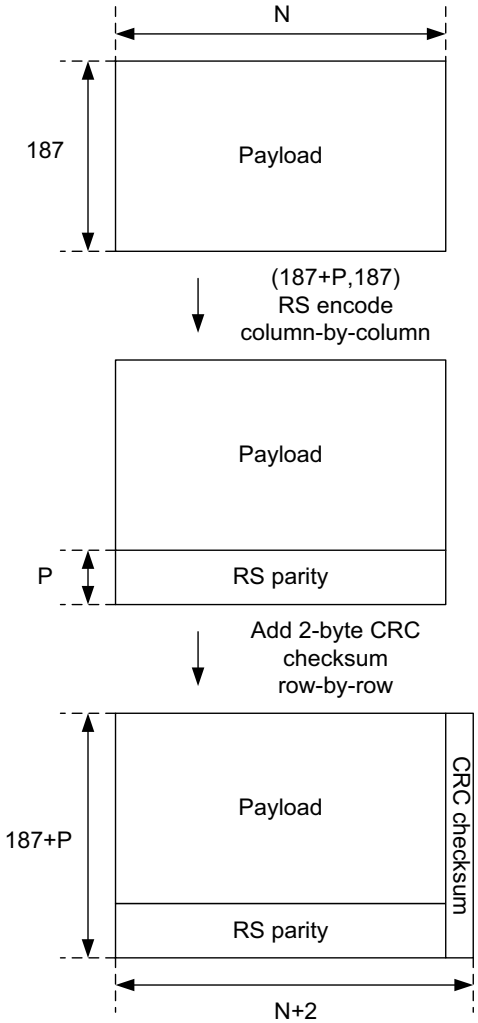

Figure 5.17 RS-CRC encoding.

Note: After all columns are encoded by the RS code, the RS Frame size is (187 + P) x N bytes.

For every row of the RS Frame encoded by RS, 2 bytes of CRC syndrome check bytes shall be added at the right end of each row. The 16-bit (2 byte) CRC checksum of the CRC code shall be generated by Equation 5.6:

$$G_{CRC} = X^{16} + X^{12} + X^5 + 1 \tag{5.6}$$

The intial value of all registers in the CRC encoder shall be 0x0000. Note: there is no use of bit reflection or XOR combination in the CRC encoding.

Note: After RS and CRC encoding, the RS Frame size is (187 + P) x (N + 2) bytes as shown in Figure 5.17.

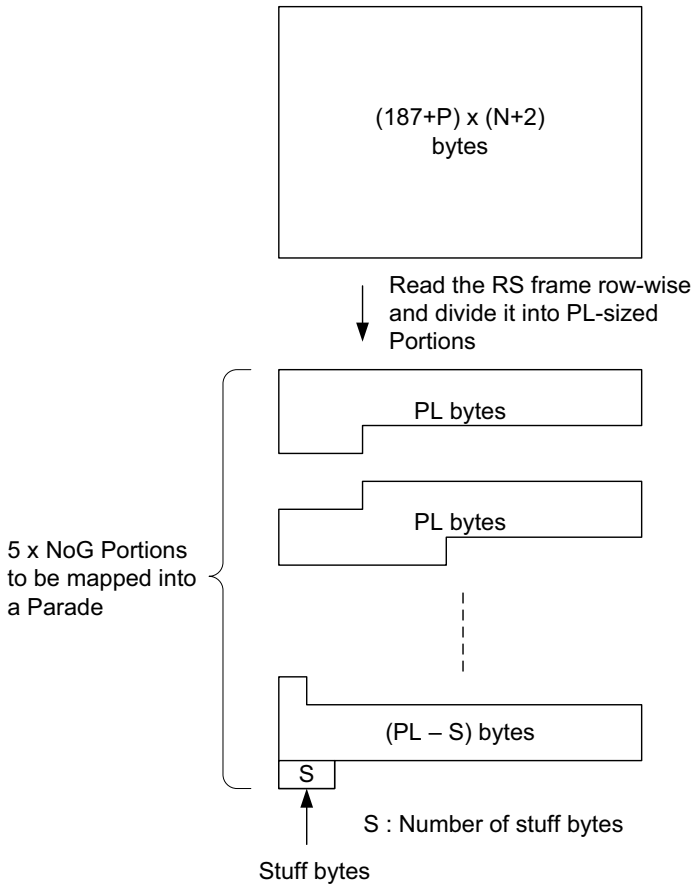

Figure 5.18 Division of a RS Frame into (5 x NoG) Portions of size PL bytes.

5.3.2.2.1.3 RS Frame Divider

The primary and secondary RS Frames are transmitted through a Parade of Groups during an M/H Frame. After RS and CRC encoding, the RS Frame consists of (187 + P) x (N + 2) bytes of data.

Because the total number of bytes of a RS- and CRC-encoded RS Frame is slightly less than or equal to 5 x NoG x PL, the RS Frame can be divided into ((5 x NoG) – 1) portions of size PL bytes plus one portion of size PL or smaller. Some padding bytes can be appended to the last portion of the encoded RS Frame data if necessary to make up a final PL-sized portion, as shown in Figure 5.18. When present, padding bytes are defined as reserved and shall have the value of 0xFF[1]. Note that each portion of a RS Frame corresponds to the amount of data to be SCCC-encoded and mapped into a single Group of a Parade.

The encoded RS Frame shall be divided into a number of sucessive *portions*. Each portion shall contain PL bytes taken from the RS Frame (where PL is the RS Frame Portion Length). The number of portions shall be (5 x NoG). The first ((5 x NoG) – 1) portions shall contain PL bytes. The last portion shall conclude with padding bytes if necessary to make it the same size (PL bytes) as the other portions.

The number of padding bytes (S) can be calculated by the equation

1. In this version of this standard, the meaning of padding bytes is not defined.

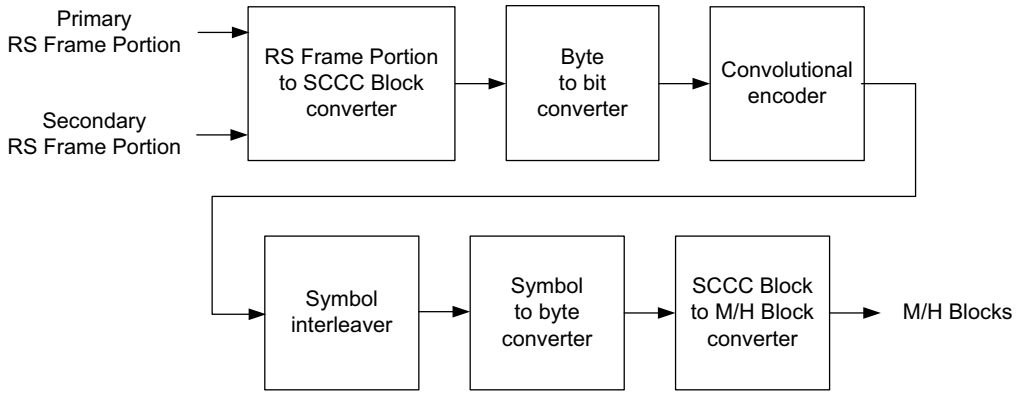

Figure 5.19 Block processor.

$$S = \left(5 \times NoG \times PL\right) - \left(187 + P\right) \times \left(N + 2\right) \tag{5.7}$$

Each portion of PL-sized data shall be fed to a Block processor.

Note: The mapping order of the RS Frame Portions to a Parade of Groups may differ from the Group assignment order defined in Equation (5.1).

Given the Group positions of a Parade in an M/H Frame, the SCCC-encoded RS Frame Portions shall be mapped *in time order*.

Example (refer to Figures 5.9 and 5.10): For Parade #1 (the second Parade that is allocated), Slot #12 is allocated first and then due to the wrapping effect of the one-in-four pattern changing to one-in-two, Slot #2 is allocated next. However, when data is placed in these allocated Slots, it is placed in time sequence (left-to-right in the illustration), that is, the first Group of Parade #1 is placed in Slot #2 and the second Group of Parade #1 is placed in Slot #12.

5.3.2.3 Block Processor

The main function of a Block processor is an outer-encoding of the SCCC for the output of the RS Frame encoder. The operations of the Block processor include RS Frame Portion to SCCC Block conversion, byte-to-bit conversion, convolutional encoding, symbol interleaving, symbol-to-byte conversion and SCCC Block to M/H Block conversion as shown in Figure 5.19. The convolutional encoder and the symbol interleaver are effectively concatenated with the trellis encoder in the post-processor to construct the SCCC (Serially Concatenated Convolutional Code).

The Block processor operates in the same data order as after ATSC byte interleaving. After the ATSC byte interleaver, an M/H Group consists of 10 M/H Blocks and is divided into four Group *Regions* (A, B, C, D). Refer to Section 5.3.1.2 for the detailed description of Group structure.

One M/H Block can constitute a single SCCC Block. But an SCCC Block boundary is not required to be identical with an M/H Block boundary. Table 5.6 explains the SCCC Block Mode, which identifies the relationship between the M/H Block and the SCCC Block. If the SCCC Block Mode is equal to '00' (Separate) then each SCCC Block consists of a single M/H Block, and thus there are 10 SCCC Blocks per Group. If the SCCC Block Mode is '01' (Paired), then two M/H Blocks constitute a single SCCC Block, and thus there are 5 SCCC Blocks per Group. In the latter

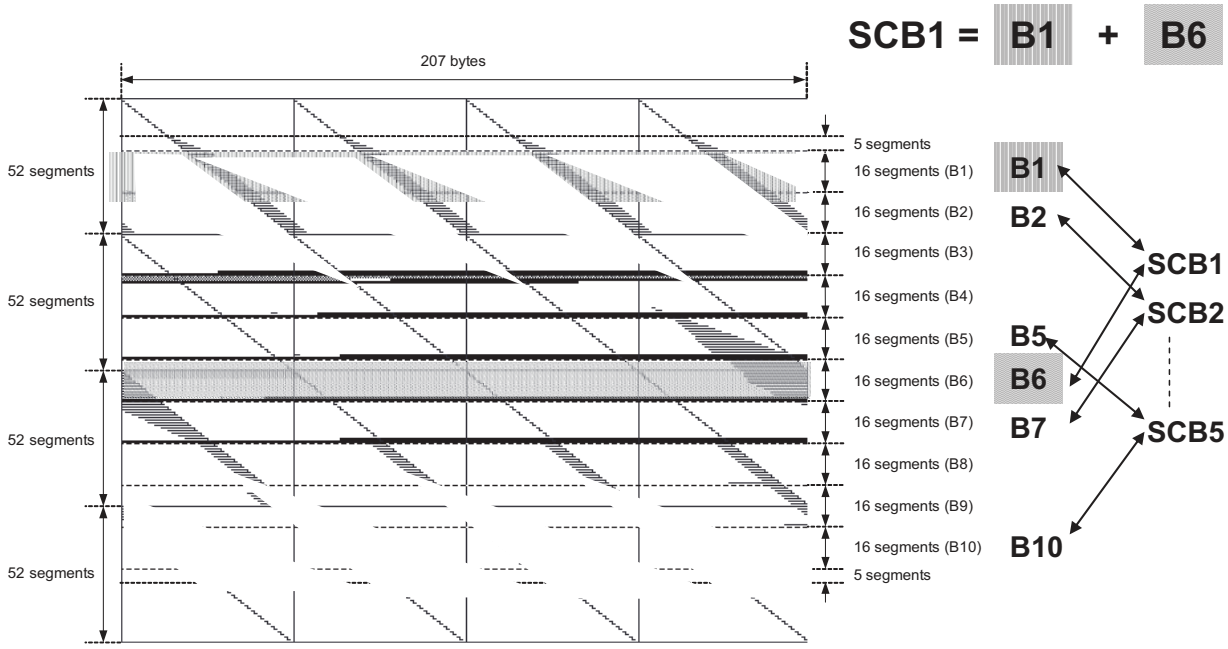

Figure 5.20 SCCC Blocks for SCCC Block Mode = '01' (Paired Block Mode)

case, the first SCCC Block (SCB1) consists of M/H Blocks B1 and B6, and the second SCCC Block (SCB2) consists of B2 and B7. Likewise, the third SCCC Block (SCB3) consists of B3 and B8, the fourth SCCC Block (SCB4) consists of B4 and B9, and the fifth SCCC Block (SCB5) consists of B5 and B10.

M/H Blocks shall be assigned to SCCC Blocks as shown in Table 5.6

Table 5.6 SCCC Block Mode

SCCC Block Mode	**00**	**01**	**10**	**11**
Description	**Seperate SCCC Block Mode**	**Paired SCCC Block Mode**	**Reserved**	**Reserved**
SCB	SCB input, M/H Block	SCB input, M/H Blocks		
SCB1	B1	B1 + B6		
SCB2	B2	B2 + B7		
SCB3	B3	B3 + B8		
SCB4	B4	B4 + B9		
SCB5	B5	B5 + B10		
SCB6	B6	-		
SCB7	B7	-		
SCB8	B8	-		
SCB9	B9	-		
SCB10	B10	-		

This method is illustrated in Figure 5.20.

The SCCC outer code rate shall be set according to the outer code mode as shown in Table 5.7.

Table 5.7 SCCC Outer Code Mode

SCCC Outer Code Mode	Description
00	The outer code rate of a SCCC Block is 1/2 rate
01	The outer code rate of a SCCC Block is 1/4 rate
10	Reserved
11	Reserved

If SCCC Block Mode = '00' (Separate Block), then the SCCC outer code mode shall be set independently for each Group Region (A, B, C, D). If the SCCC Block Mode = '01' (Paired Block), then all four Regions shall have the same SCCC outer code mode.

The SCCC Output Block Length (SOBL) for each SCCC Block shall be as shown in Table 5.8a when the SCCC Block Mode is '00'. Table 5.8a also shows the SCCC Input Block Length (SIBL), which is either 1/2 or 1/4 of the SOBL according to the outer code rate for each SCCC Block. The SOBL is equal to the number of SCCC output (or outer encoded) bytes for each SCCC Block and the SIBL is equal to the number of the SCCC input (or payload) bytes for each SCCC Block.

The SCCC Output Block Length for each SCCC Block shall be as shown in Table 5.8b when the SCCC Block Mode is '01' (Paired Block).

Related SIBL values for 1/2- and 1/4-rate SCCC coding also are given.

Table 5.8a SOBL and SIBL when SCCC Block Mode = '00' (Separate)

SCCC Block	SOBL	SIBL	
		1/2 rate	1/4 rate
SCB1 (B1)	528	264	132
SCB2 (B2)	1536	768	384
SCB3 (B3)	2376	1188	594
SCB4 (B4)	2388	1194	597
SCB5 (B5)	2772	1386	693
SCB6 (B6)	2472	1236	618
SCB7 (B7)	2772	1386	693
SCB8 (B8)	2508	1254	627
SCB9 (B9)	1416	708	354
SCB10 (B10)	480	240	120

Table 5.8b SOBL and SIBL when SCCC Block Mode = ‘01’ (Paired)

SCCC Block	SOBL	SIBL	
		1/2 rate	1/4 rate
SCB1 (B1 + B6)	3000	1500	750
SCB2 (B2 + B7)	4308	2154	1077
SCB3 (B3 + B8)	4884	2442	1221
SCB4 (B4 + B9)	3804	1902	951
SCB5 (B5 + B10)	3252	1626	813

5.3.2.3.1 RS Frame Portion to SCCC Block Converter

Depending on the RS Frame mode of a Parade, the M/H Frame encoder provides the primary RS Frame Portion (Single Frame mode) or both the primary RS Frame Portion and the secondary RS Frame Portion (Dual Frame mode) of that Parade. The RS Frame Portion to SCCC Block converter divides the received RS Frame Portion(s) into several SCCC Blocks by using the SIBL listed in Table 5.8a or 5.8b according to the RS Frame mode, the SCCC Block Mode and the SCCC outer code mode. Note that the RS Frame mode of ‘01’ (which implies Primary RS Frame data carried in Group Regions A and B and Secondary RS Frame data carried in Group Regions C and D) cannot be used in conjunction with the Paired SCCC Block Mode. This relationship is shown in Table 5.9.

Table 5.9 Frame mode, SCCC Block Mode, SOBL and SIBL, SCC Code Mode

Frame Mode	SCCC Block Mode	RS Frame Portions	Number of SCCC Blocks	Table for SOBL and SIBL	SCCC Code Mode (00 → 1/2 rate, or 01 → 1/4 rate)
00	00 (Separate)	Primary only	10	Table 5.8a	Independent per Region A,B, C, or D
00	01 (Paired)	Primary only	5	Table 5.8b	Identical for all Regions (A,B, C, and D)
01	00 (Separate)	Primary + Secondary	10	Table 5.8a	Independent per Region A,B, C, or D
01	01 (Paired)	(not allowed)	(not allowed)	(not allowed)	(not allowed)

When the RS Frame mode is set to ‘00’, a portion of the primary RS Frame equal to the amount of data which is to be SCCC outer encoded and mapped to 10 M/H Blocks of a Group shall be provided to the Block processor. If the SCCC Block Mode is set to ‘00’, then the primary RS Frame Portion shall be split into 10 SCCC Blocks according to Table 5.8a. If the SCCC Block Mode is set to ‘01’, then the primary RS Frame portion shall be split into 5 SCCC Blocks according to Table 5.8b.

If the RS Frame mode is ‘01’, then the Block processor shall receive two RS Frame Portions. The RS Frame mode of ’01’ shall not be used with the SCCC Block Mode of ‘01’. The first portion from the primary RS Frame shall be SCCC outer encoded as SCCC Blocks SCB3, SCB4, SCB5, SCB6, SCB7, and SCB8 by the Block processor. The SCCC Blocks SCB3 and SCB8 shall be mapped to the Region B and the SCCC Blocks SCB4, SCB5, SCB6, and SCB7 shall be mapped to the Region A by the Group formatter. The second portion from the secondary RS Frame also shall be SCCC outer encoded, as SCB1, SCB2, SCB9, and SCB10, by the Block processor. The Group formatter shall map the SCCC Blocks SCB1 and SCB10 to the Region D as

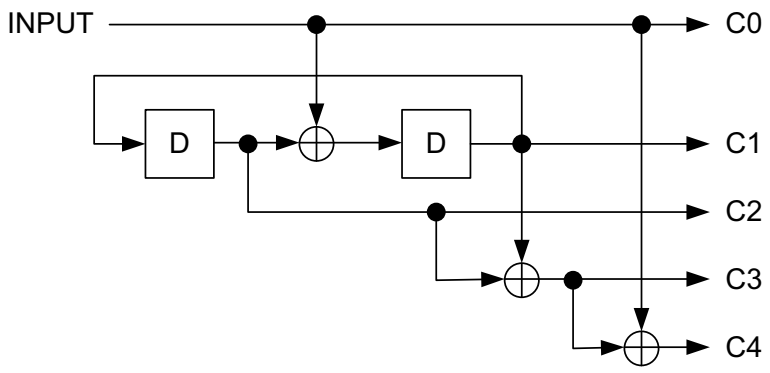

Figure 5.21. Four-state convolutional encoder.

the M/H Blocks B1 and B10, respectively. Likewise the SCCC Blocks SCB2 and SCB9 shall be mapped to the Region C as the M/H Blocks B2 and B9.

5.3.2.3.2 Byte-to-Bit Converter

For the purpose of bit-wise operation in the convolutional encoder, the byte-to-bit converter shall convert parallel bytes to serial bits. In creating serial bits, the MSB shall be sent out first: (7, 6, 5, 4, 3, 2, 1, 0).

5.3.2.3.3 Convolutional Encoder

Outer convolutional coding for the SCCC shall be performed by a single 4-state convolutional encoder of the sort shown in Figure 5.21. The blocks labeled "D" are unit-clock-time delays. A 1-bit input (S) shall be encoded into 5 output bits (C0, C1, C2, C3, C4) once perunit-clock cycle.

A punctured 1/2 rate code or punctured 1/4 rate code shall be constructed as specified in Table 5.10.

Table 5.10 Convolutional Encoder Output Symbols (bit pairs)

Region	1/2 Rate	1/4 Rate	
		SCCC Block Mode = '00'	SCCC Block Mode = '01'
A, B	(C0, C1)	(C0, C2), (C1, C4)	(C0, C2), (C1, C4)
C, D		(C0, C1), (C3, C4)	

For 1/2 rate coding, the leftmost bit, C0, of each symbol (C0, C1) shall be the MSB for definition of processing order in subsequent stages and shall be passed first to succeeding processing stages. This MSB will eventually become the X2 input to the legacy trellis encoder. The LSB (C1) will eventually become the X1 input to the legacy trellis encoder.

For the case of 1/4 rate, two output symbols shall be constructed according to the associated Region, as shown in Table 5.10. The leftmost symbol of a symbol pair shall be output first. Also, similarly to the 1/2 rate case, the leftmost bit in a symbol shall be the MSB and shall be output before the LSB. For example, in the 1/4 rate mode of Region A (or B), a first output symbol is

composed of a (C0, C2) bit-pair, and a second output symbol is composed of a (C1, C4) bit-pair, and the order of bits in the output is C0, C2, C1, C4.

The memory contents of the convolutional encoder shall be reset to zero before encoding each SCCC block.

5.3.2.3.4 Symbol Interleaver

The symbol interleaver in the Block processor scrambles the output symbols from the convolutional encoder. The symbol interleaver is a type of Block interleaver.

The Block length in symbols (B) shall be equal to 4 x SOBL per Table 5.8a or 5.8b.

> Note: B is set to 4 x SOBL because one symbol consists of 2 bits (1/4 of a byte). For the SOBL of each SCCC Block, refer to Table 5.8a and 5.8b.
>
> Note: In this section, P(i) and P'(i) refer to the interleaving pattern, and not to a number of RS parity bytes, P.

The detailed operation of the symbol interleaver is as follows:

The interleaving pattern P(i) shall be as determined by the following four-step method:

Step 1: Calculate L, where L = 2^m, m is an integer, and L is the smallest such power of 2 that is greater than or equal to B.

Step 2: List all permuted positions P'(i) in ascending order of i *(*where i is the natural number within 0 to L-1) according to the equation

$$P'(i) = \{89 \times i \times (i+1)/2\} \bmod L \tag{5.8}$$

Step 3: Discard all P'(i) that are P'(i) ≥ B.

Step 4: Condense the list by:

Starting with the lowest i, shift the P(i) entries to the left to fill the empty entry locations created by Step 3.

An example is shown in Table 5.11. The top row is the index i. The second row shows the entries generated by Equation (5.8). The entries that are to be discarded are in grayed cells. The bottom row shows the result of discarding the grayed entries and shifting remaining entries to the left.

Table 5.11 Example: Block Length in Symbols = 2112, L = 4096
(Case of SCB1 when the SCCC Block Mode = '00')

i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	…	2110	2111
P'(i)	0	89	267	534	890	1335	1869	2492	3204	4005	799	1778	2846	4003	1153	2488	…	2809	2272
P(i)	0	89	267	534	890	1335	1869	799	1778	1153	1329	526	79	2037	253	874	…	444	2048

5.3.2.3.5 Symbol-to-Byte Converter

The interleaved symbols shall be converted into bytes by the symbol-to-byte converter. The MSB of the output byte shall be the MSB in the first input symbol.

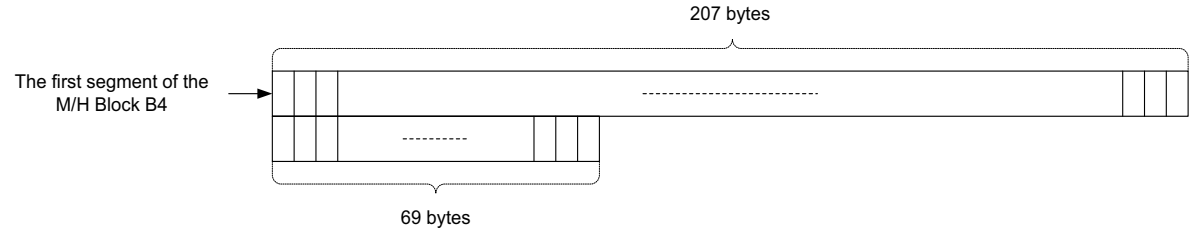

Figure 5.22 Signaling area in the interleaved Group format.

5.3.2.3.6 SCCC Block to M/H Block Converter

If the SCCC Block Mode is equal to '00', then each SCCC Block shall be mapped to a respective M/H Block of a Group.

If the SCCC Block Mode is set to '01', then the SCCC Block shall be divided into two parts. Each part is then mapped to a specific M/H Block. SCB1 shall be mapped to (B1, B6), SCB2 to (B2, B7), SCB3 to (B3, B8), SCB4 to (B4, B9), and SCB5 to (B5, B10).

The M/H Block at the output of the Block processor shall consist of only M/H service data plus FEC redundancy. Other bytes are inserted to construct a complete M/H Block having a length of 16 segments at the Group formatter.

Mapping shall be according to Table A.2. Bytes shall be mapped to M/H data locations (shown as byte type "6") by mapping into the first segment containing M/H data first, filling locations from left to right, then continuing from left to right in the next segment containing M/H data, and so on. Note that the first segment to be filled (number 6) has only one M/H byte location, which will contain the first byte of the block; and the next (number 7) has three locations, to be filled from left to right with the second through fourth bytes.

5.3.2.4 Signaling Encoder

The M/H transmission system allocates a portion of every Group for the purpose of signaling to receivers. Figure 5.22 shows the signaling area in the interleaved Group format after the data interleaver.

A signaling area shall be assigned in every Group per Table A.2 of Annex A.

This signaling area shall be used for FEC encoded signaling data.

As specified in Table A.2 of Annex A, the signaling area comprises a total of 276 (= 207 + 69) bytes, consisting of the first segment and the first 69 bytes of the second segment of the M/H Block B4. See Figure 5.22 for illustration. The first segment of the M/H Block B4 corresponds to the 17th or 173rd segment of a VSB data field.

The M/H transmission system shall include a Transmission Parameter Channel (TPC) and a Fast Information Channel (FIC). The purpose of the TPC is to signal the M/H transmission parameters such as various FEC modes and M/H Frame information. The purpose of the FIC is to enable the fast service acquisition of receivers; the FIC contains cross layer information between the physical layer and the upper layer(s). Details of the TPC data content and transmission timing, and FIC transmission timing, are specified in Section 5.2.

Figure 5.23 shows the block diagram of the Signaling Encoder. The diagram shows a (51, 37) RS code for FIC data, a (TNoG x 51) Block Interleaver, a multiplexer for combining the RS code TPC data and the block-interleaved FIC data, a randomizer of signaling data and a 1/4 rate PCCC Encoder.

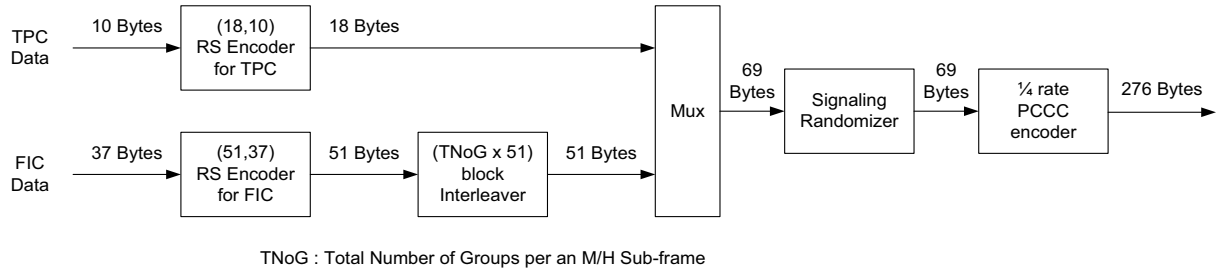

Figure 5.23 Signaling encoder.

The TPC data shall be (18, 10) R-S encoded to form the TPC codewords. The FIC data shall be (51, 37) R-S encoded and (TNoG x 51) block-interleaved to form the FIC codewords. One TPC codeword shall be followed by one FIC codeword to form each 69 byte sequence (per group). Each 69 byte sequence shall be bit randomized (per Section 5.3.2.4.5) and then 1/4 rate PCCC encoded to generate 276 bytes of signaling for each M/H group.

The Signaling Encoder shall send the 276 bytes to the Group Formatter for inclusion in a respective M/H Group.

5.3.2.4.1 (18,10) RS Encoder for TPC Codeword

An (N = 18, K = 10) RS code having an error correction capability t = 4 shall be employed as an outer code for TPC data. The (18, 10) RS code shall be defined over GF(256) and its primitive field generator polynomial shall be as defined in Equation 5.5. Its parity generator polynomial shall be defined as in Equation 5.4 with t = 4 and its parity bytes shall be appended at the end of 10 information bytes.

5.3.2.4.2 (51, 37) RS Encoder for FIC Codeword

An (N = 51, K = 37) RS code having an error correction capability t = 7 shall be employed as an outer code for FIC data. The (51, 37) RS code shall be defined over GF(256) and its primitive field generator polynomial shall be as defined in Equation 5.5. Its parity generator polynomial shall be defined as in Equation 5.4 with t = 7 and its parity bytes shall be appended at the end of 37 information bytes.

5.3.2.4.3 Block Interleaver for FIC

A variable length Block interleaver consisting of 51 columns (of bytes) and a number of rows equal to TNoG shall be employed to interleave the RS encoded FIC data within each M/H Sub-Frame. The Block interleaver shall write the incoming RS codewords of 51 bytes row-by-row from left to right and top-to-bottom and shall output the data in units of 51 bytes by reading column by column from top-to-bottom and left-to-right, as shown in Figure 5.24.

The TNoG shall be identical for all Sub-Frames in an M/H Frame.

The first byte in the FIC Block interleaver shall be the first FIC data byte of each Sub-Frame. The FIC block interleaver interleaves one block of FIC data across each subframe.

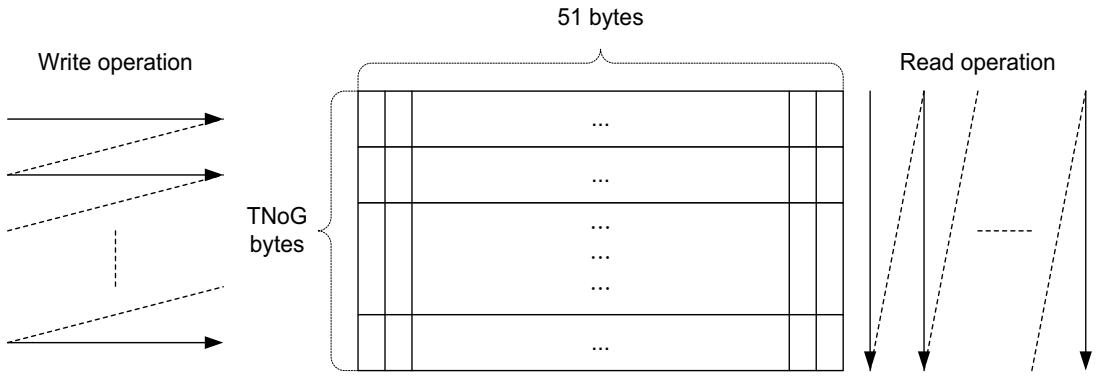

Figure 5.24 Block interleaver for FIC.

5.3.2.4.4 Multiplexing of TPC Data and FIC Data

The TPC data and Block-interleaved FIC data shall be multiplexed by appending 51-byte FIC data from the Block interleaver at the end of 18-byte TPC data. This operation is shown as "MUX" in Figure 5.23. This operation generates 69 bytes per Group.

5.3.2.4.5 Signaling Randomizer

The generator polynomial of the signaling randomizer shall be the same as that of the M/H randomizer. The initialization shall occur every Group and the initial state shall be set to F180 hex before the first signaling data byte from the multiplexer in Figure 5.23.

5.3.2.4.6 1/4 rate PCCC Encoder

A 1/4 rate PCCC (Parallel Concatenated Convolutional Code) Encoder shall be employed as an inner encoder for the M/H signaling channels. Figure 5.25 shows the block diagram of the 1/4 rate PCCC Encoder.

The PCCC Encoder shall have six identical even component encoders and six identical odd component encoders. Data bits from a byte-to-bit converter shall be directly encoded by the even-component encoders, while the same data bits shall be bit interleaved and then encoded by the odd-component encoders.

Thus, the 6-way even component encoders are parallel concatenated with the 6-way odd component encoders as a result of the action of the bit interleaver.

5.3.2.4.6.1 Byte to Bit Converter

The byte to bit converter shall convert parallel bytes to serial bits. In creating serial bits, the MSB shall be sent out first: (7, 6, 5, 4, 3, 2, 1, 0).

5.3.2.4.6.2 Bit Interleaver

The bit interleaver Block length shall be 552 (= 69 x 8) bits. The interleaving rule shall be the same as that of the symbol interleaver as given by the 4 steps in Section 5.3.2.3.4. The bit interleaving pattern shall be obtained by substituting the Block length of the bit interleaver (B = 552).

An example interleaving pattern is shown in Table 5.12. The top row is the index i. The second row shows the entries generated by Equation 5.8. The entries that are to be discarded are

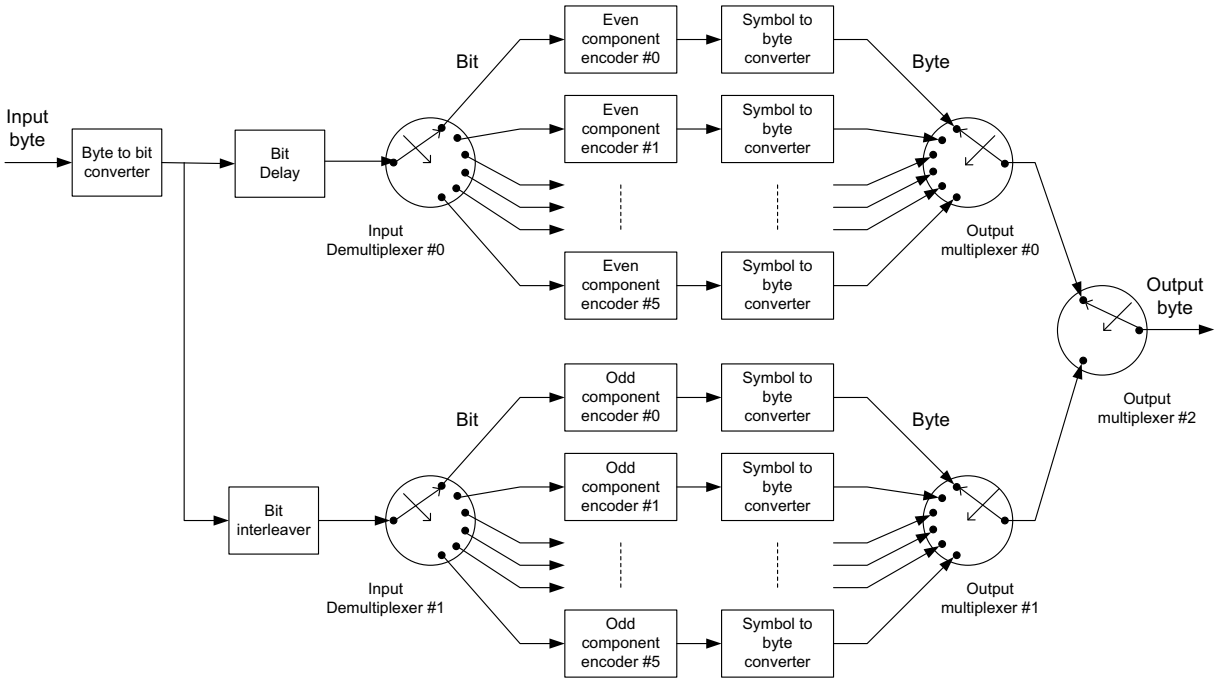

Figure 5.25 Quarter-rate PCCC encoder.

in grayed cells. The bottom row shows the result of discarding the grayed entries and shifting remaining entries to the left.

Table 5.12 Example: Block Length in Bits = 552, L = 1024

i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	…	550	551
P'(i)	0	89	267	534	890	311	845	444	132	933	799	754	798	931	129	440	…	669	556
P(i)	0	89	267	534	311	444	132	129	440	305	526	258	79	76	253	519	…	22	512

5.3.2.4.6.3 Bit Delay

A delay of 552 bits shall be included in the Even path to match the delay of 552 bits in the Bit Interleaver.

5.3.2.4.6.4 Input Demultiplexers

The input demultiplexer 0 shall distribute the incoming bits from the byte to bit converter to each of the 6 even component encoders in a circular manner in the order: Even 0, Even 1, Even 2, Even 3, Even 4, Even 5. This pattern shall repeat every 6 bits through the end of the 552-bit PCCC Block. The operation of the input demultiplexer 1 shall be identical to that of the input demultiplexer 0 except that it shall distribute to the odd component encoders.

5.3.2.4.6.5 Even and Odd Component Encoders

The structure of the even and odd component encoders shall be as shown in Figure 5.26. The delay memory elements ("D") shall be reset to zero at the beginning of each PCCC block encoding (i.e., each Slot).

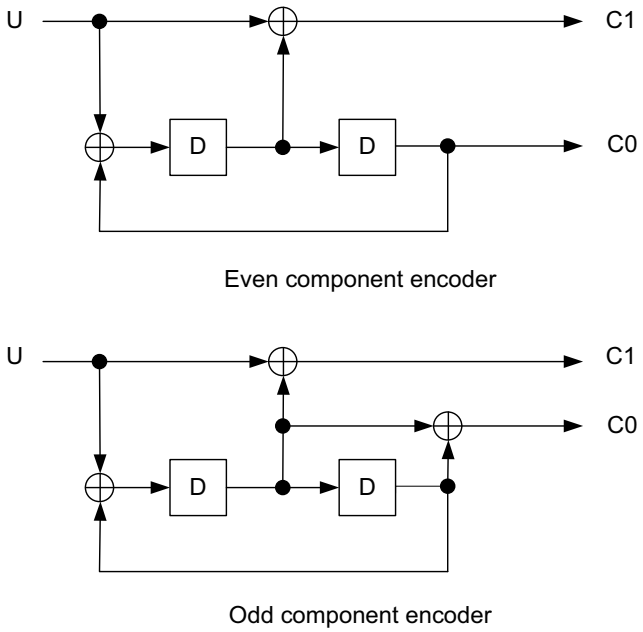

Figure 5.26 Even and odd component encoders.

Each Component Encoder receives an unencoded input bit stream (U) from an input demultiplexer. Each component encoder is a 1/2 rate convolutional encoder.

Each of the even and odd component encoders is effectively concatenated with one of the 12 legacy 8-VSB trellis encoders to construct the parallel concatenated structure. Figure 5.27 shows

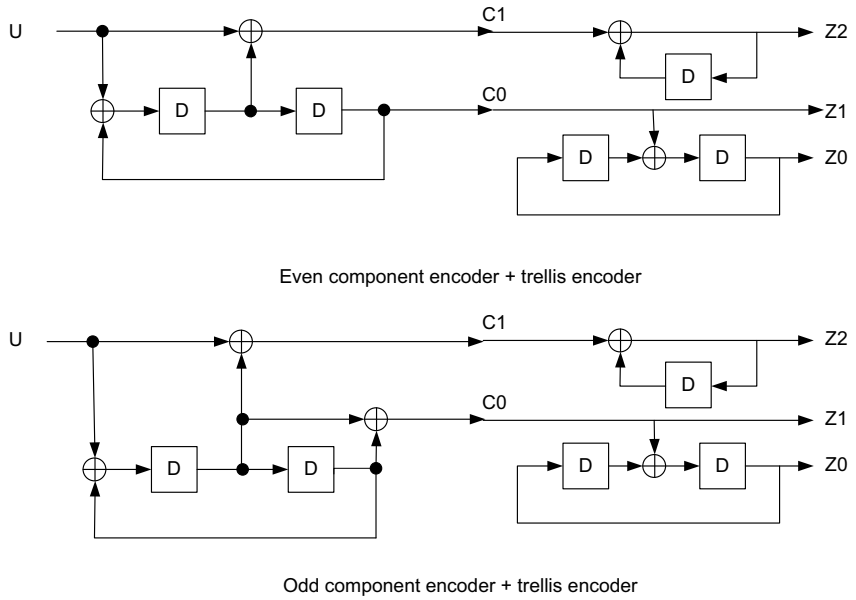

Figure 5.27 Effective component encoders of the PCCC.

the effective component encoders of the PCCC. Each effective component encoder consists of one of the component encoders of the 1/4 rate PCCC Encoder and one of the trellis encoders. At the receiver side, each effective component code can be decoded by being treated as one convolutional code.

5.3.2.4.6.6 Symbol to Byte Converter

The symbol to byte converter shall convert the output symbols into bytes. One symbol shall consist of two bits. The MSB of the first symbol (out of four symbols constituting an output byte) shall be the MSB of the output byte. There shall be 12 identical symbol to byte converters in the 1/4 rate PCCC Encoder.

5.3.2.4.6.7 Output Multiplexers

The output multiplexers collectively operate in such a manner that each of the 12 component encoders is mapped to one of the 12 legacy ATSC 8-VSB trellis encoders. The mapping relation shall be: Even 0 -> Trellis 0, Even 1 -> Trellis 2, Even 2 -> Trellis 4, Even 3 -> Trellis 6, Even 4 -> Trellis 8, Even 5 -> Trellis 10, Odd 0 -> Trellis 1, Odd 1 -> Trellis 3, Odd 2 -> Trellis 5, Odd 3 -> Trellis 7, Odd 4 -> Trellis 9, and Odd 5 -> Trellis 11.

The selection of the component encoder by the output multiplexers and its corresponding trellis encoder shall be as detailed in Table 5.13. The 1/4 rate PCCC Encoder outputs 276 bytes per M/H Group.

Note that bytes are numbered starting with byte #0. Starting from the output byte of the even component encoder #2, the outputs of the even and odd component encoders shall be output alternately in a circular manner. This 12-byte pattern shall repeat through byte #215. However, prior to outputting byte #216, the output multiplexer shall be advanced by five steps instead of one step (skipping Even 2, Odd 2, Even 3 and Odd 3), in accordance with the advancement of the 8-VSB trellis encoder during the data segment sync period (skipping trellis #4, #5, #6, and #7).

Table 5.13 Operation of the Output Multiplexers

Output Byte	Component Encoder	Trellis Encoder	Output Byte	Component Encoder	Trellis Encoder
0	Even 2	4	204	Even 2	4
1	Odd 2	5	205	Odd 2	5
2	Even 3	6	206	Even 3	6
3	Odd 3	7	207	Odd 3	7
4	Even 4	8	208	Even 4	8
5	Odd 4	9	209	Odd 5	9
6	Even 5	10	210	Even 5	10
7	Odd 5	11	211	Odd 5	11
8	Even 0	0	212	Even 0	0
9	Odd 0	1	213	Odd 0	1
10	Even 1	2	214	Even 1	2
11	Odd 1	3	215	Odd 1	3
12	Even 2	4	216	Even 4	8*
13	Odd 2	5	217	Odd 4	9

Table 5.13 Operation of the Output Multiplexers

14	Even 3	6	218	Even 5	10
15	Odd 3	7	219	Odd 5	11
16	Even 4	8	220	Even 0	0
17	Odd 4	9	221	Odd 0	1
18	Even 5	10	222	Even 1	2
19	Odd 5	11	223	Odd 1	3
20	Even 0	0	224	Even 2	4
21	Odd 0	1	225	Odd 2	5
22	Even 1	2	226	Even 3	6
23	Odd 1	3	227	Odd 3	7
24	Even 2	4	...	...	...
25	Odd 2	5	264	Even 4	8
26	Even 3	6	265	Odd 4	9
27	Odd 3	7	266	Even 5	10
28	Even 4	8	267	Odd 5	11
29	Odd 4	9	268	Even 0	0
30	Even 5	10	269	Odd 0	1
31	Odd 5	11	270	Even 1	2
32	Even 0	0	271	Odd 1	3
33	Odd 0	1	272	Even 2	4
34	Even 1	2	273	Odd 2	5
35	Odd 1	3	274	Even 3	6
…	…	…	275	Odd 3	7
* Note advancement of 4 at byte 216					

5.3.2.5 Group Formatter

Figure 5.28 shows a functional block diagram of the Group formatter. The interleaved Group format organizer operates on the Group format as it will appear *after* the byte interleaver. It maps the FEC coded M/H service data from the Block processor into the corresponding M/H Blocks of a Group, adds the pre-determined training data bytes, adds the PCCC-encoded signaling data, and the data bytes to be used for initializing the trellis encoder memories. It also inserts place-holder bytes for main service data, MPEG-2 headers and non-systematic RS parity, and some dummy data bytes to complete construction of the intended Group format as shown in Figure 5.7. The second Block is a deinterleaver that is the inverse of the byte interleaver. The output of the Group formatter is in the Group format *before* the byte interleaver, as shown in Figure 5.6.

The detailed Group format shall be as specified in Table A.2. The known training data sequences shall be as specified in Table A.3. The value of each dummy data byte shall be 0xAF.

After the interleaved Group is created, a data deinterleaver shall perform an inverse process of the convolutional byte interleaving described in Section 5.3.2.10, and provide the deinterleaved data to the packet formatter.

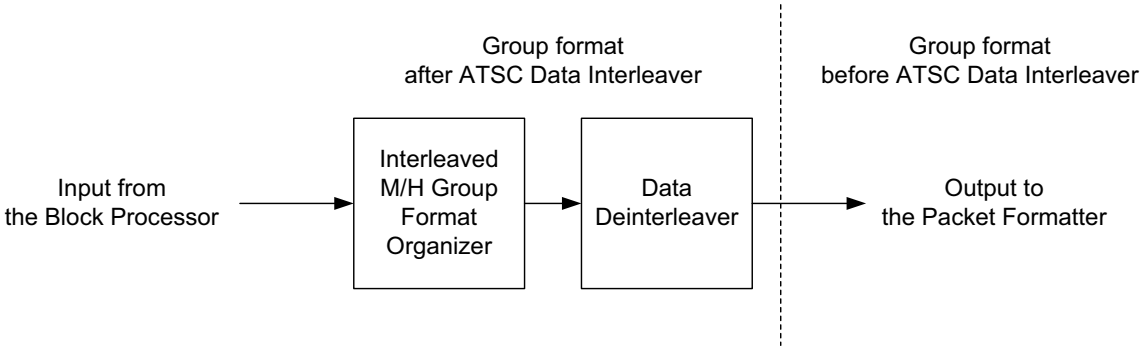

Figure 5.28 Group formatter.

Figure 5.29 shows the data deinterleaver, which is a 52 data segment convolutional byte deinterleaver.

The data deinterleaver shall be synchronized to the first byte of the VSB data field.

5.3.2.6 Packet Formatter

The Packet Formatter is the last process in the M/H pre-processor.

The packet formatter shall first remove the main service data place holders and the RS parity place holders that were inserted by the interleaved Group format organizer for proper operation of the data deinterleaver.

The packet formatter next shall replace the 3-byte MPEG header place holder with an MPEG header having an MHE packet PID (the PID of the MHE packet). An MPEG TS sync byte is then inserted before each 187-byte data packet.

Thus, the packet formatter outputs 118 M/H-data-encapsulating TS packets per Group.

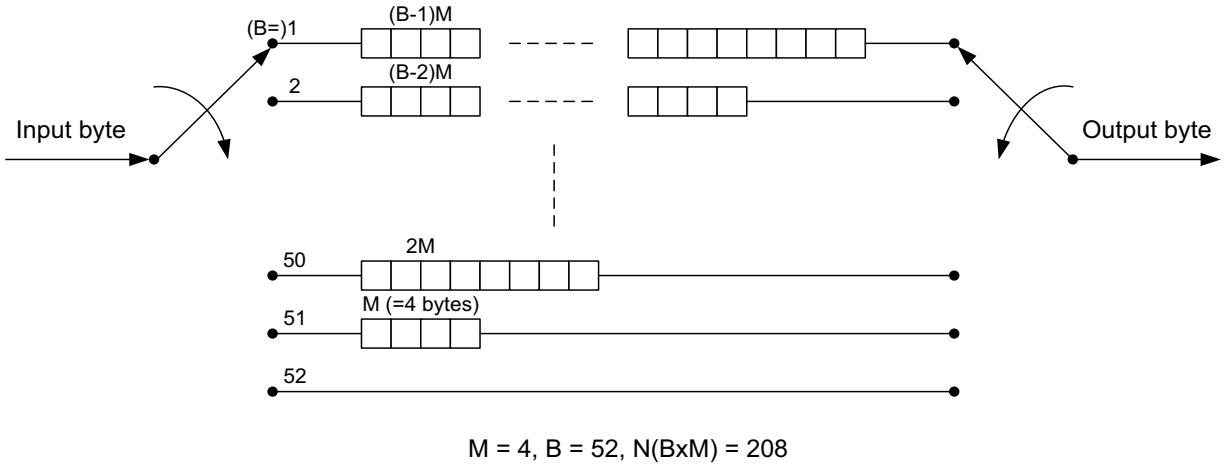

Figure 5.29 Data deinterleaver.

5.3.2.7 Packet Multiplexer

The packet multiplexer multiplexes the M/H service TS packets and the main service TS packets to construct M/H Frames. When the packet multiplexer schedules the 118 TS packets from the packet formatter, 37 packets are placed ahead of the VSB data field sync insertion position and another 81 packets are placed after the VSB data field sync insertion position as specified in the Group format (see Section 5.3.1.2 and Annex A).

5.3.2.8 Modified Data Randomizer

The Modified Data Randomizer is the first block of the post-processor.

The basic operation (including the generator polynomial and initialization) of the modified data randomizer is identical to the data randomizer defined in the ATSC 8-VSB system.

The modified randomizer shall XOR all of the main service data bytes and the MPEG header bytes of the M/H service TS packets with a 16-bit maximum length pseudo random binary sequence (PRBS) that is initialized at the beginning of the VSB data field. The modified data randomizer shall not XOR the 184 payload bytes of the M/H service TS packets; however, its PRBS generator shall continue shifting during these bytes.

To state it differently, the modified randomizer shift register operates in exactly the same manner as a legacy 8-VSB randomizer shift register, but the XOR operation is not performed on the 184-byte payload of M/H service TS (MHE-encapsulated) packets.

The generator polynomial and initialization shall be according to Figure 6.5 of ATSC A/53 Part 2 [2]. The initialization operation also shall be identical to the legacy 8-VSB initialization; i.e., initialization (pre-load) to 0xF180 (load to 1) shall occur during the VSB data segment sync interval prior to the first data segment.

5.3.2.9 Systematic/Non-Systematic RS Encoder

The systematic/non-systematic RS encoder shall perform an RS encoding process with a t = 10 (207, 187) code on the data output by the data randomizer, which will have been randomized or bypassed by the data randomizer. The RS parity generator polynomial and the primitive field generator shall be identical to those of the legacy ATSC 8-VSB system. If the inputted data corresponds to a main service data packet, the RS encoder shall perform the same systematic RS encoding process as in the legacy ATSC 8-VSB system, adding 20 bytes of RS FEC data at the end of each of these 187-byte packets. If the inputted data corresponds to an M/H service data packet, the RS encoder shall perform a non-systematic RS encoding process. In this case, 20 bytes of RS FEC data obtained from the non-systematic RS encoding process shall be inserted in a pre-determined parity byte location within each M/H data packet, as shown in Figure 5.6 and specified in Table A.1, thereby satisfying the RS requirements of legacy receivers.

5.3.2.10 Convolutional Data Byte Interleaver

The convolutional data byte interleaver shall have the same structure and operation as in the legacy ATSC 8-VSB transmission system, as described in A/53 Part 2 [2]. Thus, it will be a 52-data-segment convolutional byte interleaver, shown in commutated-shift-register form in Figure 5.30, and will be synchronized to the first data byte carried in the VSB data field.

5.3.2.11 Modified Trellis Encoder

The basic trellis encoding operation is identical to that of the ATSC 8-VSB system. The data from the convolutional data byte interleaver is demultiplexed into 12 independent streams, two bits at a

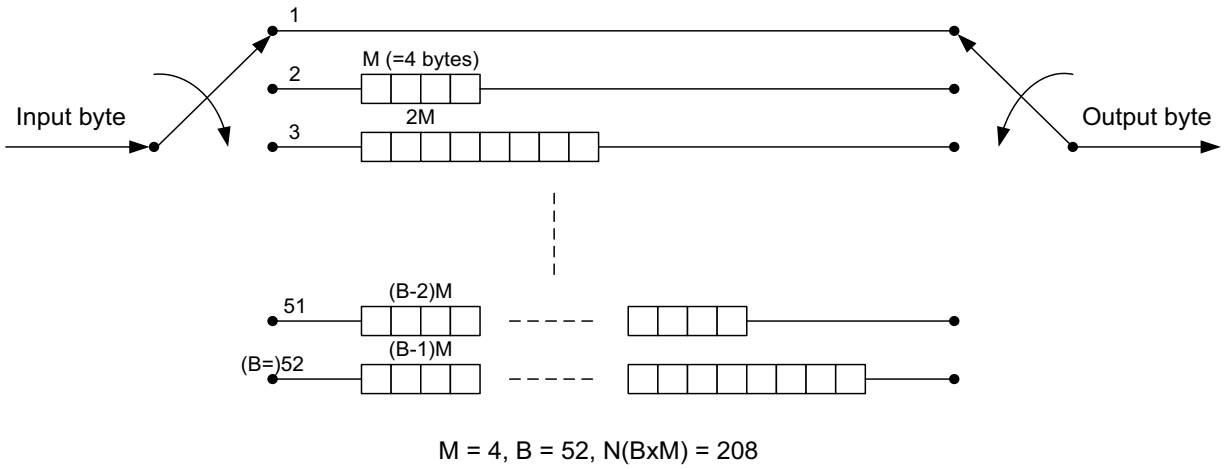

Figure 5.30 Convolutional data byte interleaver.

time. Those 12 streams of 2-bit symbols are each independently trellis encoded to create 3-bit symbols. The 12 streams of 3-bit symbols are then multiplexed to form the final symbol stream that is to be symbol mapped and modulated. The basic trellis encoding operation shall be performed as defined in A/53 Part 2 [2] Section 6.4.1.4.

For purposes of obtaining known training sequences (as shown in Table A.4), initialization of the memories in the trellis encoders just prior to each training signal is required.

Trellis initialization bytes shall be inserted according to Table A.1 and Table A.3 of Annex A. When the initial four bits of the trellis initialization bytes (which have been inserted into the data by the Group formatter) are input to one of the twelve modified trellis encoders, the memories in that trellis encoder shall be initialized. More specifically, when the first two 2-bit symbols converted from each trellis initialization byte are received, the input bits of the trellis encoder shall be replaced by the memory values of the trellis encoder, as shown in Figure 5.31.

The trellis initialization process and the start of each training sequence occur during the transmission of specific bytes within each data field. Those bytes arrive at the inputs to each of the 12 trellis encoders at such a time that the first two symbols formed from those bytes arrive when the trellis encoders are initialized and the second 2 symbols formed from those bytes arrive at the start of the training sequence. The symbols derived from those bytes arriving during initialization are ignored and not transmitted while the symbols arriving at the start of the training sequence are trellis-encoded to form the first symbols of the training sequence.

Each of the 12 modified trellis encoders shall include a multiplexer to switch between the normal input and an initialization input, which shall be fed back from the delay devices within the trellis encoder. There shall be a normal/initialization control input to the multiplexer that shall select the initialization input path when initialization is required. The normal/initialization control input shall select the initialization path during the leading 2-symbol interval of the trellis initialization byte immediately preceding each training signal. The normal/initialization control shall select the normal path at all other times.

The modified trellis encoder provides the modified input data for trellis initialization to the non-systematic RS encoder and also the input data for the 8-level symbol mapper.

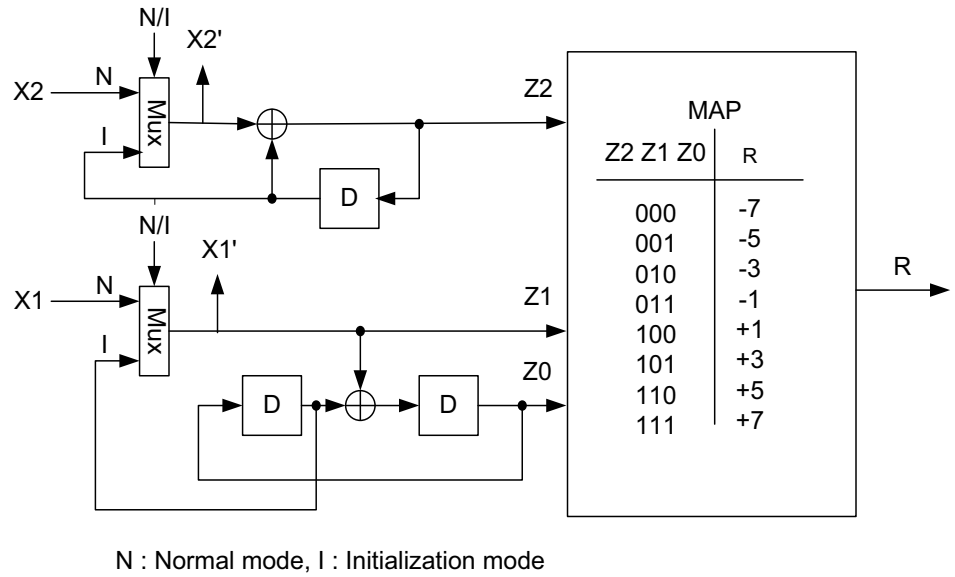

Figure 5.31 Modified trellis encoder.

One of the 12 trellis encoders is illustrated in Figure 5.31. Its 2-bit input (X2, X1) shall come from the output of the parity replacer described in Figure 5.2 and Section 5.3.2.12. The two bit output (X2', X1') shall be supplied to the input of the non-systematic RS encoder described in Section 5.3.2.12, as shown in Figure 5.2. The 3-bit output (Z2, Z1, Z0) shall be mapped to 8-level symbols as specified in A/53 Part 2 [2] (also illustrated in Figure 5.31).

Because 2 symbols (4 bits) are required for trellis initialization, the last 2 symbols (4 bits) derived from trellis initialization bytes are not used for trellis initialization and are treated as symbols from a known (training) data byte. Figure 5.31 illustrates one of the 12 modified trellis encoders. When the trellis encoder is in initialization mode, its input comes from an internal trellis state instead of from the convolutional data byte interleaver via the parity replacer.

When the trellis encoder is in the normal mode, the input symbol from the parity replacer shall be processed within the encoder, as shown in Figure 5.31.

The modified trellis encoder provides the modified input data for trellis initialization to the non-systematic RS encoder.

Note that in Figure 5.31 a mapper is shown as directly connected to one of 12 modified trellis encoders. A single mapper may be used following the 12-way multiplexer that combines the outputs of all twelve modified trellis encoders (described in ATSC A/53 Part 2 [2]).

> Note: The memory contents of the modified trellis encoder have been initialized to zero at the start of each training sequence; see Section 5.3.3.

5.3.2.12 Non-Systematic RS Encoder and Parity Replacer

The RS parity data calculated prior to the trellis initialization will be erroneous and must be replaced to ensure backwards compatibility. Therefore, the trellis encoder shall supply the changed initialization byte to the non-systematic RS encoder, which shall (non-systematically) re-calculate the RS parity of the corresponding M/H packets. The position of the non-systematic RS

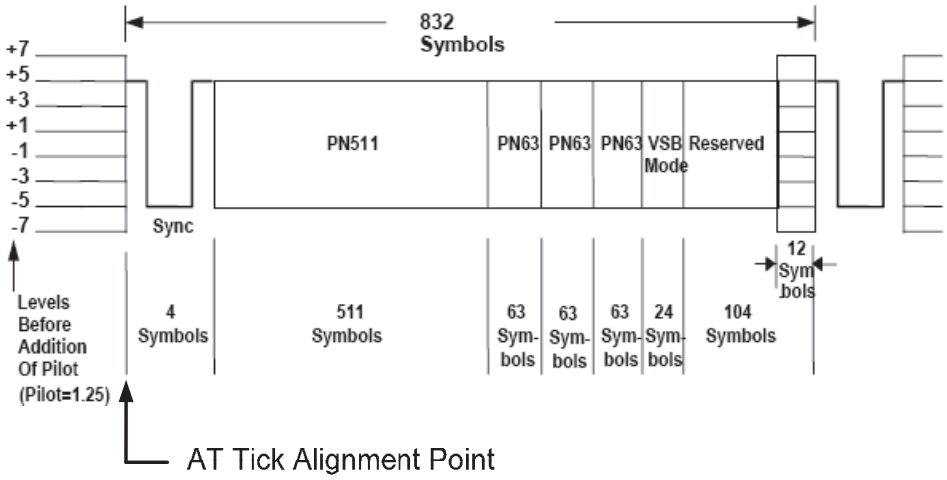

Figure 5.32 Data field sync.

parity bytes in each data segment shall be as shown in Table A.1 of Annex 1, which are the same positions as for the operation of the Systematic/Non-Systematic RS Encoder of Section 5.3.2.9.

The new RS parity bytes obtained by performing the non-systematic RS encoding process shall be supplied to the RS parity replacer. The parity replacer shall select the output of the data interleaver as the data bytes in the packet, and the output of the non-systematic RS encoder as the RS parity. The selected data shall then be supplied to the modified trellis encoder.

> Note: The locations of the non-systematic RS parity bytes of an M/H service data packet (before data interleaving) have been selected in such a way that there is no RS parity byte that comes out ahead of the trellis initialization bytes in the same data packet. Thus, it is possible to correct the non-systematic RS parity bytes of the M/H service data packet after the trellis initialization.

5.3.2.13 Synchronization

Synchronization shall be in accordance with ATSC A/53 Part 2 [2], except as indicated in the subordinate sections of this section.

When the ATSC emission contains M/H services, the 8-VSB symbol rate shall have a tolerance not greater than 2.8 ppm.

5.3.2.13.1 Data Field Sync

The diagram of the Data Field Sync in A/53 Part 2:2007 is repeated here for convenience of the reader as the reserved area is redefined in the immediately following sections (see Figure 5.32).

Emission of each ATSC M/H Frame shall be synchronized with a single, global reference time, ATSC Time (AT). AT shall be the timeline that consists of a continuum of ATSC M/H frame periods that started at 00:00 UTC on January 6, 1980 (the AT "epoch" — identical to the GPS epoch[2]). AT "ticks" shall be defined to be the instants that occur at inter multiples of M/H frame periods following the AT epoch. The intervals that occur between AT ticks are equal in time to 20 ATSC VSB frames (or approximately 0.967887927 seconds).

Each ATSC M/H frame shall be aligned such that emission at the air interface of the broadcast antenna of the starting instant of the first symbol of the first data field sync of the first (odd) 8-VSB data field following the beginning of an M/H frame (the AT Tick Alignment Point) coincides with an AT tick. (See Figures 5.5 and 5.32.) The tolerance of this symbol timing shall be no greater than 1 symbol time RMS, and should be no greater than 15 nanoseconds RMS. In a single-frequency network (SFN), emission time may be shifted by a fixed offset value for each transmitter in the network, as necessary for network operation, in which case the emission time of each particular transmitter shall be maintained at its associated offset tick time within one symbol time RMS and should be maintained at its associated offset tick time within 15 ns RMS. In the cases of translators and digital on-channel repeaters (DOCRs) that receive their inputs over the air from other broadcast transmitters, the ATSC Time requirement shall not apply. Since these equipment types receive their input feeds from other over-the-air transmitters, the propagation and signal processing delays inherent in the network topology render meeting the AT requirement impossible in the re-radiated signal. The delays in output emission times of the re-radiators in such networks shall be the minimum practical for the particular network topologies and technologies employed, and those emission times shall be stabilized to the maximum extent permitted by the technologies employed.

AT (in M/H frame periods) shall be derived from and synchronized to GPS time[3] (in GPS seconds) according to the mathematical relationship

$$AT = GPS\ Time \times \frac{4809375}{4654936} \tag{5.9}$$

5.3.2.13.2 PN127

When M/H transmission is present, the first 82 symbols of the data field sync following the VSB mode symbols (a portion of the symbols shown as Reserved in Figure 5.32 above) are strongly recommended to be filled with the portion of a PN127 sequence defined in this section. The sequence is defined as X7 + X4 + 1 with a pre-load value of 1001001. When the middle PN63 in the data field sync is inverted, the 82 symbols of PN127 also shall be inverted. The fill sequence shall be:

1001 0011 0100 1111 0111 0000 1111 1110 0011 1011 0001 0100 1011 1110 1010 1000 0101 1011 1100 1110 01

The generators for the PN63, PN511, and PN127 sequences are shown in Figure 5.33.

2. Definitions of GPS time and other GPS terminology can be found in the document titled "Navstar GPS Space Segment/Navigation User Interfaces," Revision D., March 2006 [14], as published by the Navstar GPS Joint Program Office (http://www.losangeles.af.mil/shared/media/document/AFD-070803-059.pdf).
3. Section 3.3.4 of [14] provides the following definition of GPS time: "GPS time is established by the Control Segment and is referenced to Coordinated Universal Time (UTC) as maintained by the U.S. Naval Observatory (UTC(USNO)) zero time-point defined as midnight on the night of January 5, 1980/morning of January 6, 1980. The largest unit used in stating GPS time is one week defined as 604,800 seconds. GPS time may differ from UTC because GPS time shall be a continuous time scale, while UTC is corrected periodically with an integer number of leap seconds."

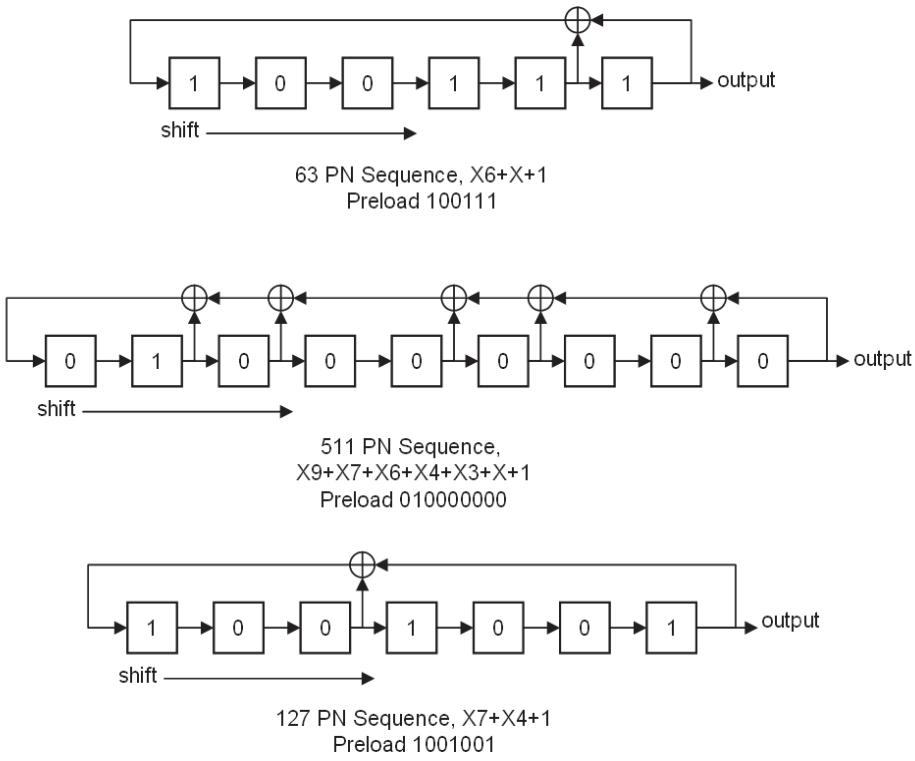

Figure 5.33 Field sync PN sequence generators.

5.3.2.13.3 Enhancement Signaling

The Context Bits and Enhancement Bits defined in A/53 Part 2, Section 6.5.2.6, shall be set as follows[4]:

Context Bits 83 and 84 shall carry a Context Number of 0. (This result is obtained when Context Bits 83 and 84 both are set to a value of 0.)

When the M/H transmission is present, Enhancement Bit 85 shall be set to a value of 1; it shall be set to a value of 0 otherwise.

When the PN127 sequence per Section 5.3.2.13.2 is present, Enhancement Bit 86 shall be set to a value of 1; it shall be set to a value of 0 otherwise.

5.3.3 Training Signals

The M/H transmission system inserts long and regularly spaced training sequences into each Group. Training signal regularity provides the greatest benefit for a given number of training symbols in high-Doppler rate conditions. The length of the training sequences provides fast acquisition of the channel during bursted power-saving operation of the demodulator.

Each M/H Group contains 6 training sequences. The training sequences shall be inserted prior to trellis encoding of the signal by the modified trellis encoders. These trellis encoded sequences

4. For reference, bits having a value of 0 are indicated by corresponding symbols having the level –5 during odd data fields (i.e., those fields having a non-inverted PN63 sequence within the preceding structure) and +5 during even data fields (i.e., those fields in which the preceding PN63 sequence is inverted). Bits having the value 1 are indicated by corresponding symbols having the level +5 during odd data fields and –5 during even data fields.

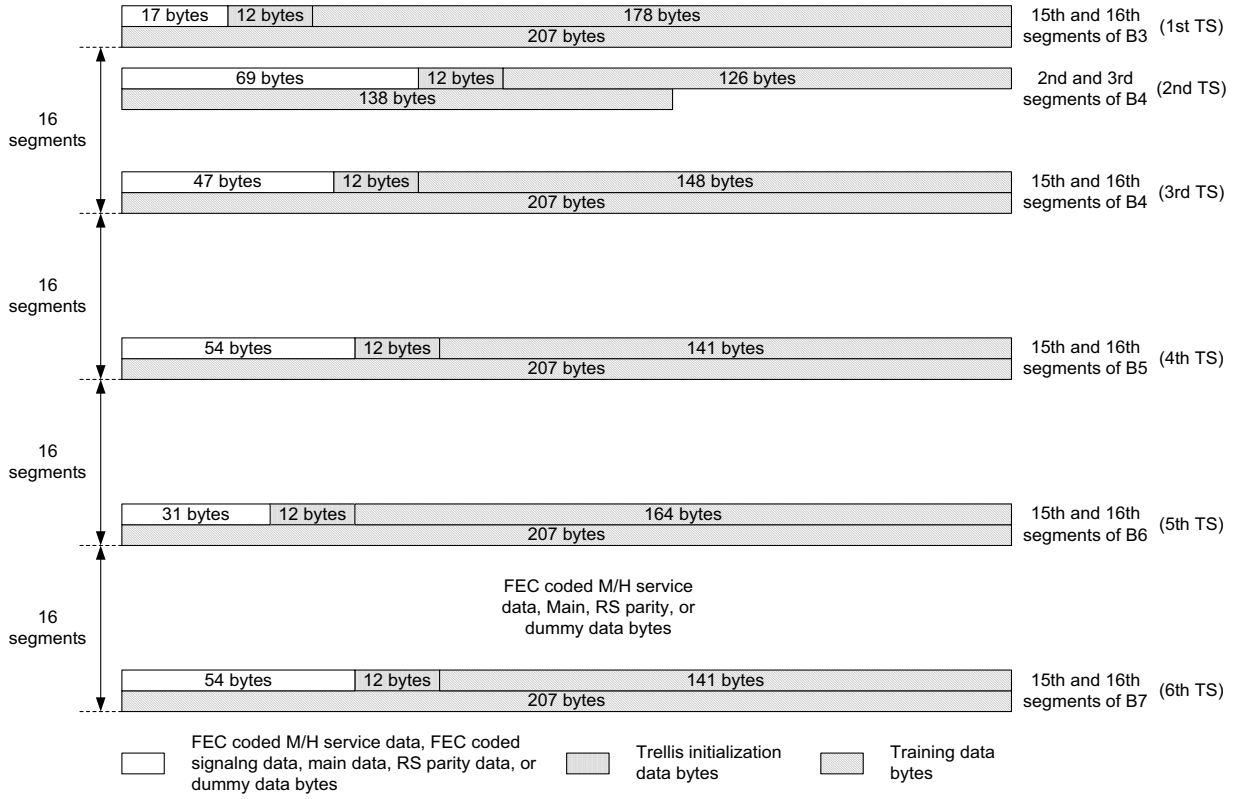

Figure 5.34 Training sequences at the byte level.

are known sequences because the trellis encoder memories are initialized to pre-determined values at the beginning of each sequence. The form of the 6 training sequences at the byte level (before trellis encoding) is shown in Figure 5.34. This is the arrangement of the training sequence at the Interleaved M/H Group Format Organizer discussed in Section 5.3.2.5.

The content of the 6 training sequences at the byte level (prior to interleaving and trellis encoding) shall be as specified in Table A.3 of Annex A.

> Note that Table A.3 includes all 6 training sequences, with trellis initialization bytes, sequentially concatenated.

The 1st training sequence shall be located at the last 2 segments of the M/H Block B3.

The 2nd training sequence shall be inserted at the 2nd and 3rd segments of the M/H Block B4.

The 3rd training sequence, the 4th training sequence, the 5th training sequence and the 6th training sequence shall be placed at the last 2 segments of the M/H Blocks B4, B5, B6, and B7, respectively.

As shown in Figure 5.34, the 1st training sequence, the 3rd training sequence, the 4th training sequence, the 5th training sequence and the 6th training sequence shall be spaced 16 segments apart. In Figure 5.34, the dotted areas indicate trellis initialization data bytes, the lined areas indicate training data bytes, and the white areas include other bytes such as the M/H service data bytes, signaling data, main data bytes, RS parity data bytes (for backwards compatibility with legacy ATSC receivers), and dummy data bytes.

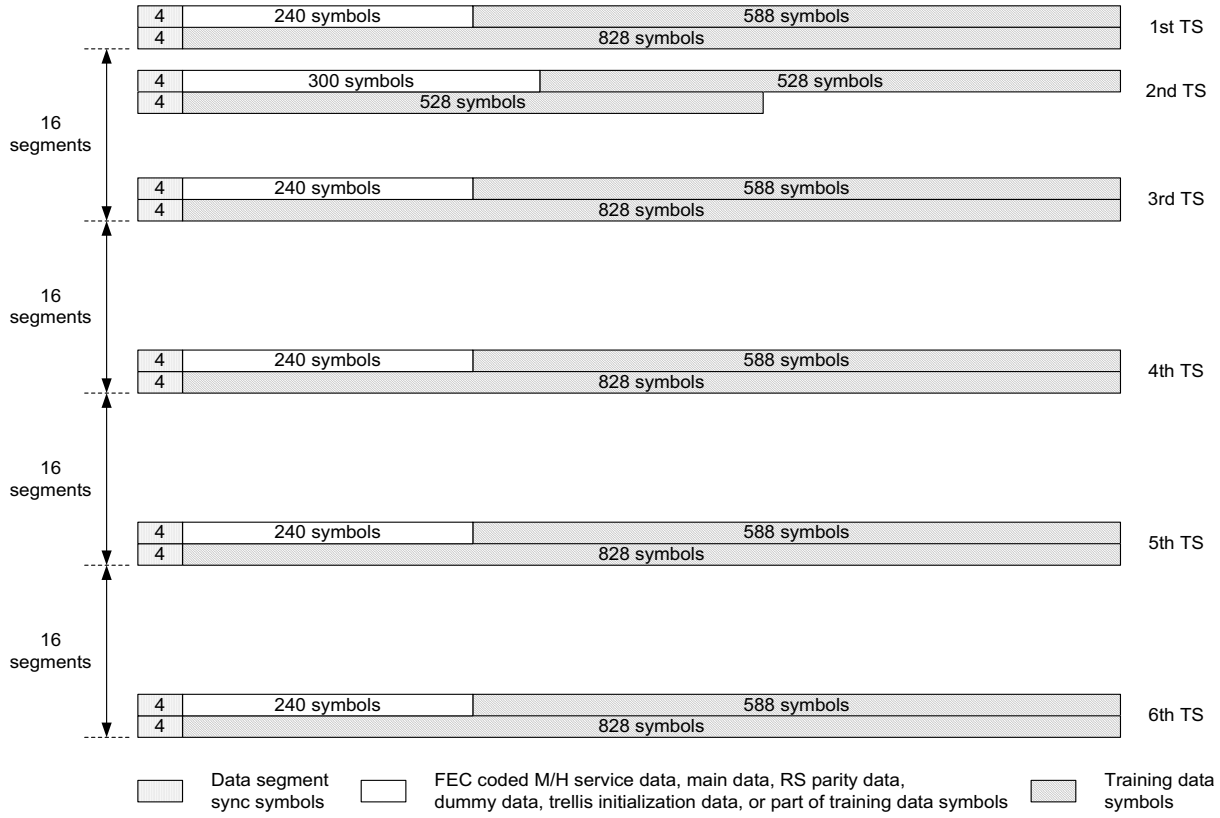

Figure 5.35 Training sequences at the symbol level.

Figure 5.35 shows the training sequences (at the symbol level) after trellis encoding by the modified trellis encoder. In Figure 5.35, the dotted area indicates data segment sync symbols, the lined area indicates training data symbols, and the white area includes other symbols such as FEC coded M/H service data symbols, FEC coded signaling data, main data symbols, RS parity data symbols (for backwards compatibility with legacy ATSC receivers), dummy data symbols, trellis initialization data symbols and/or the first part of the training sequence data symbols. Due to the intra-segment interleaving of the modified trellis encoder, the various kinds of data symbols will be mixed in the white area.

After trellis encoding, the last 1416 (= 588 + 828) symbols of the 1st training sequence, the 3rd training sequence, the 4th training sequence, the 5th training sequence, and the 6th training sequence shall have the same data pattern in common. The total length of each common training pattern is 1424 symbols, including the data segment sync symbols in the middle of and after each sequence.

The 2nd training sequence has a first 528-symbol sequence and a second 528-symbol sequence that have the same data pattern. The 528-symbol sequence is repeated after the 4-symbol data segment sync signal.

Table A.4 in Annex A provides details of the 1424-symbol sequence that shall appear in training sequences #1, 3, 4, 5, and 6, and the 528-symbol sequence that shall appear twice in training sequence #2.

At the start of each training sequence, the contents of the memories in each of the twelve modified trellis encoders (see Section 5.3.2.11) have been set to zero.

The contents of the training sequences are designed such that at the end of each training sequence, the contents of the memories in each of the twelve modified trellis encoders are zero without any explicit reset operation.

6 ADDITIONAL SYSTEM ATTRIBUTES

This section provides additional information about the M/H system version signaled by enhancement signaling symbol 85 (in the data field sync) and tpc_protocol_version '11111.'

6.1 Data Rates and Efficiency

The M/H transmission system has various FEC modes and sets the FEC modes independently for each Parade. Thus, it is possible to control the robustness of each Parade independently.

Equation (6.1) gives a general definition of efficiency of the M/H transmission system. As shown in the equation, the efficiency is stated as the percentage of total payload bits per second of the M/H service multiplex (payload data rate, PDR) divided by the total bits per second taken from the main service multiplex (main data rate loss, MDRL).

$$\text{Efficiency} = \frac{\text{Total payload bits per second of M/H service multiplex}}{\text{Total bits per second taken from main service multiplex}} \times 100\% = \frac{PDR}{MDRL} \times 100\% \tag{6.1}$$

One M/H Parade can carry one or two RS Frames depending on RS Frame mode: primary RS Frame and secondary RS Frame.

The number of columns in each RS Frame payload, N is obtained by Equation (5.2). N depends on NoG and FEC modes such as the RS Frame mode, RS code mode, SCCC Block Mode and SCCC outer code modes.

Each column of an RS Frame payload consists of 187 bytes. Thus, the number of payload bytes per RS Frame is N x 187. This quantity is the numerator of the efficiency equation when restated on a per-Frame basis.

The denominator of the efficiency equation on a per-Frame basis is the MDRL per Frame, which includes as a major component the product of the number of *portions* per M/H Frame (i.e., 5 x NoG) and the portion Length PL. Note that this quantity includes the padding bytes, giving the correct over-all efficiency. Note also that everything else not part of the RS Frame, such as the TPC data, FIC data and training sequences also are included in the MDRL per M/H Frame. This can be directly computed as the product of the number of Groups per M/H Frame (5 x NoG), the number of segments taken from the main stream (118 per Group) and the number of main stream bytes carried by a segment (188).

Let N_P and N_S denote the number of columns in the primary RS Frame payload and the secondary RS Frame payload, respectively.

Then, the efficiency of the primary RS Frame (E_P) and the efficiency of the secondary RS Frame (E_S) can be calculated by Equation (6.2) and (6.3), respectively.

$$\text{Efficiency of the primary RS frame}\left(\mathrm{E_P}\right) = \frac{N_P \times 187}{5 \times NoG \times 118 \times 188} \times 100\ (\%) \tag{6.2}$$

$$\text{Efficiency of the secondary RS frame}\ \left(\mathrm{E_S}\right) = \frac{N_S \times 187}{5 \times NoG \times 118 \times 188} \times 100\ (\%) \tag{6.3}$$

Since the primary RS Frame and the secondary RS Frame are transmitted simultaneously through a single Parade, the total efficiency is the sum of E_T and E_S as given in Equation (6.4).

$$\text{Efficiency}\left(\mathrm{E_T}\right) = \mathrm{E_P} + \mathrm{E_S} = \frac{\left(N_P + N_S\right) \times 187}{5 \times NoG \times 118 \times 188} \times 100\ (\%) \tag{6.4}$$

In Equation (6.4), the denominator equals the number of bytes taken from the main service multiplex for a particular Parade during an M/H Frame and the numerator is equal to the total number of bytes transmitted through both the primary and the secondary RS Frame during an M/H Frame.

Table 6.1 shows the efficiency for cases when there is only the primary RS Frame (Single Frame mode). In this table, the number of RS parity bytes per RS Frame column (P) is 48 and the table details the system efficiency according to several combinations of SCCC outer code rates. As shown in Table 6.1, the efficiency of the M/H transmission system is almost constant regardless of NoG (which determines the amount of data taken from the main service multiplex for given FEC modes).

If SCCC Block Mode is set to Paired Block mode (consisting of 2 M/H Blocks), then the SCCC outer code rate is identical for all Group Regions, and therefore is given by either the all 1/2 rate case or the all 1/4 rate case in Table 6.1.

Table 6.2 shows the efficiency of cases when there are two separate RS Frames (RS Frame mode = '01'). It shows separate efficiencies of the primary RS Frame and the secondary RS Frame.

The total data rate taken from the main service multiplex for each Parade is determined exactly (that is, no compensation for padding bytes is needed) by the number of Groups per Sub-Frame (NoG) of that Parade and its Parade repetition cycle (PRC) as shown in Equation (6.5).

$$\mathrm{MDRL} = \frac{118 \times NoG}{156 \times 16 \times PRC} \times 19.392658\ (\mathrm{Mbps}) \tag{6.5}$$

The MDRL is a function of NoG and PRC. NoG determines the amount of data taken from the main service data per M/H Sub-Frame (16 Slots) and PRC is also a factor which determines the data rate loss of the main service multiplex.

The minimum increment of data rate that may be taken from the main service stream is in the case when NoG = 1 and PRC = 7. This minimum MDRL is about 130.1 Kbps.

The M/H payload data rate can be calculated by multiplying the efficiency and the main data rate loss, which can be formulated as Equation (6.6).

$$\text{PDR} = \frac{N \times 187}{40 \times 312 \times 188 \times PRC} \times 19.392658 \text{ (Mbps)} \tag{6.6}$$

Tables 6.1 and 6.2 also provide PDR and MDRL for the case of PRC = 1.

Table 6.1 Efficiency in Case of RS Frame Mode = '00' (P=48, PRC=1)

SCCC Outer Code Rate (for each Group Region)				P	NoG	N_P	E_T (=E_P)	PDR_P (Kbps)	MDRL (Mbps)
A	B	C	D						
1/2	1/2	1/2	1/2	48	1	202	34.1	312.2	0.917
					2	407	34.3	629.1	1.834
					3	612	34.4	945.9	2.750
					4	817	34.4	1262.8	3.667
					5	1021	34.4	1578.1	4.584
					6	1226	34.4	1894.9	5.501
					7	1431	34.5	2211.8	6.418
					8	1636	34.5	2528.7	7.334
1/2	1/2	1/2	1/4	48	1	197	33.2	304.5	0.917
					2	396	33.4	612.1	1.834
					3	596	33.5	921.2	2.750
					4	795	33.5	1228.8	3.667
					5	995	33.5	1537.9	4.584
					6	1194	33.5	1845.5	5.501
					7	1393	33.5	2153.1	6.418
					8	1593	33.6	2462.2	7.334
1/2	1/2	1/4	1/4	48	1	181	30.5	279.8	0.917
					2	365	30.8	564.2	1.834
					3	549	30.9	848.6	2.750
					4	732	30.9	1131.4	3.667
					5	916	30.9	1415.8	4.584
					6	1100	30.9	1700.2	5.501
					7	1283	30.9	1983.0	6.418
					8	1467	30.9	2267.4	7.334
1/2	1/4	1/4	1/4	48	1	155	26.1	239.6	0.917
					2	313	26.4	483.8	1.834
					3	471	26.5	728.0	2.750
					4	628	26.5	970.7	3.667
					5	786	26.5	1214.9	4.584
					6	944	26.5	1459.1	5.501
					7	1102	26.5	1703.3	6.418
					8	1259	26.5	1946.0	7.334

Table 6.1 Efficiency in Case of RS Frame Mode = '00' (P=48, PRC=1)

1/4	1/4	1/4	1/4	48	1	100	16.9	154.6	0.917
					2	202	17.0	312.2	1.834
					3	305	17.1	471.4	2.750
					4	407	17.2	629.1	3.667
					5	509	17.2	786.7	4.584
					6	612	17.2	945.9	5.501
					7	714	17.2	1103.6	6.418
					8	817	17.2	1262.8	7.334

Table 6.2 Efficiency in Case of RS Frame Mode = '01' (P=48, PRC=1)

SCCC Outer Code Rate (for each Group Region)				P	NoG	N_P	E_P	PDR_P (Kbps)	N_S	E_S	PDR_S (Kbps)	E_T	MDRL (Mbps)
A	B	C	D										
1/2	1/2	1/2	1/2	48	1	160	27.0	247.3	40	6.7	61.8	33.7	0.917
					2	323	27.2	499.2	82	6.9	126.7	34.1	1.834
					3	485	27.3	749.6	124	7.0	191.7	34.2	2.750
					4	648	27.3	1001.6	166	7.0	256.6	34.3	3.667
					5	811	27.3	1253.5	208	7.0	321.5	34.4	4.584
					6	973	27.3	1503.9	250	7.0	386.4	34.4	5.501
					7	1136	27.4	1755.8	292	7.0	451.3	34.4	6.418
					8	1299	27.4	2007.8	335	7.1	517.8	34.4	7.334
1/2	1/2	1/2	1/4	48	1	160	27.0	247.3	34	5.7	52.6	32.7	0.917
					2	323	27.2	499.2	71	6.0	109.7	33.2	1.834
					3	485	27.3	749.6	108	6.1	166.9	33.3	2.750
					4	648	27.3	1001.6	145	6.1	224.1	33.4	3.667
					5	811	27.3	1253.5	181	6.1	279.8	33.4	4.584
					6	973	27.3	1503.9	218	6.1	336.9	33.5	5.501
					7	1136	27.4	1755.8	255	6.1	394.1	33.5	6.418
					8	1299	27.4	2007.8	292	6.2	451.3	33.5	7.334
1/2	1/2	1/4	1/4	48	1	160	27.0	247.3	19	3.2	29.4	30.2	0.917
					2	323	27.2	499.2	40	3.4	61.8	30.6	1.834
					3	485	27.3	749.6	61	3.4	94.3	30.7	2.750
					4	648	27.3	1001.6	82	3.5	126.7	30.8	3.667
					5	811	27.3	1253.5	103	3.5	159.2	30.8	4.584
					6	973	27.3	1503.9	124	3.5	191.7	30.8	5.501
					7	1136	27.4	1755.8	145	3.5	224.1	30.9	6.418
					8	1299	27.4	2007.8	166	3.5	256.6	30.9	7.334

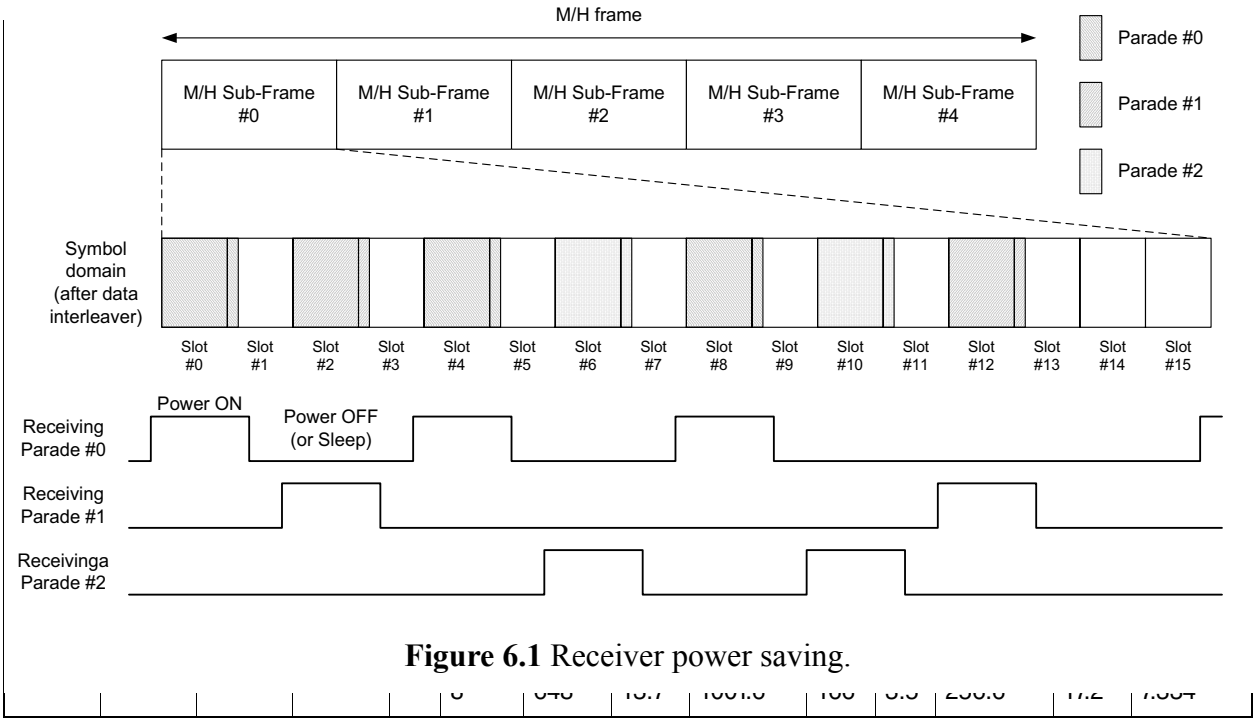

Figure 6.1 Receiver power saving.

6.2 Receiver Power Saving

Time slicing is accomplished by carrying M/H service data in M/H Groups at a much higher data rate than the average required for the M/H service. With the aid of training sequences, the receiver synchronization time is small and this allows the M/H receivers to cycle tuner and demodulator (base-band processor) power on during reception of Groups of a particular M/H Parade and off the rest of the time. One Group consists of 118 consecutive MPEG-2 transport packets (MHE packets) delivering M/H service data. After data interleaving, the Group will be interspersed throughout 171 or 170 data segments depending on the presence of the field sync segment. Figure 6.1 describes the receiver power management. When receiving a Parade with a particular parade_id (supplied by the upper layer), the M/H demodulator can utilize power on/off control.

Note that interleaving delays some of the data in each Group and spreads it out in time beyond the corresponding 156 data segments of a Slot, such that each ON period is a minimum of 171 data segments, or approximately 13.2 ms. In addition, there is some time required for receiver

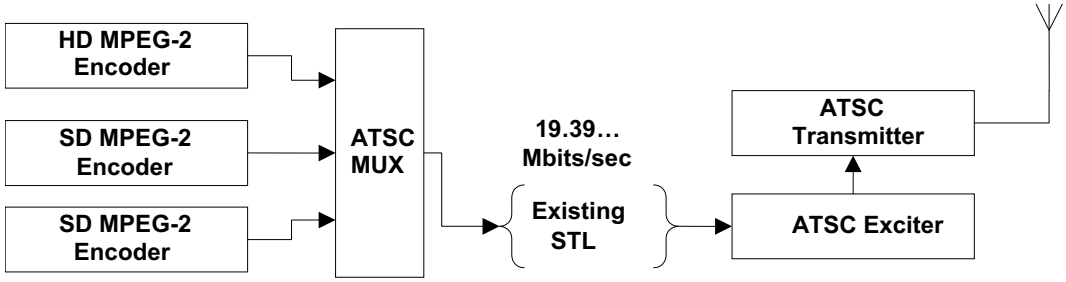

Figure 6.2 ATSC STL to single transmitter.

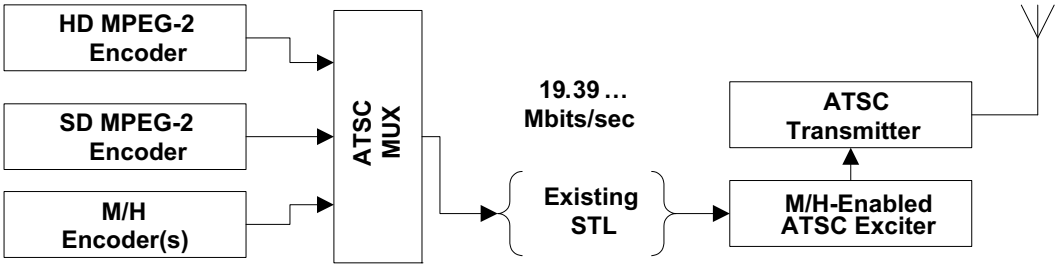

Figure 6.3 M/H with existing STL to single transmitter.

front end stabilization at the beginning of the ON period, which depends on receiver design, but can be on the order of 2 to 4 ms.

6.3 Integration of the M/H Transmission System into Legacy ATSC Transmission Systems

The M/H system has been designed and architected to preserve the significant consumer investment in ATSC-compliant receiver hardware. Additionally, the system is based on considerations of integrating into the existing transmission infrastructure at typical ATSC stations, and also utilization of the Distributed Transmission (DTx) structures defined in ATSC A/110 [11] and suitable extensions thereof.

This section provides (non-normative) examples of how M/H transmission can be implemented in several typical ATSC broadcast scenarios. Still other configurations are possible for each of these scenarios to accommodate different existing ATSC installations or provide the best economy for new installations.

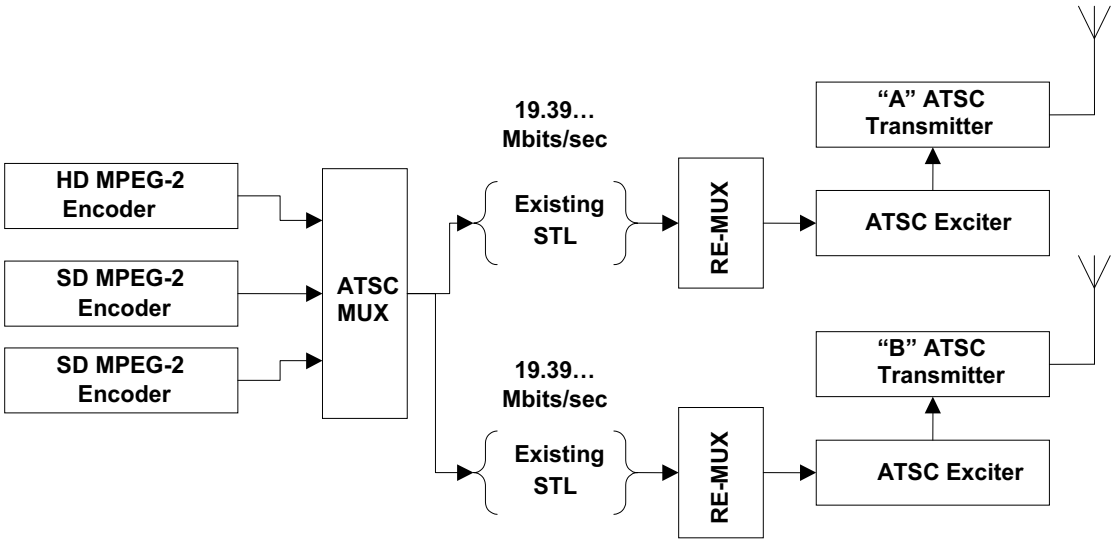

Figure 6.4 ATSC with remultiplexing at multiple transmitters.

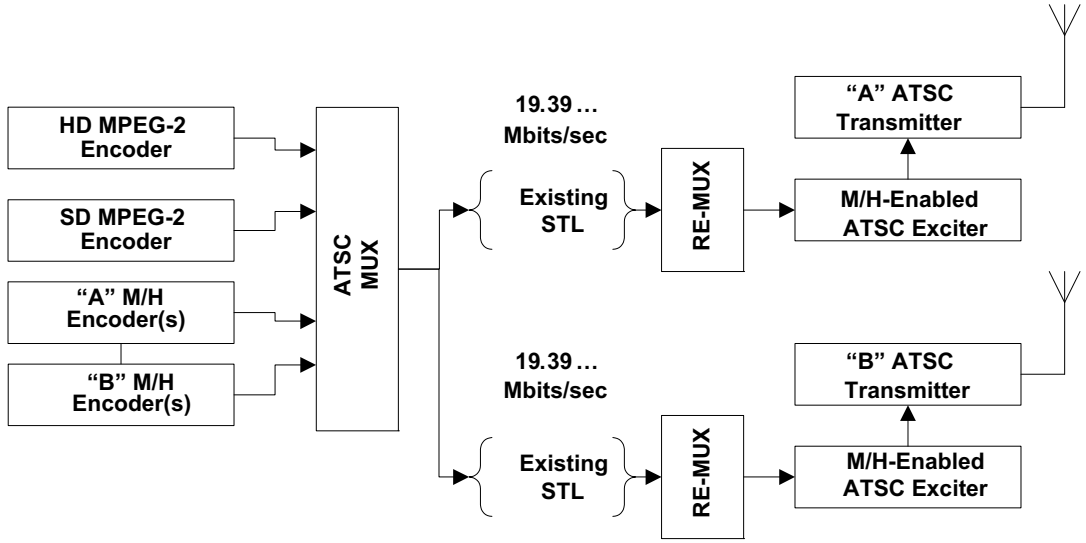

Figure 6.5 M/H with remultiplexing at multiple transmitters.

6.3.1 Example 1: ATSC STL to a Single Transmitter

By far the most common ATSC configuration today is an encoder/multiplexer setup that generates a 19.39 Mbits/second ATSC transport stream, connected through a single (or redundant) STL, to a single transmitter. Figure 6.2 illustrates this case.

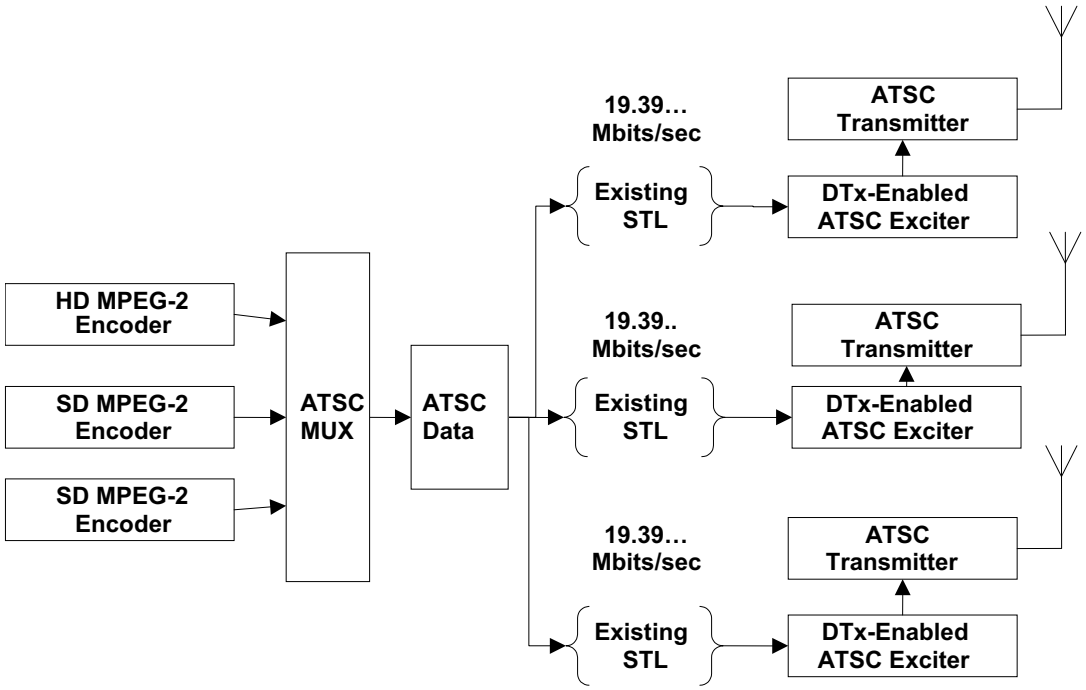

Figure 6.6 ATSC distributed transmission network.

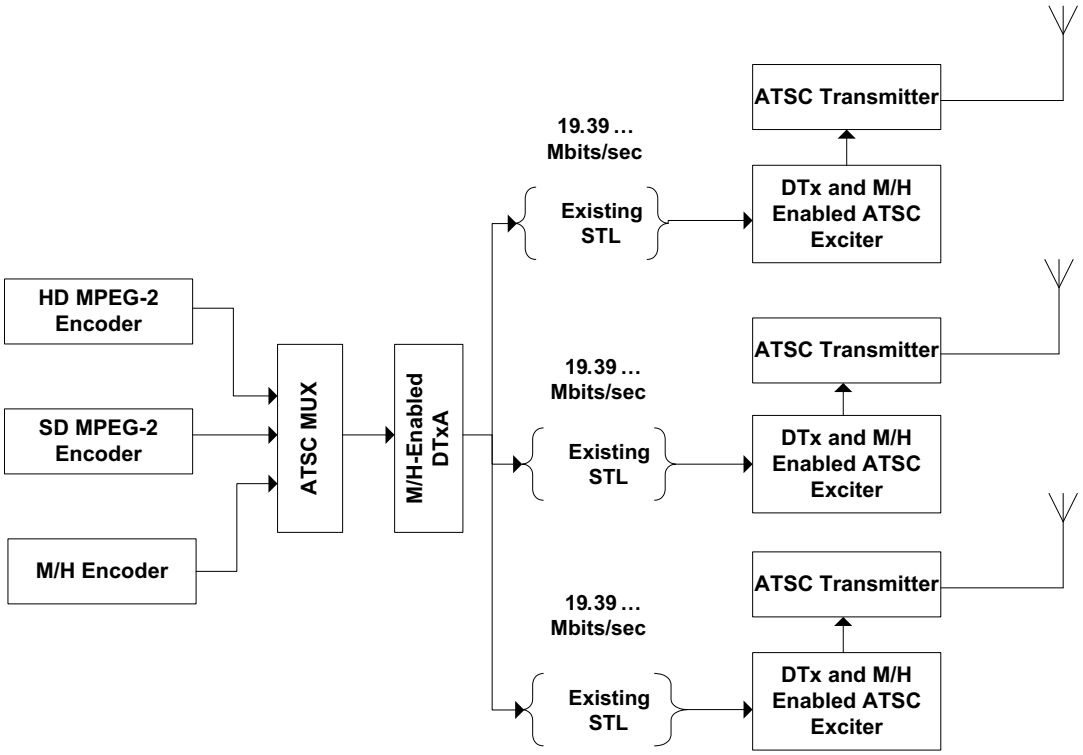

Figure 6.7 Distributed transmission network for M/H.

In the M/H system, the total payload to be transmitted is always *less* than the original 19.39 Mbits/sec of the legacy ATSC system. In a typical implementation for a single transmitter, single STL system, the M/H programs are multiplexed into the studio signal using traditional MPEG-2 multiplexing techniques [12], which will frequently be accommodated by the existing multiplexers at the station. The PSIP of the main signal is unaffected. The M/H-enabled exciter will then perform the time-multiplexing of the legacy (Main) and M/H data in order to put each in the proper time slots for final transmission. This arrangement is shown in Figure 6.3.

6.3.2 Example 2: ATSC STL to Multiple Transmitters with Lineup and PSIP Customization Per Site

In many public television networks, a different but related ATSC multiplex is formed, with PSIP customization (and in some cases program lineup customization) at each remote transmitter. Figure 6.4 shows a simplified example where each transmitter has a different but similar feed.

In this network, each transmitter utilizes a remultiplexer to choose the programs which will be transmitted at that location, and to localize the PSIP information to reflect the specifics of the transmitter and program lineup. The addition of M/H streams to this situation is also easily accommodated as shown in Figure 6.5.

Again, the inclusion of the M/H data in the existing STL arrangement as extra programs in the distribution to the transmitters is done through normal MPEG-2 TS multiplexing processes, and the final time multiplexing of the main ATSC and M/H data streams is performed in the M/H-enabled exciter.

6.3.3 Example 3: ATSC Distributed Transmission Networks

In the case of Distributed Transmission Networks (DTxNs) the existing ATSC technique for implementation of DTxNs documented in ATSC A/110 [11] can be extended to support the M/H system.

In the DTxN situation, the exact identical symbol stream is emitted by all of the exciters. The exact time of emission of the symbols by each transmitter in the distributed network is an individual network design parameter. As shown in Figure 6.6, the identical streams and controlled timing are accomplished through "pre-modulation" of the transport stream in the DTxA (distributed transmission network adaptor). This determines the desired modulator state, which is then transmitted in-band to the transmitter sites with timing control information, using the Cadence Signal (sync inversion) and Distributed Transmission Packet (DTxP) methods articulated in A/110 [11].

The M/H system can likewise be used in a DTxN environment, employing the same techniques which are already defined in A/110, but extended for the M/H system. (See Figure 6.7.) In particular, the Cadence Signal occurrence is used to mark M/H Frames rather than VSB Frames, and the DTxP incorporates additional M/H modulator state and transmission parameters. The time multiplexing of Main and M/H data is performed once in the Distributed Transmission adapter, and then the re-arranged stream is time-marked with the Cadence Signal, and DTxP is included. The M/H-enabled DTxN is very similar to the current DTxN scheme, utilizing the same techniques and mechanisms which have already been established.

Annex A: Group Format (Normative)

Table A.1 Group Format Before Data Interleaver

Note: The 207 variable bytes of each 208-byte MPEG-2 Transport Stream packet are shown. The initial MPEG-2 sync byte of each packet is not shown.

(0: Normal VSB Data / 1: Signaling Bytes / 2: Dummy data bytes / 3: Trellis Initialization Bytes / 4: MPEG Header / 5 Known (Training) Data Sequence / 6: M/H Data / 9: RS Parity Bytes)

TP	Group Format
0	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 9 9 9 9 9 2 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 9 9 9 9 9 2 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 9 9 9 9 9 2 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 9 9 9 9 9 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
1	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 5 9 9 9 9 9 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 9 9 9 9 9 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 9 9 9 9 9 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 1 9 9 9 9 9 2 6 6 6 6 6 6 6 6 6 6 6 6 6 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
2	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 5 1 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 1 1 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
3	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 5 1 1 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 1 1 5 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
4	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 5 1 1 5 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 5 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 1 1 5 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 2 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
5	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 5 1 1 5 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 5 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 1 1 5 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
6	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 5 1 1 5 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 5 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 1 1 5 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
7	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 5 1 1 5 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 5 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 1 1 5 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
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9	4 4 4 6 6 6 6 6 6 6 6 6 6 6 5 5 1 1 5 6 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 5 6 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 5 1 5 6 6 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 5 1 1 5 6 6 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
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109	4 4 4 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 6 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 2 6 6 6 6 6 6 6 9 9 9 9 9 6 6 6 6 6 6 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
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114	4 4 4 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 6 6 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 6 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 6 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 6 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
115	4 4 4 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 6 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 5 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6

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Table A.2 Group Format After Data Interleaver

Note: The 207 variable bytes of each 208-byte MPEG-2 Transport Stream packet are shown. The initial MPEG-2 sync byte of each packet is not shown.

In a group containing a data field sync segment, the data field sync segment shall be inserted between M/H group segments # 36 and #37; i.e., 37 M/H group segments precede a data field sync segment.

(0: Normal VSB Data / 1: Signaling Bytes / 2: Dummy data bytes / 3: Trellis Initialization Bytes / 4: MPEG Header / 5 Known (Training) Data Sequence / 6: M/H Data / 9: RS Parity Bytes)

seg	Group Format
0	000000000000000900000000000000000000000000000000000000000000000000 090000000000000000000000000000000000000000000000000009000000000000 000000000000000000000000000000000000000900000000000000000000000000 000000000
1	000000000000000099000000000000000000000000000000000000000000000000 009900000000000000000000000000000000000000000000000000990000000000 000000000000000000000000000000000000000099000000000000000000000000 000000000
2	000000000000000009990000000000000000000000000000000000000000000000 000999000000000000000000000000000000000000000000000000099900000000 000000000000000000000000000000000000000009990000000000000000000000 000000000
3	000000000000000000999900000000000000000000000000000000000000000000 000099990000000000000000000000000000000000000000000000009999000000 000000000000000000000000000000000000000000999900000000000000000000 000000000
4	000000000000000000099999000000000000000000000000000000000000000000 000009999900000000000000000000000000000000000000000000000999990000 000000000000000000000000000000000000000000099999000000000000000000 000000000
5	000000000000000000009999920000000000000000000000000000000000000000 000000999992000000000000000000000000000000000000000000000099999200 000000000000000000000000000000000000000000009999920000000000000000 000000000
6	000000000000000000000999992200000000000000000000000000000000000000 000000099999220000000000000000000000000000000000000000000009999922 000000000000000000000000000000000000000000000999992600000000000000 000000000
7	000000000000000000000099999666000000000000000000000000000000000000 000000009999966600000000000000000000000000000000000000000000999996 660000000000000000000000000000000000000000000000999996660000000000 000000000
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38	0444444444444444444444444444444444444444000000000000000666666666666666666666666660000000000000006666666666666666666666666600000000000000066666666666666666666666666000000000
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45	6 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
46	6 6 6 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
47	6 6 6 6 6 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
48	6 6 6 6 6 6 6 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6
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140	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9
141	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9
142	9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9
143	9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9
144	9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9
145	9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6

146	9999900000000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666
147	6999990000000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666
148	6699999000000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000006666662222222
149	6669999900000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000066666666666
150	6666999990000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666
151	6666699999000000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000006666666
152	6666669999900000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000066666
153	6666666999990000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000006666
154	6666666699999000000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000000666
155	6666666666999990000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000000000
156	0666666666999990000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000000000
157	0006666666699999000000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000000000
158	0000066666669999900000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000000000
159	0000000666666999990000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000000000
160	0000000006666699999000000000000000000666666666666666666999990000000000000000000000000000000000666666666666666666999990000000000000000000000000000000000000000000

161	0 0 0 0 0 0 0 0 0 0 0 6 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
162	0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
163	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 6 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
164	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
165	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
166	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
167	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
168	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
169	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 9 0

Table A.3 Known Data (Training) Bytes
(including trellis initialization bytes)

1st Training Sequence (397 Bytes)	08 03 09 07 0A 0E 04 01 0E 0E 08 05 FD 93 4E BF F8 CC 6D 37 01 0F C4 36 44 6E 48 BA 32 A4 90 5E F3 A2 00 DF EE B4 F0 2D 64 AD 69 E6 36 3B A0 2B A9 02 90 BF 92 0B 02 42 42 D2 92 D9 BF F4 2F FF 64 49 D9 DB 6D FF 4B 2F F6 9B FD 6F BF 0B 00 40 BF F6 DB D0 DB F6 09 6D 64 42 90 2F D2 40 64 00 6D 6F 02 2F 99 F6 99 6D D0 2D 00 02 02 49 DB D9 90 DB 02 26 92 00 0B 49 F4 00 49 B4 00 49 F4 FF 40 26 FD 99 2D BF 09 02 BD 9B BF D2 B4 F4 99 92 09 6F 0B 64 90 6D 6F 4B 9B 99 BF 6D 92 64 6F B4 02 0B F6 D2 DB 2D 40 BD F4 09 49 0B 66 D2 6F 42 D0 90 24 9B B4 BF 24 66 6F 4B DB 66 B6 BF 90 49 00 40 66 42 6F F6 BF 00 09 FD 26 4B F4 24 DB 4B D2 6D 40 2D B4 B4 F6 DB 90 02 F4 6F 40 92 92 09 00 92 42 F6 BD D9 0B D2 BD FF 6F 00 2D D9 D2 66 09 24 6F 64 BD 49 42 92 2D 2F 66 6F 0B 09 6D 24 BD 99 FD D0 99 66 49 66 FD 00 BD 24 99 B6 26 9B 0B FF 24 F6 2F 24 BF 9B 00 F4 D0 66 F6 FF 90 D9 40 2F D0 42 99 24 24 D2 40 F4 09 92 BD 66 99 D9 BF BD 2D D2 BF 2D BF 64 99 DB 0B 2D 64 92 2F 6D 66 2D 6F 9B 24 66 D2 2F BD D9 42 26 42 0B D2 FD 00 6D D9 66 09 99 F4 DB 6F 6D F6 00 26 0B 26 6D 99 99 00 4B F6 92 42 B6 42 F6 40 99 9B 02 B6 D2 4B DB 40 DB 66 D2 99 90 4B 42 6D F4 42 D0 00 64 D0 DB BE BF DE 46 9F 9A F7 0E 22 2F 26
2nd Training Sequence (276 Bytes)	04 0B 0B 0B 0B 02 00 0D 0B 04 06 09 90 42 FF 64 FD 6D B6 26 49 00 66 BF 26 40 DB 99 B4 B6 6D 40 2D 92 6F D9 42 24 D9 24 26 F4 02 90 24 40 4B 2D FF 0B 99 BD 6D 92 4B B4 2F 02 4B 99 4B FF 26 2F BF 49 6F 02 6F F4 64 2F F6 40 D2 42 4B BD F4 FD 40 00 24 6D 64 26 D0 6F 6D 0B 24 BF 9B 09 24 2F 26 64 B6 64 9B D2 99 F6 64 BF BF 64 4B 00 F6 0B DB 6F BF 6D 02 FF 40 90 40 B4 FD 64 6D D9 42 99 DB D2 BD 9B EB 34 36 A9 64 6B 7B 7B BB A2 B0 ED 90 42 FF 64 FD 6D B6 26 49 00 66 BF 26 40 DB 99 B4 B6 6D 40 2D 92 6F D9 42 24 D9 24 26 F4 02 90 24 40 4B 2D FF 0B 99 BD 6D 92 4B B4 2F 02 4B 99 4B FF 26 2F BF 49 6F 02 6F F4 64 2F F6 40 D2 42 4B BD F4 FD 40 00 24 6D 64 26 D0 6F 6D 0B 24 BF 9B 09 24 2F 26 64 B6 64 9B D2 99 F6 64 BF BF 64 4B 00 F6 0B DB 6F BF 6D 02 FF 40 90 40 B4 FD 64 6D D9 42 99 DB D2 BD 9B E0 3A 35 AF 60 6A 75 7F B0 AA B5 EF
3rd Training Sequence (367 Bytes)	0C 0F 05 08 02 09 08 04 00 0D 04 0D 69 F6 F6 2B 20 3B 29 02 90 BF 92 0B 02 42 42 D2 92 D9 BF F4 2F FF 64 49 D9 DB 6D FF 4B 2F F6 9B FD 6F BF 0B 00 40 BF F6 DB D0 DB F6 09 6D 64 42 90 2F D2 40 64 00 6D 6F 02 2F 99 F6 99 6D D0 2D 00 02 02 49 DB D9 90 DB 02 26 92 00 0B 49 F4 00 49 B4 00 49 F4 FF 40 26 FD 99 2D BF 09 02 BD 9B BF D2 B4 F4 99 92 09 6F 0B 64 90 6D 6F 4B 9B 99 BF 6D 92 64 6F B4 02 0B F6 D2 DB 2D 40 BD F4 09 49 0B 66 D2 6F 42 D0 90 24 9B B4 BF 24 66 6F 4B DB 66 B6 BF 90 49 00 40 66 42 6F F6 BF 00 09 FD 26 4B F4 24 DB 4B D2 6D 40 2D B4 B4 F6 DB 90 02 F4 6F 40 92 92 09 00 92 42 F6 BD D9 0B D2 BD FF 6F 00 2D D9 D2 66 09 24 6F 64 BD 49 42 92 2D 2F 66 6F 0B 09 6D 24 BD 99 FD D0 99 66 49 66 FD 00 BD 24 99 B6 26 9B 0B FF 24 F6 2F 24 BF 9B 00 F4 D0 66 F6 FF 90 D9 40 2F D0 42 99 24 24 D2 40 F4 09 92 BD 66 99 D9 BF BD 2D D2 BF 2D BF 64 99 DB 0B 2D 64 92 2F 6D 66 2D 6F 9B 24 66 D2 2F BD D9 42 26 42 0B D2 FD 00 6D D9 66 09 99 F4 DB 6F 6D F6 00 26 0B 26 6D 99 99 00 4B F6 92 42 B6 42 F6 40 99 9B 02 B6 D2 4B DB 40 DB 66 D2 99 90 4B 42 6D F4 42 D0 00 64 D0 DB BE BF DE 46 9F 9A F7 0E 22 2F 26
4th Training Sequence (360 Bytes)	04 00 0D 04 0D 09 06 06 0B 00 0B 09 02 90 BF 92 0B 02 42 42 D2 92 D9 BF F4 2F FF 64 49 D9 DB 6D FF 4B 2F F6 9B FD 6F BF 0B 00 40 BF F6 DB D0 DB F6 09 6D 64 42 90 2F D2 40 64 00 6D 6F 02 2F 99 F6 99 6D D0 2D 00 02 02 49 DB D9 90 DB 02 26 92 00 0B 49 F4 00 49 B4 00 49 F4 FF 40 26 FD 99 2D BF 09 02 BD 9B BF D2 B4 F4 99 92 09 6F 0B 64 90 6D 6F 4B 9B 99 BF 6D 92 64 6F B4 02 0B F6 D2 DB 2D 40 BD F4 09 49 0B 66 D2 6F 42 D0 90 24 9B B4 BF 24 66 6F 4B DB 66 B6 BF 90 49 00 40 66 42 6F F6 BF 00 09 FD 26 4B F4 24 DB 4B D2 6D 40 2D B4 B4 F6 DB 90 02 F4 6F 40 92 92 09 00 92 42 F6 BD D9 0B D2 BD FF 6F 00 2D D9 D2 66 09 24 6F 64 BD 49 42 92 2D 2F 66 6F 0B 09 6D 24 BD 99 FD D0 99 66 49 66 FD 00 BD 24 99 B6 26 9B 0B FF 24 F6 2F 24 BF 9B 00 F4 D0 66 F6 FF 90 D9 40 2F D0 42 99 24 24 D2 40 F4 09 92 BD 66 99 D9 BF BD 2D D2 BF 2D BF 64 99 DB 0B 2D 64 92 2F 6D 66 2D 6F 9B 24 66 D2 2F BD D9 42 26 42 0B D2 FD 00 6D D9 66 09 99 F4 DB 6F 6D F6 00 26 0B 26 6D 99 99 00 4B F6 92 42 B6 42 F6 40 99 9B 02 B6 D2 4B DB 40 DB 66 D2 99 90 4B 42 6D F4 42 D0 00 64 D0 DB BE BF DE 46 9F 9A F7 0E 22 2F 26
5th Training Sequence (383 Bytes)	06 0A 07 07 0A 0A 0E 0B 0B 05 02 09 7C 1B 68 92 9E 95 01 D0 2A F9 1C 34 70 AD 34 6D 79 66 F6 6B 30 3B F9 02 90 BF 92 0B 02 42 42 D2 92 D9 BF F4 2F FF 64 49 D9 DB 6D FF 4B 2F F6 9B FD 6F BF 0B 00 40 BF F6 DB D0 DB F6 09 6D 64 42 90 2F D2 40 64 00 6D 6F 02 2F 99 F6 99 6D D0 2D 00 02 02 49 DB D9 90 DB 02 26 92 00 0B 49 F4 00 49 B4 00 49 F4 FF 40 26 FD 99 2D BF 09 02 BD 9B BF D2 B4 F4 99 92 09 6F 0B 64 90 6D 6F 4B 9B 99 BF 6D 92 64 6F B4 02 0B F6 D2 DB 2D 40 BD F4 09 49 0B 66 D2 6F 42 D0 90 24 9B B4 BF 24 66 6F 4B DB 66 B6 BF 90 49 00 40 66 42 6F F6 BF 00 09 FD 26 4B F4 24 DB 4B D2 6D 40 2D B4 B4 F6 DB 90 02 F4 6F 40 92 92 09 00 92 42 F6 BD D9 0B D2 BD FF 6F 00 2D D9 D2 66 09 24 6F 64 BD 49 42 92 2D 2F 66 6F 0B 09 6D 24 BD 99 FD D0 99 66 49 66 FD 00 BD 24 99 B6 26 9B 0B FF 24 F6 2F 24 BF 9B 00 F4 D0 66 F6 FF 90 D9 40 2F D0 42 99 24 24 D2 40 F4 09 92 BD 66 99 D9 BF BD 2D D2 BF 2D BF 64 99 DB 0B 2D 64 92 2F 6D 66 2D 6F 9B 24 66 D2 2F BD D9 42 26 42 0B D2 FD 00 6D D9 66 09 99 F4 DB 6F 6D F6 00 26 0B 26 6D 99 99 00 4B F6 92 42 B6 42 F6 40 99 9B 02 B6 D2 4B DB 40 DB 66 D2 99 90 4B 42 6D F4 42 D0 00 64 D0 DB BE BF DE 46 9F 9A F7 0E 22 2F 26
6th Training Sequence (360 Bytes)	04 00 0D 04 0D 09 06 06 0B 00 0B 09 02 90 BF 92 0B 02 42 42 D2 92 D9 BF F4 2F FF 64 49 D9 DB 6D FF 4B 2F F6 9B FD 6F BF 0B 00 40 BF F6 DB D0 DB F6 09 6D 64 42 90 2F D2 40 64 00 6D 6F 02 2F 99 F6 99 6D D0 2D 00 02 02 49 DB D9 90 DB 02 26 92 00 0B 49 F4 00 49 B4 00 49 F4 FF 40 26 FD 99 2D BF 09 02 BD 9B BF D2 B4 F4 99 92 09 6F 0B 64 90 6D 6F 4B 9B 99 BF 6D 92 64 6F B4 02 0B F6 D2 DB 2D 40 BD F4 09 49 0B 66 D2 6F 42 D0 90 24 9B B4 BF 24 66 6F 4B DB 66 B6 BF 90 49 00 40 66 42 6F F6 BF 00 09 FD 26 4B F4 24 DB 4B D2 6D 40 2D B4 B4 F6 DB 90 02 F4 6F 40 92 92 09 00 92 42 F6 BD D9 0B D2 BD FF 6F 00 2D D9 D2 66 09 24 6F 64 BD 49 42 92 2D 2F 66 6F 0B 09 6D 24 BD 99 FD D0 99 66 49 66 FD 00 BD 24 99 B6 26 9B 0B FF 24 F6 2F 24 BF 9B 00 F4 D0 66 F6 FF 90 D9 40 2F D0 42 99 24 24 D2 40 F4 09 92 BD 66 99 D9 BF BD 2D D2 BF 2D BF 64 99 DB 0B 2D 64 92 2F 6D 66 2D 6F 9B 24 66 D2 2F BD D9 42 26 42 0B D2 FD 00 6D D9 66 09 99 F4 DB 6F 6D F6 00 26 0B 26 6D 99 99 00 4B F6 92 42 B6 42 F6 40 99 9B 02 B6 D2 4B DB 40 DB 66 D2 99 90 4B 42 6D F4 42 D0 00 64 D0 DB BE BF DE 46 9F 9A F7 0E 22 2F 26

Table A.4 Periodic Symbols
(-7→0 / -5→1 / -3→2 / -1→3 / 1→4 / 3→5 / 5→6 / 7→7)

	Symbols
1st, 3rd, 4th, 5th, 6th training sequence (1424 symbols)	20626422404410717655202604145566747116775444767605251544450254617000103725336762631360744775215677270012753653652372336116711165662632170142263647725146311137262143561674272547761625511706411120230464521653205530401661152036501501466347001461307535701535721735705033257401407702266553504354540460441262646105522043047666474041645234136445741374261247543124462304504560214165567376726130531657745573137215460761346331113001470503265365756354423133557623672532155267574344755776042672651750757657417016747557432333050054442503303711071310135732614641113440737274552534145313370476331533644561167344256425476277705564724451374431564657235172174112464264754636665402210607150267232155647377501621657150210223104113641750235131330721010101375460453155462535271123742432701522145106371350306657631264424661625046710107507401102622004262751212341334220305526536261552776745534366035070677247324313065441501171645203342125305724264567365717412334435045263671331775765222303315757360410675440530701261557770154343007420323144334524067107111416576561516101610777356656032012635222453366207271721071037174521512450407155230233713232047253370261527070621564234441660653655654531007770103030276507633701570533654314202152133207235370663411116400624643050730577530576150075431207370701144631444337237313752216031314143050043417715436034351627223033373400703043000007700070531647441051254360120050233353271415567667476476202002020020611 6
2nd training sequence (528 symbos)	24444006422412222407215643737645306171353121110651676633502255246654715757711177446314726605170235046675656444765175613675354641533550201253000053432340315711614111102771156524112021231703501365466443314533666120643736551231633402006050174157372431667623537664245262327123345330204677141530001272143340446342140270266155541014311102744436166536007201126313725712531657751744352672027076274502362315442035136134257356177505747530125754710366165425067627535520767231371017310313267307627514442514607757202365546677545602200022202 0

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Annex B:
Example Method of Packet Timing and PCR Adjustment of Main Service Data (Informative)

B.1 OVERVIEW

In Figure B.1, the source stream includes data for enhanced processing (M/H) and data for main stream processing (Main) along with Null Packets for filler to obtain the full interface rate (typically 19.4 Mbps). (Subsequent processing replaces some of these Null packets with enhanced FEC symbols.) Enhanced stream packets are demultiplexed into a specific process path resulting in a much-reduced data rate. All other packets are routed to the main stream path. Notice that the timing of the main stream packets is not changed. To facilitate this, null packets have been introduced where enhanced packets were removed. Alternatively, all null packets could be removed, and non-null packets could carry a time stamp.

Since the M/H data is not used by legacy equipment, packet timing accommodation for the M/H data can be defined into the process and the receiver model and need not be discussed here. However, the main data path must work with legacy receiver equipment and generally will require new processing at the source to follow legacy buffer definitions.

When data space is modified to allow enhanced packet placement, the main stream packets must be moved around to fit the remaining data space. An example data space is shown in Figure B.2.

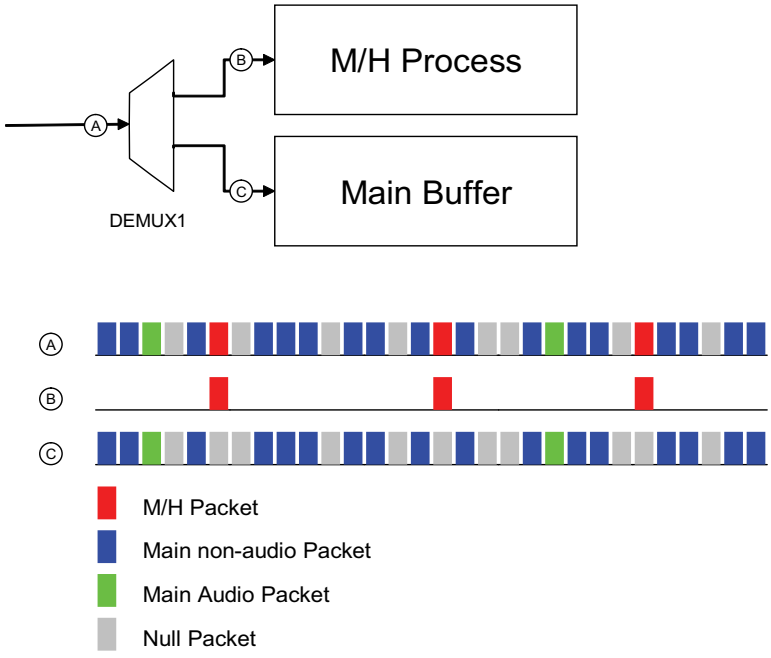

Figure B.1 Model of input portion of M/H exciter.

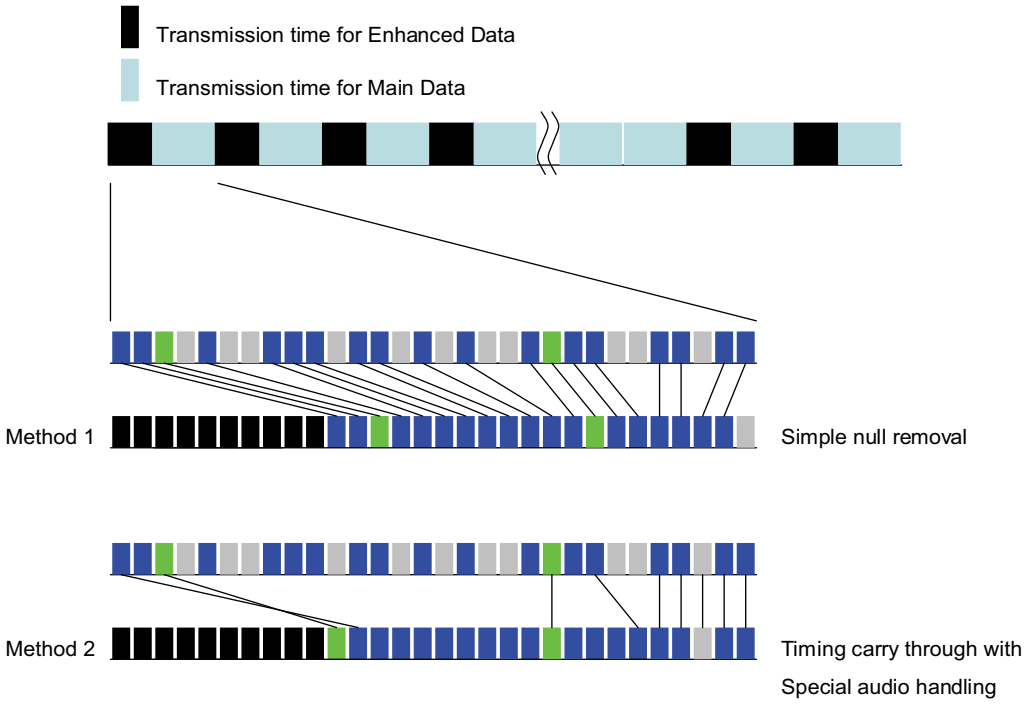

Figure B.2 Packing method example.

Figure B.2 shows Groups of Enhanced Data and Main Data. Two methods are shown for packing the Main Data into the new data space. The first method has three simple steps consisting of null removal, data packing and null fill. This method is generally adequate for meeting the constraints of the legacy decoder video buffer model, which consists of a single large buffer stage. However, it can easily exceed the limits of the legacy decoder audio transport buffer model, which is a small buffer preceding the audio decoder buffer model. While many receiver hardware implementations might use copious physical buffers for audio, some might follow the model closely, and those will be affected by transport buffer excursions and possibly decoder buffer excursions.

The second method has more complex steps consisting of:

- Priority placement of audio packets
- Ignoring delayed null packets
- Placing non-audio packets as second priority

This results in minimal displacement of the audio packets (note shorter displacement lines in the diagram) and reduced displacement to the non-audio packets (more vertical displacement lines) compared to the first method. While the simple example above shows the aspects of the improvement, the actual degree of improvement is much greater over the full repeat cycle of the Enhanced/ Main packing pattern.

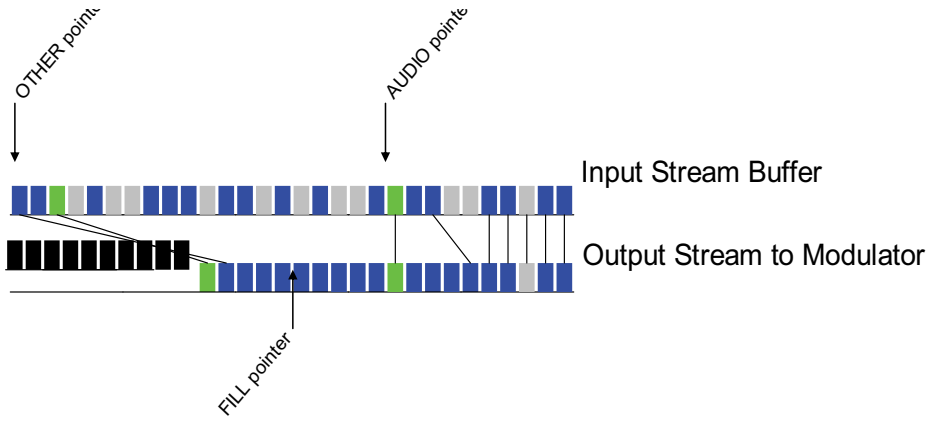

Figure B.3 Example Packing algorithm using pointers.

A pseudo code of the second example packing algorithm for audio is stated below. This is more easily understood with the concept of data pointers as shown in Figure B.3.

```
WHILE FILL_ptr < total packets of maximum cycle;for largest cadence cycle
    IF FILL_ptr is in enhanced modulation space
    Do not use MAIN data
    ELSE IF AUDIO_ptr <= FILL_ptr;copy audio first
    COPY AUDIO PACKET TO OUTPUT STREAM
    AUDIO_ptr++      ;next audio packet
    FILL_ptr++             ;next space to fill
    ELSE IF OTHER_ptr <= FILL_ptr
    COPY OTHER PACKET TO OUTPUT STREAM
    OTHER_ptr++      ;next other packet (non-audio, non-null)
    FILL_ptr++
    ELSE
    WHILE NOT END OF FIELD
        COPY FROM INPUT STREAM;copy other, audio and null
        FILL_ptr++
    END WHILE
    AUDIO_ptr++      ;next audio packet (past FILL_ptr)
    OTHER_ptr++      ;next other packet (non-audio, non-null)(past FILL_ptr)
```

There is one addition to the above algorithm to prevent violating the audio transport buffer model. This buffer can hold three packets of data, but only empties at a 2 Mbit/s rate. This means that more than 3 packets of audio information in a row will cause this buffer to overflow, since the

input rate is specified by as 20 Mbps. The remedy to prevent overflow is to delay the next (4th) audio packet by about 10 packet times. The pseudo code for this is:

```
ELSE IF AUDIO_ptr <= FILL_ptr
    IF A_TB < 20
        COPY AUDIO PACKET TO OUTPUT STREAM
        AUDIO_ptr++;next audio packet
        FILL_ptr++;next space to fill
        A_TB= +10;add 10 packet times to audio transport buffer delay counter
                        ;decrement A_TB on subsequent FILL_ptr increments – minimum zero
```

The last operation that is required is a buffer fullness offset. Since the data stream is generally shifted relative to its original spacing incarnation, the receiver buffer fullness will tend to be different than the original stream. A PCR adjustment should be done to adjust the average data in the receiver buffers. The PCR is based on a 27 MHz clock. A one millisecond offset is a count of 27,000.

As an example, experimentation with the M/H prototype system showed a need to offset the PCR by about -21 msec. or a count of –570,000. When taking packets from the Main buffer, the PCR should be restamped to compensate for the repositioning done by the algorithm above. Additionally, the offset should be made to the PCR value at that time. Since the PTS and DTS values are not changed, and the PCR value is changed, the decoding will occur at a different time, causing a change in the average buffer fullness.

The techniques shown in above method, as well as other techniques, can be applied to data packet streams whose elementary buffers may be in jeopardy of being violated absent appropriate techniques.

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