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TELEVISION AND SOUND TRANSMISSION

DIGITAL MULTI-PROGRAMME SYSTEMS FOR TELEVISION SOUND AND DATA SERVICES FOR CABLE DISTRIBUTION

ITU-T Recommendation J.83

(Previously “CCITT Recommendation”)

FOREWORD

The ITU-T (Telecommunication Standardization Sector) is a permanent organ of the International Telecommunication Union (ITU). The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1 (Helsinki, March 1-12, 1993).

ITU-T Recommendation J.83 was prepared by ITU-T Study Group 9 (1993-1996) and was approved under the WTSC Resolution No. 1 procedure on the 24th of October 1995.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

CONTENTS

SUMMARY

This Recommendation "Digital multi-programme systems for television, sound and data services for cable distribution" covers the definition of the framing structure, channel coding and modulation for digital multi-programme signals for television, sound and data services distributed by cable networks.

This Recommendation has four Annexes, that provide the specifications for the four digital television cable systems submitted to the ITU-T. This reflects the fact that standardization of digital cable television systems is being addressed for the first time by the ITU-T and that a number of systems had been developed and provisionally implemented when this standardization effort was undertaken by the ITU.

This Recommendation recommends that those implementing new digital multi-programme services on existing and future cable networks should use one of the systems whose framing structure, channel coding and modulation are specified in the Annexes to this Recommendation.

INTRODUCTION

The development of new digital technology is now reaching the point at which it is evident that they enable digital systems to offer significant advantages, in comparison with conventional analogue techniques, in terms of vision and sound quality, spectrum and power efficiency, service flexibility, multimedia convergence and potentially lower equipment costs. Moreover, the use of cable distribution for the delivery of video and audio signals to individual viewers and listeners is continually growing, and has already become the dominant form of distribution in many parts of the world. It is also evident that these potential benefits can best be achieved through the economies of scale resulting from the widespread use of digital systems designed to be easily implementable on existing infrastructure and which take advantage of the many possible synergies with related audiovisual systems.

This Recommendation has four Annexes, that provide the specifications for the four digital television cable systems submitted to the ITU-T.

This reflects the fact that standardization of digital cable television systems is being addressed for the first time by the ITU-T and that a number of systems had been developed and provisionally implemented when this standardization effort was undertaken by the ITU.

Administrations and private operators planning the introduction of digital cable television services are encouraged to consider the use of one of the systems described in the Annexes, and to seek opportunities for further convergence, rather than developing a different system based on the same technologies.

DIGITAL MULTI-PROGRAMME SYSTEMS FOR TELEVISION, SOUND AND DATA SERVICES FOR CABLE DISTRIBUTION

(Geneva, 1995)

1 Scope

The scope of this Recommendation is the definition of the framing structure, channel coding and modulation for digital multi-programme television, sound and data signals distributed by cable networks (e.g. CATV systems) possibly in frequency-division multiplex. A separate Recommendation defines the transmission characteristics for digital multi-programme signals distributed through SMATV networks.

NOTE – The system input is specified to be the MPEG-2 transport layer; this provides some ancillary data capacity in the forward channel, which can be used to accommodate the needs of interactive services (a description of the provision and characteristics of the return channel is outside the scope of this Recommendation).

Being highly flexible, the MPEG-2 transport layer can be configured to deliver any desired mix of television, sound and data signals (with sound either related or unrelated to the video signal content, and at various possible levels of quality). The transport layer can even be totally devoted to the delivery of sound programming, although it may not necessarily be optimised for this application.

The specific case of the delivery of a multiplex only containing sound signals may be addressed in a future Recommendation.

This Recommendation is intended to ensure that the designers and operators of cable distribution (e.g. CATV) networks carrying multi-programme signals, will have the information they need to be able to establish and maintain fully satisfactory networks. It also provides the information needed by the designers and manufacturers of equipment (including receivers) for digital multi-programme signals distributed by cable networks.

2 References

The following Recommendations and other references contain provisions which, through reference in the text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of currently valid ITU-T Recommendations is regularly published.

[1] ITU-R Recommendation BO.1211 (1995), *Digital multi-programme emission systems for television, sound and data services for satellites operating in the 11/12 GHz frequency range.*

[2] ITU-T Recommendation H.222.0 (1995) | ISO/IEC 13818-1:1996, *Information technology – generic coding of moving pictures and associated audio information systems*.

3 Terms and definitions

No unconventional terms or definitions are used in this Recommendation.

4 Symbols and abbreviations

4.1 Symbols

For the purposes of this Recommendation, the following symbols are used:

α	Roll-off factor
A_k, B_k	Most Significant Bits at the output of the Byte to m-tuple converter
byte	Eight bits
bps	Bits per second

f_0	Channel centre frequency
f_N	Nyquist frequency
g(x)	RS code generator polynomial
$G_{(256)}$	RS primitive field generator polynomial
$G_{(16)}$	Randomizer generator polynomial
I	Interleaving depth (bytes)
I, Q	In-phase, Quadrature phase components of the modulated signal
j	Branch index
k	Number of bytes mapped into n symbols
m	Power of 2^m-level QAM: 4,5,6 for 16-QAM, 32-QAM, 64-QAM, respectively
M	Convolutional interleaver branch depth for j = 1, M = N/I
ms	millisecond
n	Number of symbols mapped from k bytes
N	Error protected frame length (bytes)
p(x)	RS field generator polynomial
PN(x)	Pseudo random sequence, identified by the number following the symbol
r_m	In-band ripple (dB)
R	Randomized sequence
R_s	Symbol rate corresponding to bilateral Nyquist bandwidth of modulated signal
R_u	Useful bit rate after MPEG-2 transport multiplexer
$R_{u'}$	Bit rate after RS outer coder
q	Number of bits: 2,3,4 for 16-QAM, 32-QAM, 64-QAM, respectively
T	Number of bytes which can be corrected in RS error-protected packet
T_s	Symbol period

4.2 Abbreviations

For the purposes of this Recommendation, the following abbreviations are used:

BB	Baseband
BER	Bit Error Ratio
CATV	Community Antenna Television
C/N	Carrier to Noise Ratio
DTVC	Digital Television by Cable
FEC	Forward Error Correction
FIFO	First In First Out
HEX	Hexadecimal
IF	Intermediate Frequency
IRD	Integrated Receiver Decoder

LSB	Least Significant Bit
MMDS	Multichannel Multipoint Distribution System
MPEG	Motion Picture Expert-Group
MSB	Most Significant Bit
MUX	Multiplex
P	Parity
PDH	Plesiochronous Digital Hierarchy
PN	Pseudo Noise
ppm	Parts per million
PRBS	Pseudo-Random Binary Sequence
QAM	Quadrature Amplitude Modulation
QEF	Quasi Error Free
RF	Radio Frequency
RS	Reed-Solomon
SMATV	Satellite Master Antenna Television
SNR	Signal to Noise Ratio
sps	Symbols per second
Sync	Synchronizing signal
TBD	To be determined
TDM	Time Division Multiplex
TS	Transport Stream
VLSI	Very Large Scale Integration
VSB	Vestigial SideBand
XOR	Exclusive OR
8-VSB	8 level VSB
16-VSB	16 level VSB

5 Digital multi-programme systems for cable distribution

It is recommended that those implementing new digital multi-programme services on existing and future cable networks should use one of the systems whose framing structure, channel coding and modulation are specified in the Annexes to this Recommendation. The specifications are compared in Table 1, indicating common features.

TABLE 1/J.83

Comparison of specifications in summary form indicating common features

Item		Annex B	Annex A	Annex C	Annex D
Input signals		Modified MPEG-2 transport stream. A parity checksum is substituted for the sync byte, supplying improved packet delineation functionality, and error detection capability independent of the FEC layer. (See B.4)	MPEG-2 transport Stream (See A.3, C.3, D.3)		
Framing structure		An FEC frame consists of a six 7-bits symbol sync header followed by 60 RS blocks, with each block containing 128 symbols. An RS symbol consists of 7-bits. Thus, there is a total 53 802 bits in an FEC frame. (See B.5.1)	The framing organization is based on the MPEG-2 transport packet structure (See A.4, C.4, D.4)		
Channel coding	Randomization	The 3-word polynominal for the PRS: $X^3 + X + \alpha^3$ over GF 128 (See B.5.4)	The 15-bit polynominal for the PRBS: $1 + X^{14} + X^{15}$ (See A.5.1, C.5.1)		The 16-bit polynominal for the PRBS: $1 + X + X^3 + X^6 + X^7 + X^{11} + X^{12} + X^{13} + X^{16}$ (See D.5.1)
	FEC	Concatenated coding, RS (128, 122) GF 128 with convolutional coding (See B.5)	RS (204, 188) GF 256 (See A.5.2, C.5.2)		RS (207, 187) GF 256 (See D.5.2)
	Interleaving	Convolutional interleaving depth: I = 128 (See B.5.2)	Convolutional interleaving, depth: I = 12 (See A.5.3, C.5.3)		Convolutional interleaving, depth: I = 52 (See D.5.3)
Modulation	Byte to symbol mapping	See B.5.5	See A.6, C.6.1		See D.6.1
	Differential coding	See B.5.5	See A.6, C.6.2		None
	Trellis coding	See B.5.5	None		
	Bandwidth	6 MHz	8 MHz	6 MHz	
	Constellation	64-QAM Figure B.13	16, 32, 64-QAM Figure A.7	64-QAM Figure C.7	16-VSB
	Roll-off factor	18% See B.8	15% See A.7	13% See C.6.4	11.5% See D.6.3
	Baseband filter characteristics	Table B.1	Figure A.8	Figure C.8	Figure D.11

Annex A

Digital multi-programme System A

(This annex forms an integral part of this Recommendation)

A.1 Introduction

This annex derives from work done on digital television satellite broadcasting in Europe; it describes the framing structure, channel coding and modulation (denoted "the System" for the purposes of this Annex) for digital multi-programme television distribution by cable. This System can be used transparently with the modulation/channel coding system used for digital multi-programme television by satellite (see Reference [1]). The System allows for further evolution as technology advances.

The System is based on MPEG-2 (see Reference [2] as regards source coding and transport multiplexing. It is based on Quadrature Amplitude Modulation (QAM). It allows for 16, 32, or 64-QAM constellations and permits future extension to higher constellations, such as 128-QAM and 256-QAM.

The System FEC is designed to improve the Bit Error Ratio (BER) from 10^{-4} to a range of 10^{-10} to 10^{-11}, ensuring "Quasi Error Free" (QEF) operation with approximately one uncorrected error event per transmission hour.

A.2 Cable system concept

The cable system shall be defined as the functional block of equipment performing the adaptation of the baseband TV signals to the cable channel characteristics (see Figure A.1). In the cable head-end, the following TV baseband signal sources can be considered:

– satellite signal(s);

– contribution link(s);

– local programme source(s).

The following processes shall be applied as shown in Figure A.1.

A.2.1 Baseband interfacing[1] and sync

This unit shall adapt the data structure to the format of the signal source. The framing structure shall be in accordance with MPEG-2 transport layer including sync bytes.

A.2.2 Sync 1 inversion and randomization

This unit shall invert the Sync 1 byte according to the MPEG-2 framing structure, and randomizes the data stream for spectrum shaping purposes.

A.2.3 Reed-Solomon (RS) coder

This unit shall apply a shortened Reed-Solomon (RS) code to each randomized transport packet to generate an error-protected packet. This code shall also be applied to the Sync byte itself.

A.2.4 Convolutional interleaver

This unit shall perform a depth I = 12 convolutional interleaving of the error-protected packets. The periodicity of the sync bytes shall remain unchanged.

A.2.5 Byte to m-tuple conversion

This unit shall perform a conversion of the bytes generated by the interleaver into QAM symbols.

A.2.6 Differential encoding

In order to get a rotation-invariant constellation, this unit shall apply a differential encoding of the two Most Significant Bits (MSBs) of each symbol.

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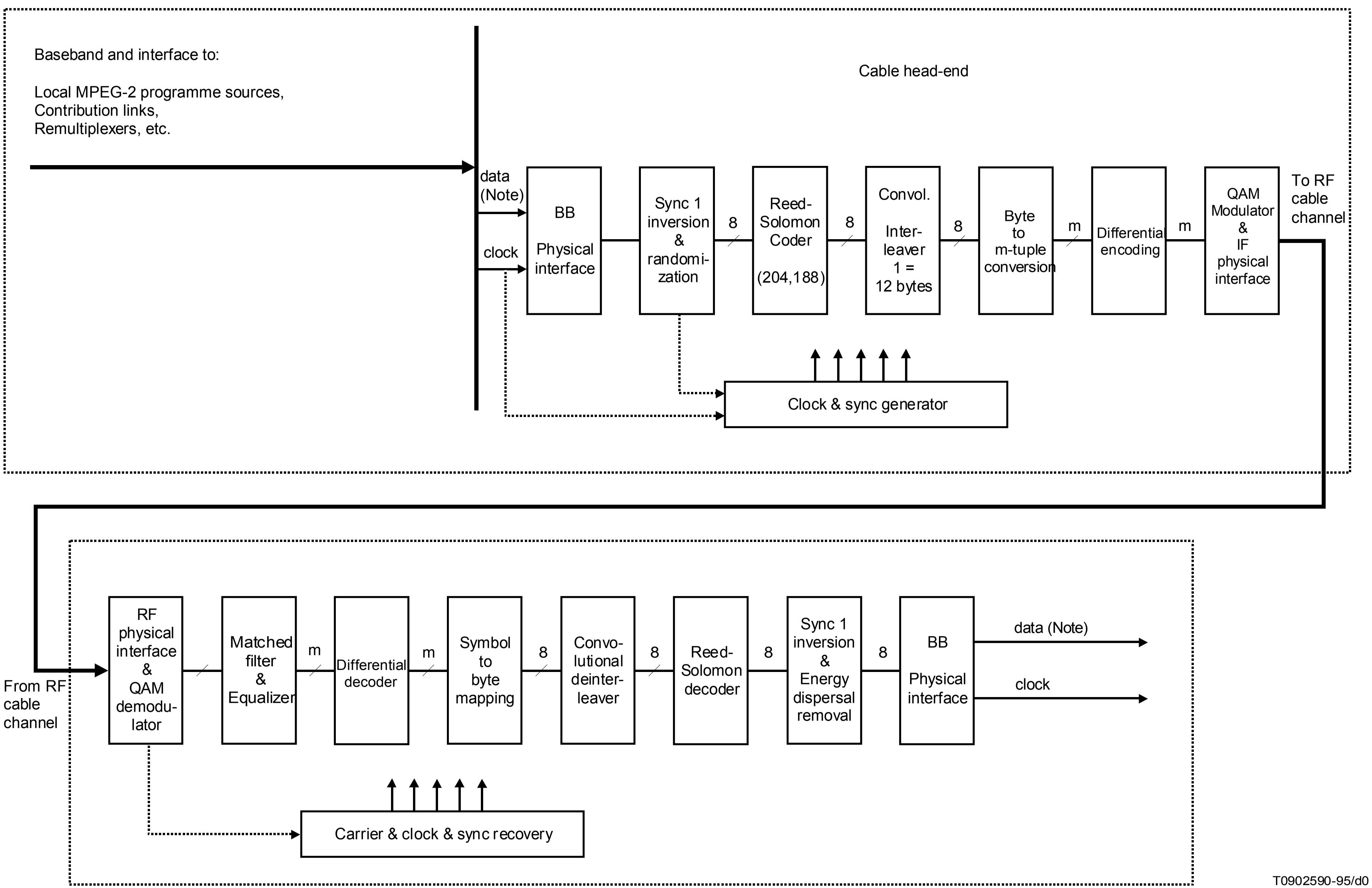
[1] Interfaces are not part of this Recommendation.



NOTE – MPEG-2 transport MUX packets.

FIGURE A.1/J.83

Conceptual block diagram of elements at the cable head-end and receiving site

A.2.7 QAM modulation and physical interface

This unit performs a square-root raised cosine filtering of the I and Q signals prior to QAM modulation. This is followed by interfacing the QAM modulated signal to the Radio Frequency (RF) cable channel.

A.2.8 Cable receiver

A System receiver shall perform the inverse signal processing, as described for the modulation process above, in order to recover the baseband signal.

A.3 MPEG-2 transport layer

The MPEG-2 transport layer is defined in Reference [2]. The transport layer for MPEG-2 data is comprised of packets having 188 bytes, with one byte for synchronization purposes, three bytes of header containing service identification, scrambling and control information, followed by 184 bytes of MPEG-2 or auxiliary data.

A.4 Framing structure

The framing organization shall be based on the MPEG-2 transport packet structure. The System framing structure is shown in Figure A.2.

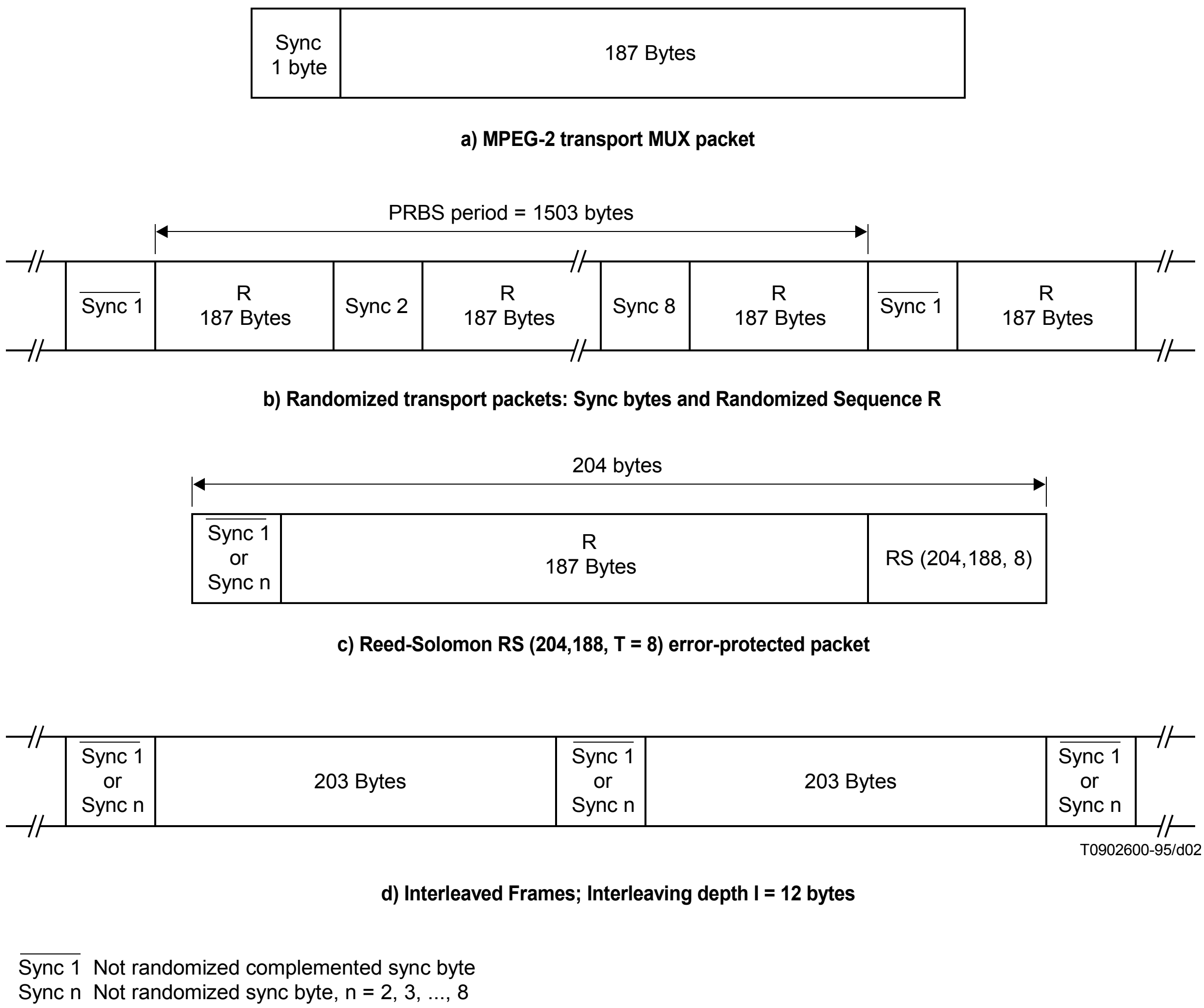


FIGURE A.2/J.83

Framing structure

A.5 Channel coding

To achieve the appropriate level of error protection required for cable transmission of digital data, a FEC based on Reed-Solomon encoding shall be used. In contrast to the Baseline System for satellite described in Reference [1], no convolutional coding shall be applied to cable transmission. Protection against burst errors shall be achieved by the use of byte interleaving.

A.5.1 Randomization for spectrum shaping

The System input stream shall be organized in fixed length packets (see Figure A.2), following the MPEG-2 transport multiplexer. The total packet length of the MPEG-2 transport MUX packet is 188 bytes. This includes 1 sync-word byte (i.e. 47_{HEX}). The processing order at the transmitting side shall always start from the MSB (i.e. 0) of the sync word-byte (i.e. 01000111).

In order to comply with the System for satellite (see Reference [1]) and to ensure adequate binary transitions for clock recovery, the data at the output of the MPEG-2 transport multiplex shall be randomized in accordance with the configuration depicted in Figure A.3.

The polynomial for the Pseudo Random Binary Sequence (PRBS) generator shall be:

$$1 + x^{14} + x^{15}$$

Loading of the sequence "100101010000000" into the PRBS registers, as indicated in Figure A.3, shall be initiated at the start of every eight transport packets. To provide an initialization signal for the descrambler, the MPEG-2 sync byte of the first transport packet in a group of eight packets shall be bit wise inverted from 47_{HEX} to $B8_{HEX}$.

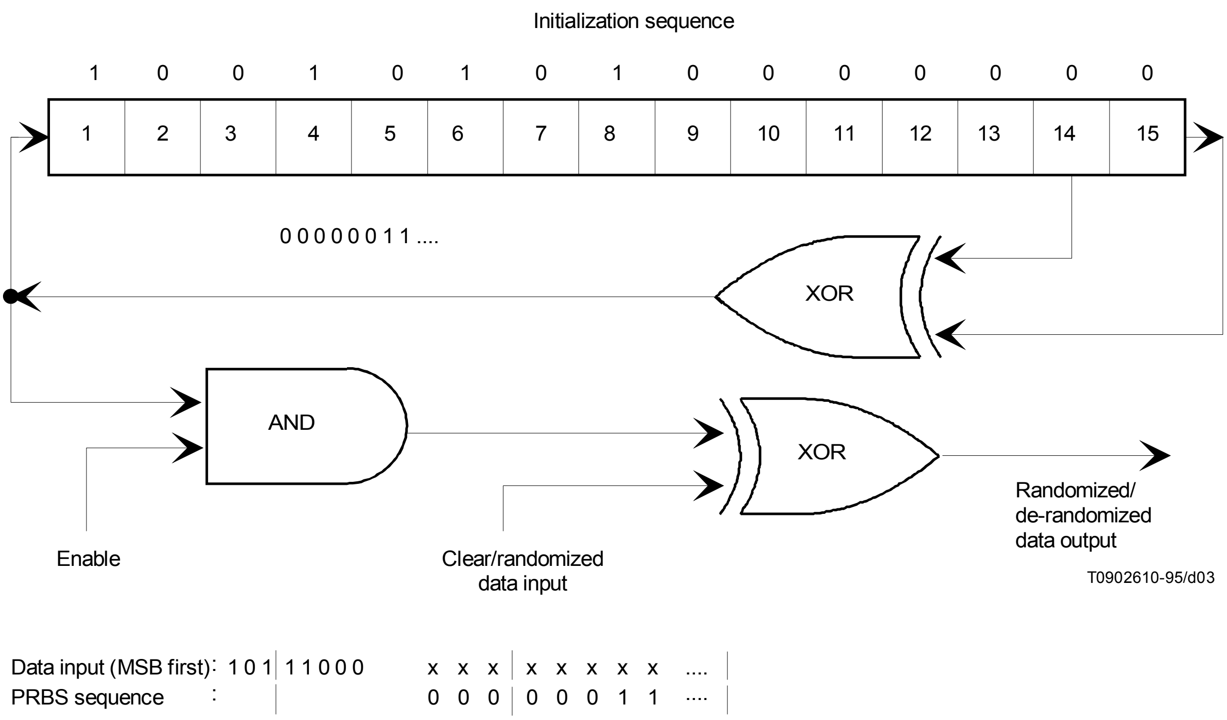


FIGURE A.3/J.83

Scrambler/descrambler schematic diagram

The first bit at the output of the PRBS generator shall be applied to the first bit of the first byte following the inverted MPEG-2 sync byte (i.e. $B8_{HEX}$). To aid other synchronization functions, during the MPEG-2 sync bytes of the subsequent 7 transport packets, the PRBS generation continues, but its output shall be disabled, leaving these bytes unrandomized. The period of the PRBS sequence shall therefore be 1503 bytes.

The randomization process shall be active also when the modulator input bit stream is non-existent, or when it is non-compliant with the MPEG-2 transport stream format (i.e. 1 sync byte + 187 packet bytes). This is to avoid the emission of an unmodulated carrier from the modulator.

A.5.2 Reed-Solomon coding

Following the energy dispersal randomization process, systematic shortened Reed-Solomon encoding shall be performed on each randomized MPEG-2 transport packet, with T = 8. This means that 8 erroneous bytes per transport packet can be corrected. This process adds 16 parity bytes to the MPEG-2 transport packet to give a codeword (204, 188).

NOTE – RS coding shall also be applied to the packet sync byte, either non-inverted (i.e. 47_{HEX}) or inverted (i.e. $B8_{HEX}$).

Code Generator Polynomial: $g(x) = (x + \lambda^0)(x + \lambda^1)(x + \lambda^2) \ldots (x + \lambda^{15})$, where $\lambda = 02_{HEX}$

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

The shortened Reed-Solomon code shall be implemented by appending 51 bytes, all set to zero, before the information bytes at the input of a (255, 239) encoder; after the coding procedure these bytes are discarded.

A.5.3 Convolutional interleaving

Following the scheme of Figure A.4, convolutional interleaving with depth I = 12 shall be applied to the error-protected packets [see Figure A.2 c)]. This results in an interleaved frame [see Figure A.2 d)].

The convolutional interleaving process shall be based on the Forney approach which is compatible with the Ramsey type III approach, with I = 12. The Interleaved Frame shall be composed of overlapping error-protected packets and shall be delimited by MPEG-2 sync bytes (preserving the periodicity of 204 bytes).

The interleaver may be composed of I = 12 branches, cyclically connected to the input byte-stream by the input switch. Each branch shall be a First In First Out (FIFO) shift register, with depth (Mj) cells (where M = 17 = N/I, N = 204 = error-protected frame length, I = 12 = interleaving depth, j = branch index). The cells of the FIFO shall contain 1 byte, and the input and output switches shall be synchronized.

For synchronization purposes, the sync bytes and the inverted sync bytes shall be always routed in the branch “0” of the interleaver (corresponding to a null delay).

NOTE – The de-interleaver is similar, in principle, to the interleaver, but the branch indexes are reversed (i.e. j = 0 corresponds to the largest delay). The de-interleaver synchronization can be carried out by routing the first recognized sync byte in the “0” branch.

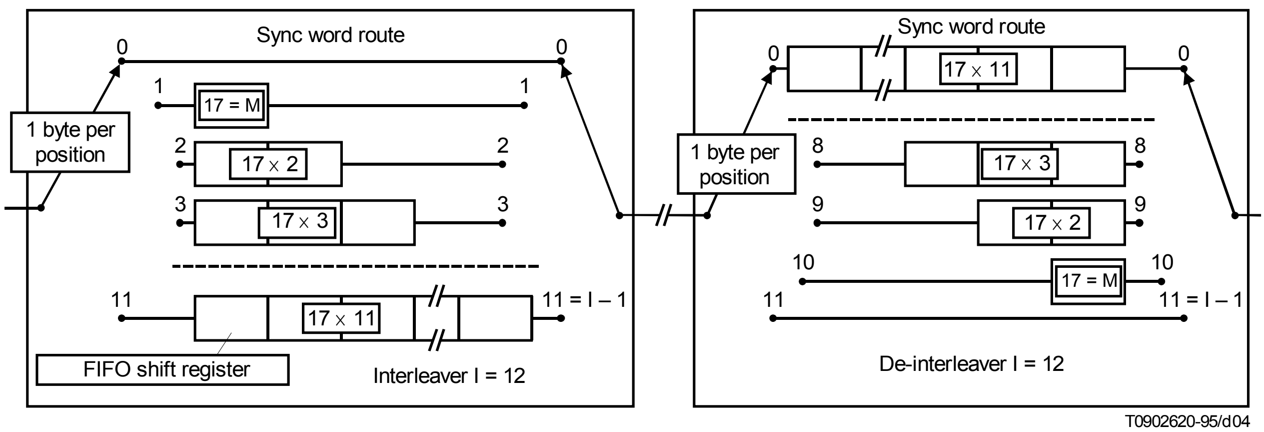


FIGURE A.4/J.83

Conceptual diagram of the convolutional interleaver and de-interleaver

A.6 Byte to symbol mapping

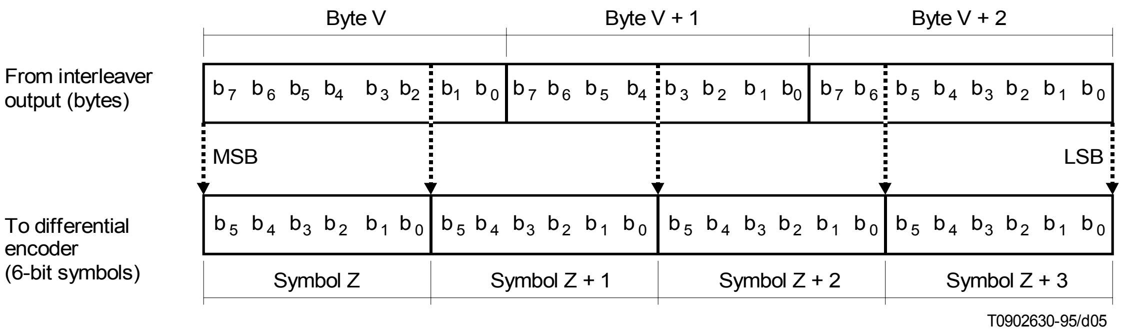
After convolutional interleaving, an exact mapping of bytes into symbols shall be performed. The mapping shall rely on the use of byte boundaries in the modulation system.

In each case, the MSB of symbol Z shall be taken from the MSB of byte V.

Correspondingly, the next significant bit of the symbol shall be taken from the next significant bit of the byte. For the case of 2^m-QAM modulation, the process shall map k bytes into n symbols, such that:

$$8\,k = n \cdot m$$

The process is illustrated for the case of 64-QAM (where m = 6, k = 3 and n = 4) in Figure A.5:



NOTES

1 b_0 shall be understood as being the Least Significant Bit (LSB) of each byte or m-tuple.

2 In this conversion, each byte results in more than one m-tuple, labelled Z, Z + 1, etc. with Z being transmitted before Z + 1.

FIGURE A.5/J.83

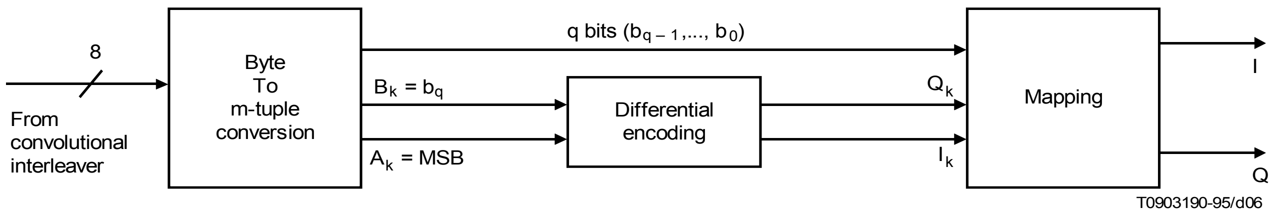
Byte to m-tuple conversion for 64-QAM

The two most significant bits of each symbol shall then be differentially coded in order to obtain a π/2 rotation-invariant QAM constellation. The differential encoding of the two MSBs shall be given by the following expression:

$$I_k = \overline{(A_k \oplus B_k)} \cdot (A_k \oplus I_{k-1}) + (A_k \oplus B_k) \cdot (A_k \oplus Q_{k-1})$$

$$Q_k = \overline{(A_k \oplus B_k)} \cdot (B_k \oplus Q_{k-1}) + (A_k \oplus B_k) \cdot (B_k \oplus I_{k-1})$$

Figure A.6 gives an example of implementation of byte to symbol conversion.



q = 2 for 16-QAM
3 for 32-QAM
4 for 64-QAM

FIGURE A.6/J.83

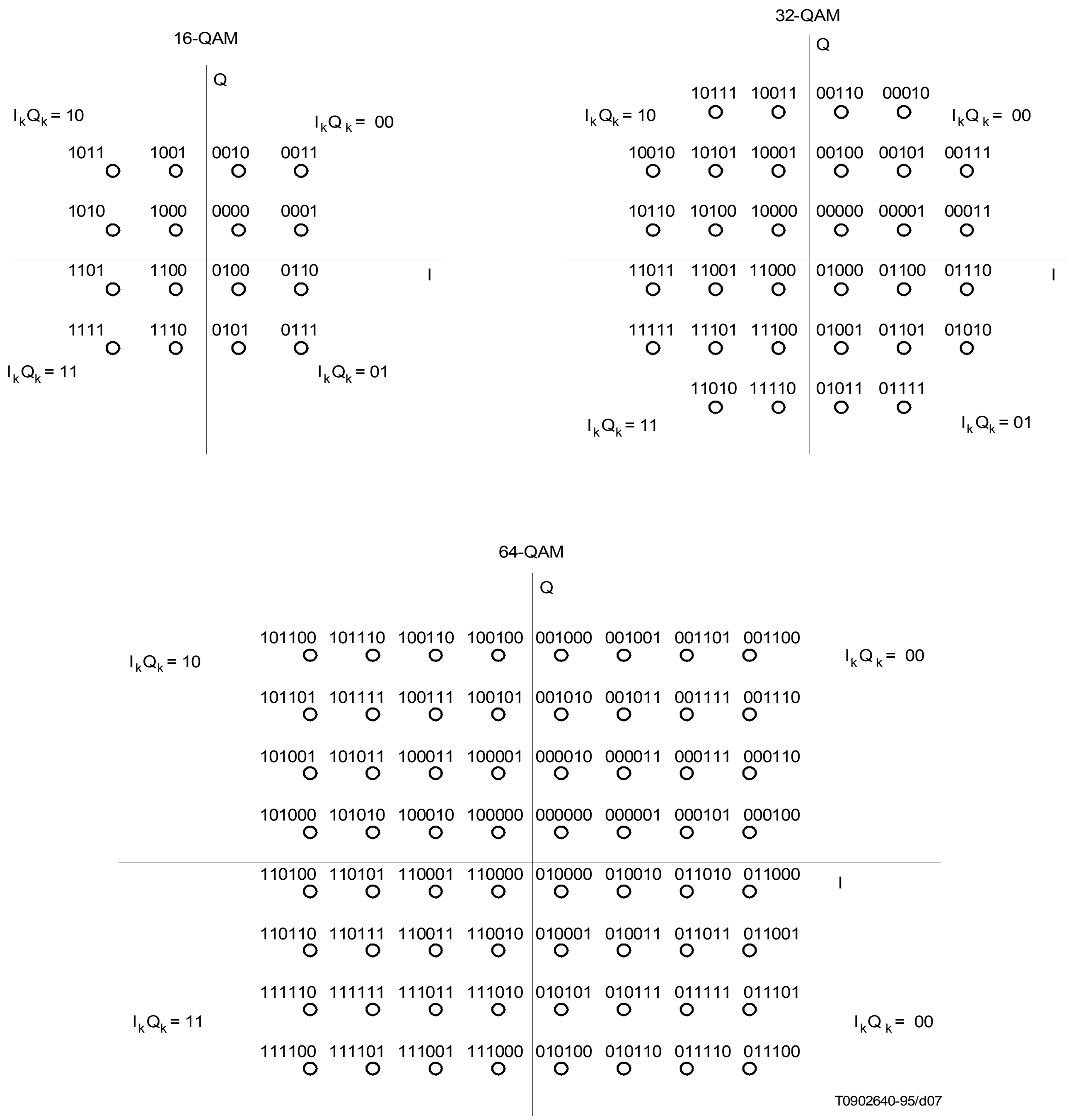
Example of an implementation of the byte to m-tuple conversion and the differential encoding of the two MSBs

A.7 Modulation

The modulation of the System shall be Quadrature Amplitude Modulation (QAM) with 16, 32, or 64 points in the constellation diagram.

The System constellation diagrams for 16-QAM, 32-QAM and 64-QAM are given in Figure A.7.

As shown in Figure A.7, the constellation points in Quadrant 1 shall be converted to Quadrants 2, 3 and 4 by changing the two MSB (i.e. I_k and Q_k) and by rotating the q LSBs according to the rule given in Table A.1.



NOTE – I_kQ_k are the two MSBs in each quadrant.

FIGURE A.7/J.83

Constellation diagrams for 16-QAM, 32-QAM and 64-QAM

TABLE A.1/J.83

Conversion of constellation points of quadrant 1 to other quadrants of the constellation diagram given in Figure A.7

Quadrant	MSBs	LSBs rotation
1	00	
2	10	$+ \pi 2$
3	11	$+ \pi$
4	01	$+ 3\pi/2$

NOTE – Receivers shall support at least 64-QAM modulation.

Prior to modulation, the I and Q signals shall be square-root raised-cosine filtered. The roll-off factor shall be 0.15.

The square-root raised cosine filter shall have a theoretical function defined by the following expression:

$$H(f) = 1 \text{ for } |f| < f_N(1-\alpha)$$

$$H(f) = \left\{\frac{1}{2} + \frac{1}{2} \sin \frac{\pi}{2 f_N}\left[\frac{f_N - |f|}{\alpha}\right]\right\}^{1/2} \text{ for } f_N(1-\alpha) \leq |f| \leq f_N(1+\alpha)$$

$$H(f) = 0 \text{ for } |f| > f_N(1+\alpha)$$

where:

$$f_N = \frac{1}{2\,T_s} = \frac{R_s}{2} \text{ is the Nyquist frequency and roll-off factor } \alpha = 0.15.$$

The transmitter filter characteristic is given in A.8.

A.8 Baseband filter characteristics

The template given in Figure A.8 shall be used as a minimum requirement for hardware implementation of the Nyquist filter. This template takes into account not only the design limitations of the digital filter, but also the artefacts coming from the analogue processing components of the System (e.g. D/A conversion, analogue filtering, etc).

The value of in-band ripple r_m in the pass-band up to $(1-\alpha)\ f_N$ as well as at the Nyquist frequency f_N shall be lower than 0.4 dB. The out-of-band rejection shall be greater than 43 dB.

The filter shall be phase-linear with the group delay ripple $\leq 0.1\ T_s$ (ns) up to f_N

where:

$$T_s = 1/R_s \text{ is the symbol period.}$$

NOTE – The values for in-band ripple and out-of-band rejection given in this annex are subject to further study.

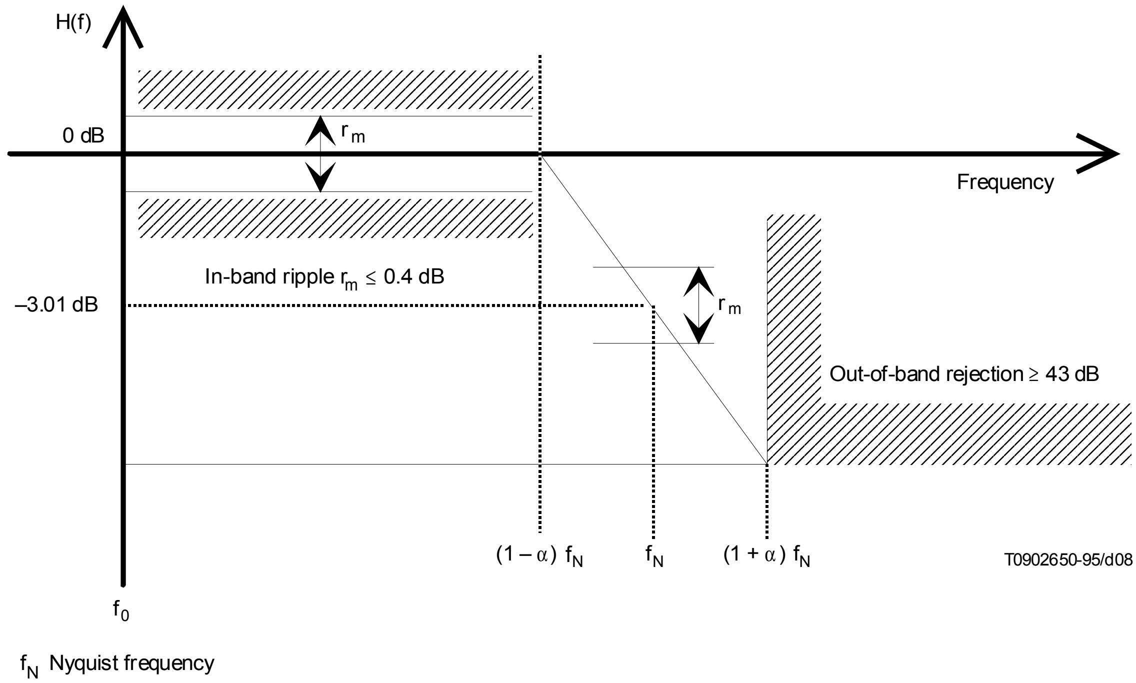


FIGURE A.8/J.83

Half-Nyquist baseband filter amplitude characteristics

Annex B

Digital multi-programme System B

(This Annex forms an integral part of this Recommendation)

B.1 Introduction

This annex describes the framing structure, channel coding and modulation for digital multi-programme television distribution by cable. The design of the modulation, interleaving and coding is based upon testing and characterization of cable systems in North America. The modulation is Quadrature Amplitude Modulation with a 64 point signal constellation (64-QAM), and the QAM symbol rate and occupied bandwidth are optimized for a 6 MHz channel plan. The Forward Error Correction (FEC) is based on a concatenated coding approach that produces high coding gain at moderate complexity and overhead. The system FEC is optimized for quasi-error-free operation at a threshold output error event rate of one error event per 15 minutes.

The system also allows for further evolution to higher and lower order QAM constellations. Appropriate modifications to the forward error correction coding and to the QAM symbol mapping are currently under study, e.g. 256-QAM.

B.2 Cable system concept

Channel coding and transmission are specific to a particular medium or communication channel. The expected channel error statistics and distortion characteristics are critical in determining the appropriate error correction and demodulation. The cable channel, including fibre trunking, is primarily regarded as a bandwidth-limited linear channel, with a balance combination of white noise, interference, and multi-path distortion. The Quadrature Amplitude Modulation (QAM) technique used, together with adaptive equalization and concatenated coding is well suited to this application and channel.

The basic layered block diagram of cable transmission processing is shown in Figure B.1.

The following subclauses define these layers from the “outside” in, and from the perspective of the transmit side.

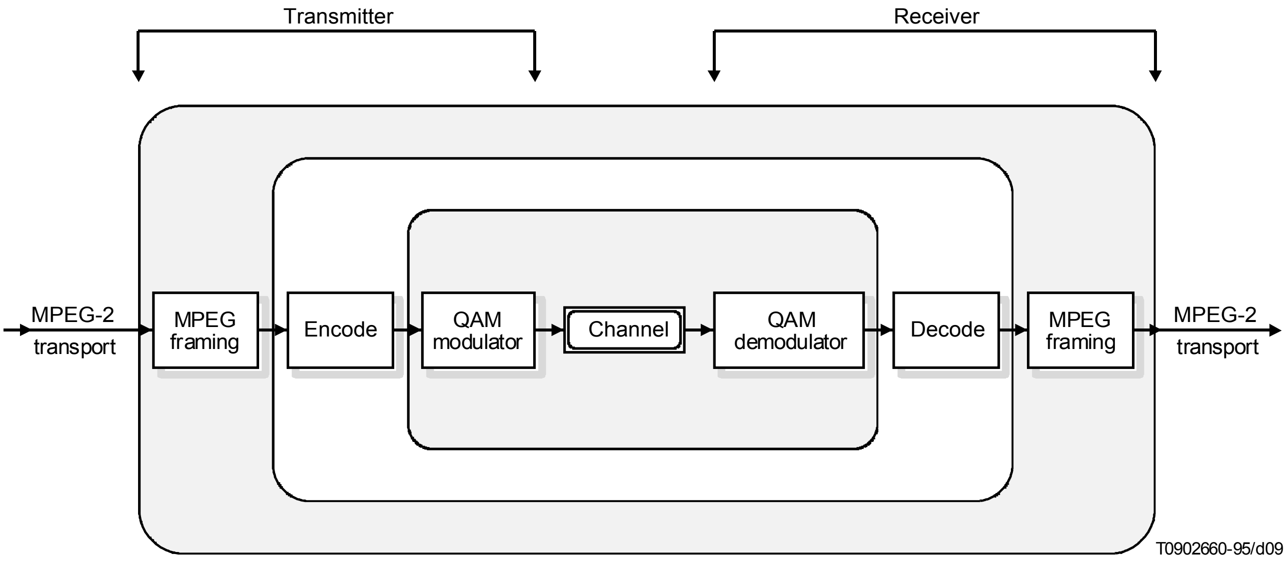


FIGURE B.1/J.83

Cable transmission block diagram

B.3 MPEG-2 transport layer

The MPEG-2 transport layer is defined in Reference [2]. The transport layer for MPEG-2 data is comprised of packets having 188 bytes, with one byte for synchronization purposes, three bytes of header containing service identification, scrambling and control information, followed by 184 bytes of MPEG-2 or auxiliary data.

B.4 MPEG transport framing

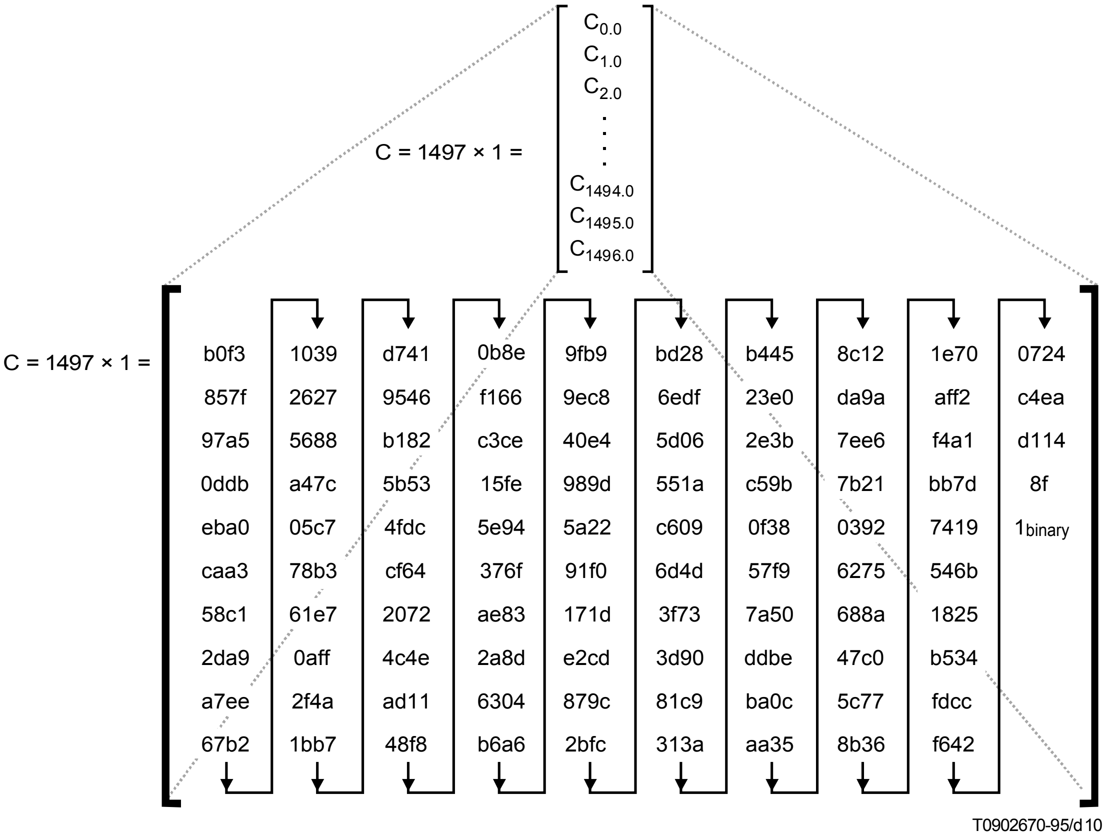
The MPEG transport framing is the outermost layer of processing. This processing block receives an MPEG-2 transport data stream consisting of a continuous stream of fixed length 188 byte packets. This data stream is transmitted in serial fashion, MSB first. The first byte of a packet is specified to be sync byte having a value of 47_{HEX}.

The sync byte is intended to facilitate packet delineation at a decoder. The cable transmission system has incorporated an additional layer of processing to make use of the information bearing capacity of this sync byte. A parity checksum is substituted for this sync byte, supplying improved packet delineation functionality, and error detection capability independent of the FEC layer.

The parity checksum is computed over the adjacent 187 bytes, which constitute the immediately preceding MPEG-2 packet contents (minus sync byte). It is then possible to support simultaneous packet synchronization and error detection. The decoder computes a sliding checksum on the serial data stream, using the detection of a valid code word to detect start of packet. Once a locked alignment condition is established, the absence of a valid code word at the expected location will indicate a packet error. The error flag of the previous packet can then be set. As the data is passed out of the decoder front end, the normal sync word can be re-inserted in place of the checksum to provide a standard MPEG-2 data stream.

A parity check matrix is used by the decoder to identify a valid checksum. The code has been designed such that when the appropriate 188 bytes of bitstream (including the checksum) are multiplied against the parity check matrix, a positive match is indicated when the calculated product produces an 47_{HEX} result. Each of the 8 columns of the parity check matrix “P” includes a 1497 bit vector, hereafter referred to as “C”. This vector is defined in Figure B.2.

Proceeding from the leftmost column of the matrix “P”, the 1497-bit column “C” is duplicated in subsequent columns of the matrix “P”, shifted down by one bit position. The bit positions unoccupied by the column data are filled with zeros, as illustrated in Figure B.3.



All entries are in hexadecimal format except where otherwise noted

"C" Column Vector

FIGURE B.2/J.83

"C" column vector (replicated inside the parity check matrix)

Note that the checksum is calculated based on the previous 187 bytes and not the 187 bytes yet to be received by the MPEG-2 sync decoder. This is in contrast to the conventional notion of an MPEG packet structure, in that the sync byte is usually described as the first byte of a received packet.

The received vector "R" is the MPEG-2 data consisting of 187 bytes followed by the checksum byte, yielding a total of 1504 bits. This "R" vector is multiplied (modulo 2) by the parity check "P" matrix, yielding an "S" vector whose length is 8-bits, as illustrated in Figure B.4.

A valid checksum is indicated when S = [0100, 0111] = 47_{HEX}.

Note that this layered approach supports the carriage of transport formats other than MPEG-2 transport. The framing section would be replaced with one appropriate to the transport, and all other portions of this specification (modulation, coding, interleaving) would be directly applicable.

B.5 Forward error correction

The Forward Error Correction (FEC) definition is composed of four processing layers. See Figure B.5.

The FEC section uses various types of error correcting algorithms and de-interleaving techniques to transport data reliably over the cable channel.

- Reed-Solomon (RS) coding – Provides block encoding and decoding to correct up to three symbols within an RS block.
- Interleaving – Evenly disperses the symbols, protecting against a burst of symbol errors from being sent to the RS decoder.

- Randomization – Randomizes the data on the channel to allow effective QAM demodulator synchronization.
- Convolutional coding – Provides convolutional encoding and soft decision trellis decoding of random channel errors.

The following subclauses define these 4 layers.

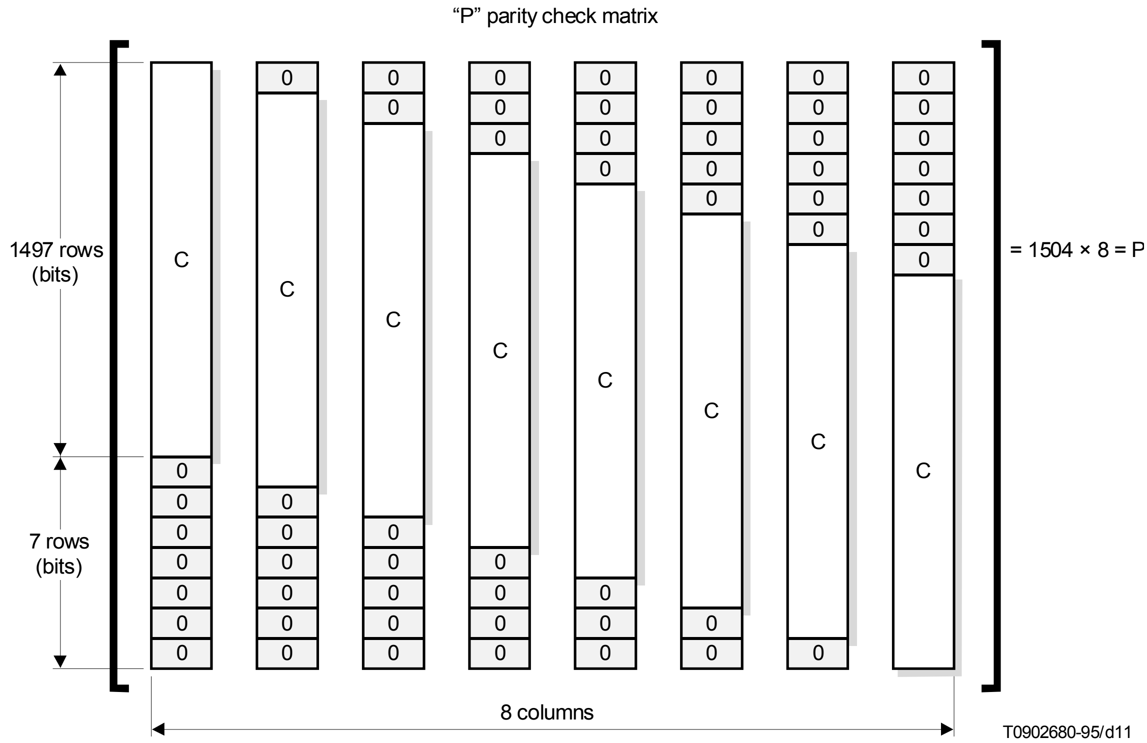


FIGURE B.3/J.83

Structure of the parity check matrix "P"

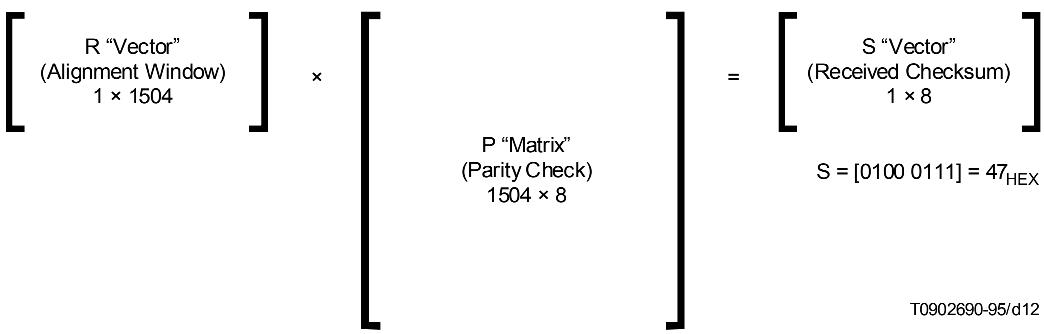


FIGURE B.4/J.83

Received MPEG-2 vector and parity check matrix multiplication

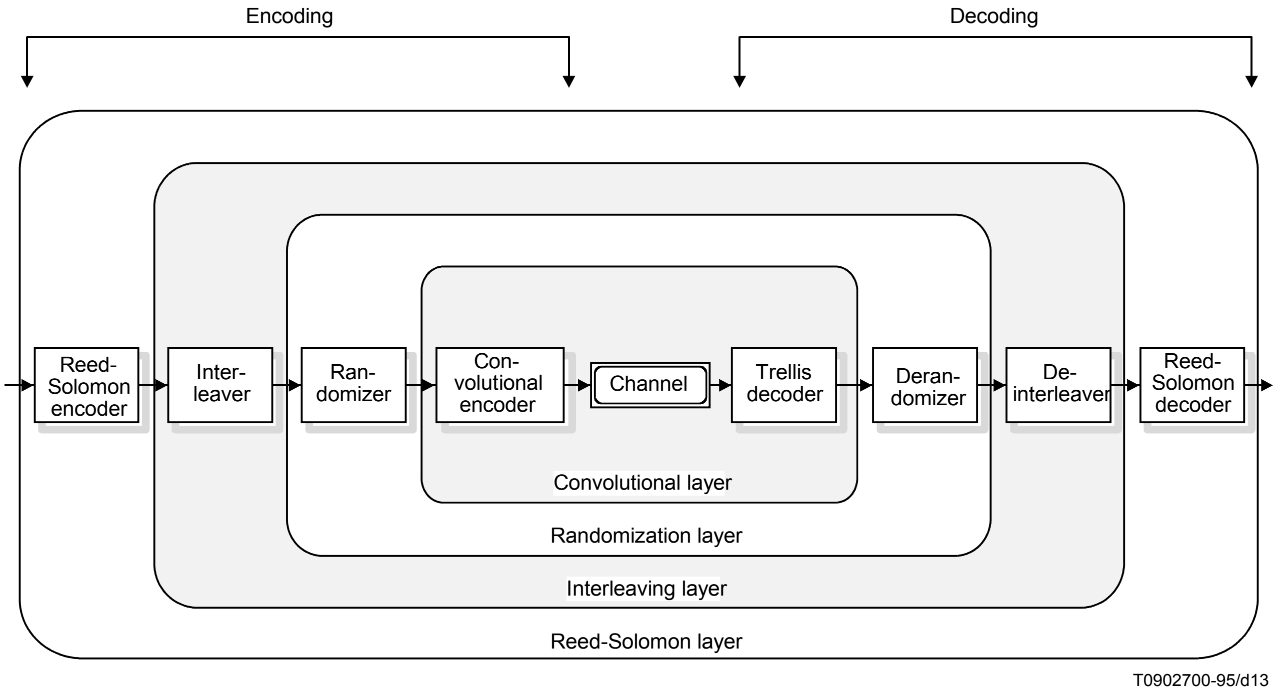


FIGURE B.5/J.83

Layers of processing in the FEC

B.5.1 Reed-Solomon coding

An FEC frame consists of a six 7-bit symbol sync header followed by 60 RS blocks, with each block containing 128 symbols. An RS symbol consists of 7-bits. Thus, there is a total of 53 802 bits in an FEC frame.

The MPEG-2 transport stream shall be RS coded with a code of (128, 122) as shown in Figure B.6.

Six symbols of the 128 symbols in an RS block are parity symbols, used to correct up to 3 symbol errors ($t = 3$) within each block of the 122 symbols (896 bits).

The Galois Field (128) is based on the primitive polynomial:

$$x^7 + x^3 + 1$$

The extended RS code uses the following generating polynomial:

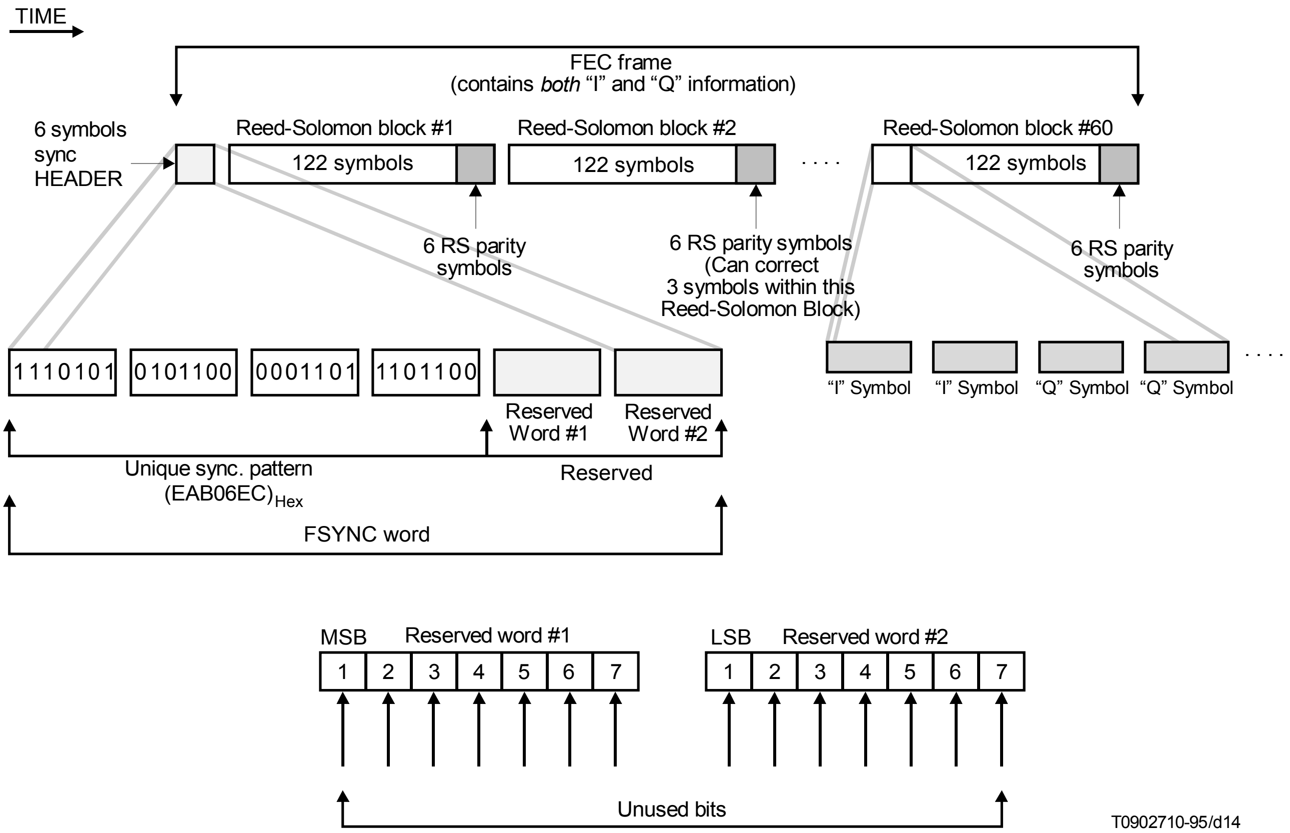
$$g(x) = (x + \alpha)(x + \alpha^2)(x + \alpha^3)(x + \alpha^4)(x + \alpha^5)$$
$$g(x) = x^5 + \alpha^{52}x^4 + \alpha^{116}x^3 + \alpha^{119}x^2 + \alpha^{61}x + \alpha^{15}$$

which is used to compute the first 5 parity symbols of the code. The sixth extended parity symbol is obtained by evaluating the 127 symbol codeword as shown below:

$$c(x) = c_0 + c_1x + c_2x^2 + \ldots + c_{126}x^{126}$$

at the point α^6, where c_i denotes the i^{th} codeword symbol. Thus

$$c(\alpha^6) = c_0 + c_1\alpha^6 + c_2\alpha^{12} + \ldots + c_{126}\alpha^{756}$$



NOTE – A symbol consists of 7 bits.

FIGURE B.6/J.83

Frame packet format

The 122 data symbols are also simultaneously sent to the transmission channel. After the 122 data symbols have been encoded, 6 parity symbols are shifted out to the transmission channel. The codewords are transmitted in ascending symbol order, MSB first.

The first 4 symbols of the FSYNC word contain the 28-bit “unique” synchronization pattern (1110101 0101100 0001101 110110) or $(75\ 2C\ 0D\ 6C)_{HEX}$. It will be inserted by the encoder and shall be detected at the decoder. The decoder circuits search for this pattern and determine the location of the frame end when it is found. The remaining 2 symbols are reserved for future applications.

NOTE – There is no synchronization relationship between the transmitted RS block and MPEG Transport Stream packets. MPEG-2 synchronization is independent of RS frame synchronization maintaining a clean distinction between these communication systems layers.

B.5.2 Interleaving

Interleaving is included in the modem between the RS block coding and the randomizer to enable the correction of burst noise induced errors. In the absence of all other impairments, the burst tolerance is 80 µsec. To accomplish this, and to account for some error propagation from the trellis decoder, the interleaving depth has been set at 128 RS symbols.

Convolutional interleaving is illustrated in Figure B.7. The interleaving commutator position increments at RS symbol frequency, with a single symbol output from each position. The first interleaver path has zero delay, the second has a single symbol period of delay, the third two symbol periods of delay, and so on, up to the 128th path which has 127 symbol periods of delay. This is reversed for the de-interleaver in the cable decoder such that the net delay of each RS symbol is the same through the interleaver and de-interleaver. Burst noise in the channel causes a series of incorrect symbols. These are spread over many RS blocks by the de-interleaver such that the resultant symbol errors per block are within the range of the RS decoder correction capability.

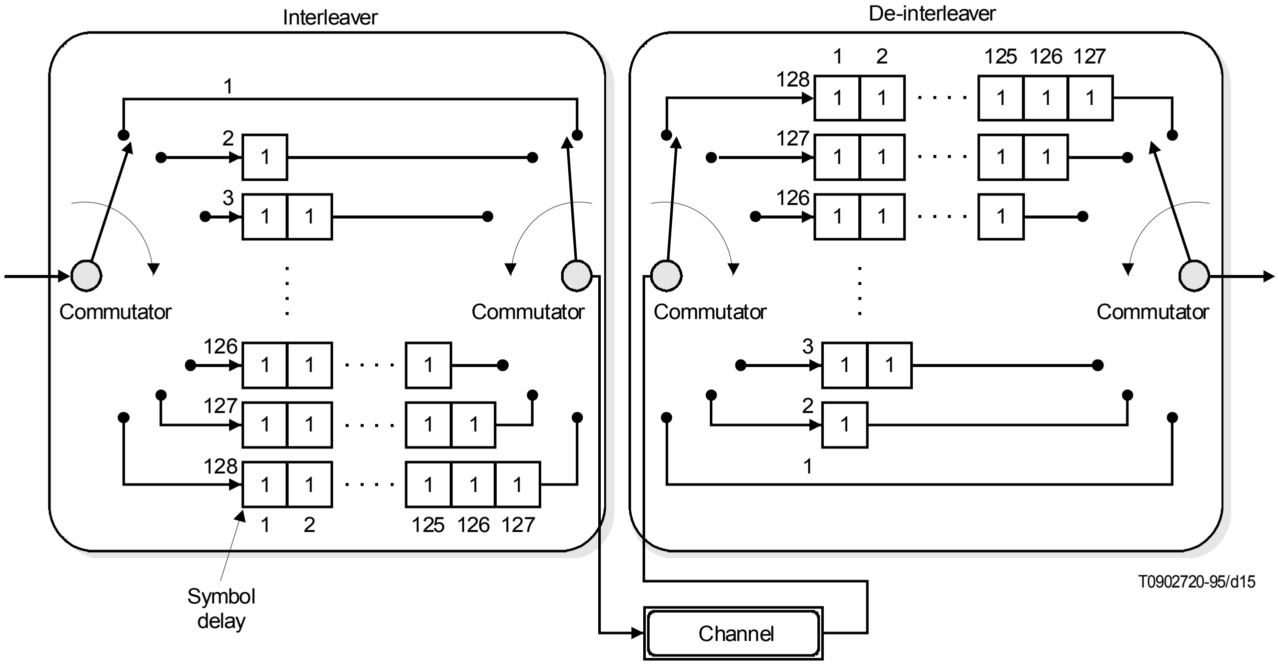


FIGURE B.7/J.83

Interleaving functional block diagram

B.5.3 Frame header insertion

The frame header inserter inserts the 6 RS header symbols at the beginning of a FEC frame as shown in Figure B.6. This insertion occurs after the interleaver. The frame sync pattern inside the header symbols is used for synchronizing the FEC frame in the receiver. The block and symbol structure is aligned with the beginning of the frame. The sync pattern is designed to have low auto correlation.

B.5.4 Randomization

The randomizer is the third layer of processing in the FEC block diagram. The randomizer provides for even distribution of the symbols in the constellation, which enables the modem to maintain proper lock. The randomizer adds a Pseudo-random Noise (PN) sequence to the transmitted signal to assure a random transmitted sequence.

The randomizer is initialized during the FEC frame header symbols, and is enabled immediately after these 6 symbols. Thus the header itself is not randomized. Initialization is defined as preloading to the "all ones" state, for the randomizer structure shown below.

The randomizer uses a linear feedback shift register specified by a GF(2^7) trinomial. This polynomial has only one non-zero non-unit coefficient, and is defined as follows:

$$f(x) = x^3 + x + \alpha^3$$

The randomizer structure is shown in Figure B.8.

B.5.5 Trellis coded modulation

As part of the concatenated coding scheme, trellis coding is employed for the inner code. It allows the introduction of redundancy to improve the SNR by increasing the symbol constellation without increasing the symbol rate. As such, it is more properly termed "trellis coded modulation." A block diagram for the trellis coded modulator is shown in Figure B.9.

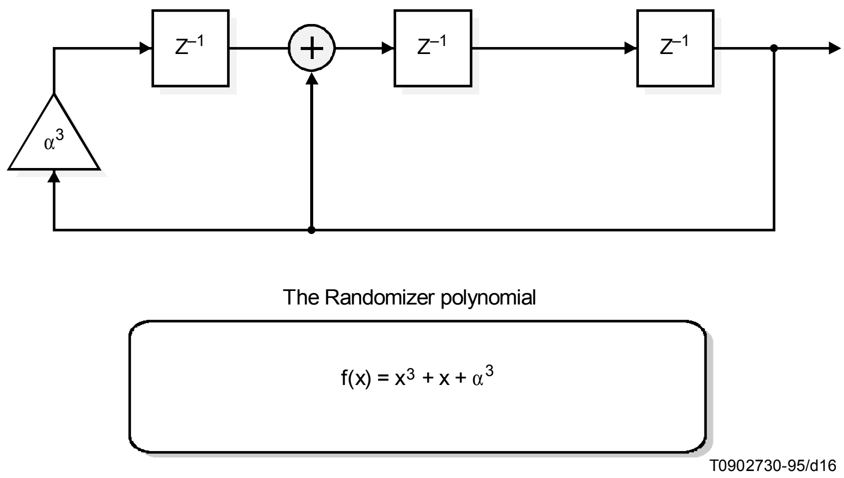


FIGURE B.8/J.83

Randomizer (7-bit byte scrambler)

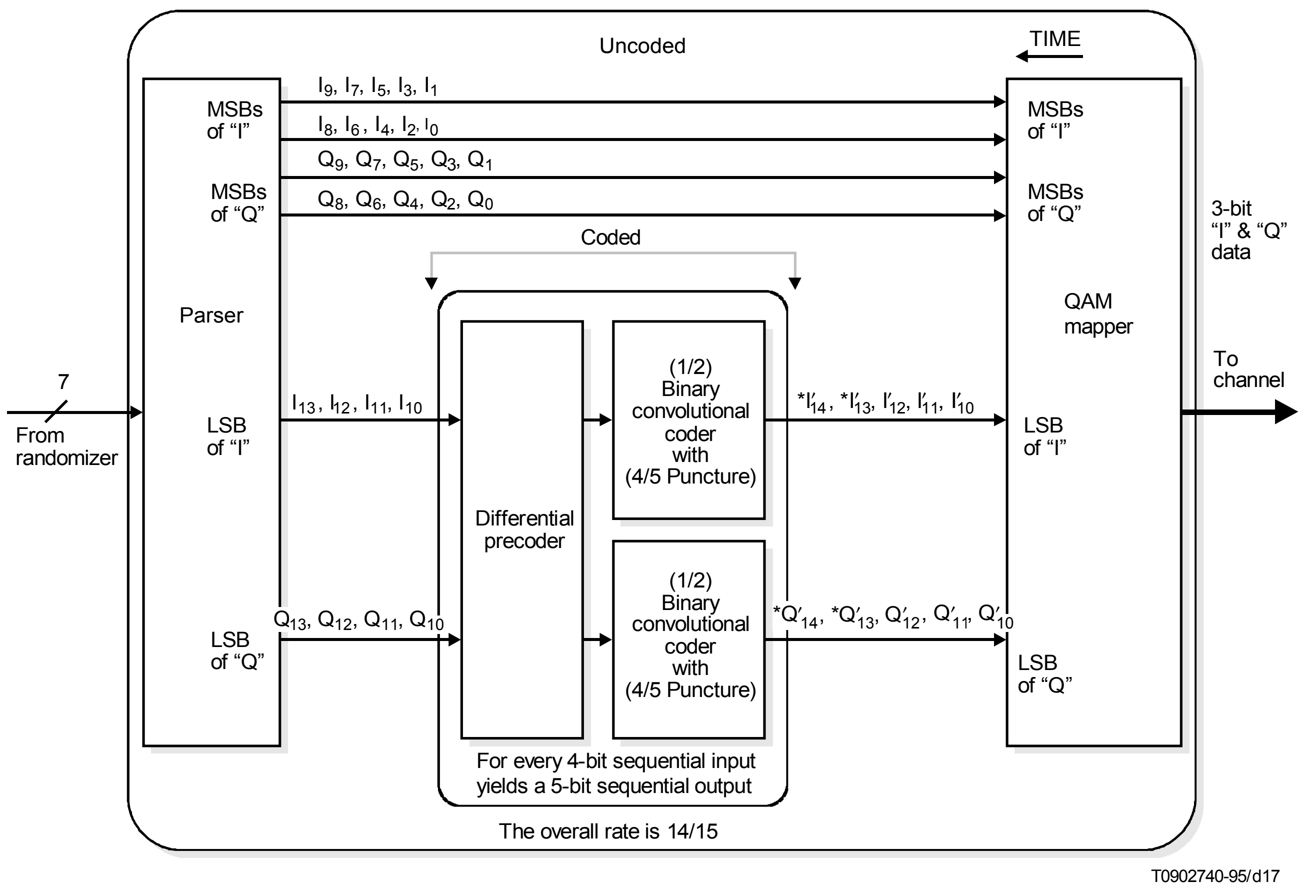


FIGURE B.9/J.83

Trellis coded modulator block diagram

The input to the trellis coded modulator is a sequence of 7-bit symbols, which are parsed into pairs of "I" symbols, and "Q" symbols, as illustrated in Figure B.9. The total of the combined "I" and "Q" pairs is 28 bits. This combined dual "I" and "Q" is further divided into bits into two groups: two upper or MSB uncoded bit streams and one lower or LSB coded bit stream. Figure B.10 shows more detail of the data flow, especially for the "I" processing.

The trellis coded modulator includes a punctured binary rate 1/2 binary convolutional encoder that is used to introduce the redundancy in the LSBs of the "I" and "Q" symbols. Coding only the LSBs of "I" and "Q" provides for appropriate SNR gain. The convolutional encoder is a 16-state non-systematic 1/2 rate encoder with the generator:

$$G1 = 010\ 101,\ G2 = 011\ 111\ (25{,}37_{\text{octal}})$$

or equivalently the generator matrix:

$$[1 \oplus D^2 \oplus D^4, 1 \oplus D \oplus D^2 \oplus D^3 \oplus D^4].$$

NOTE – "D" is used to represent the delay element "z^{-1}".

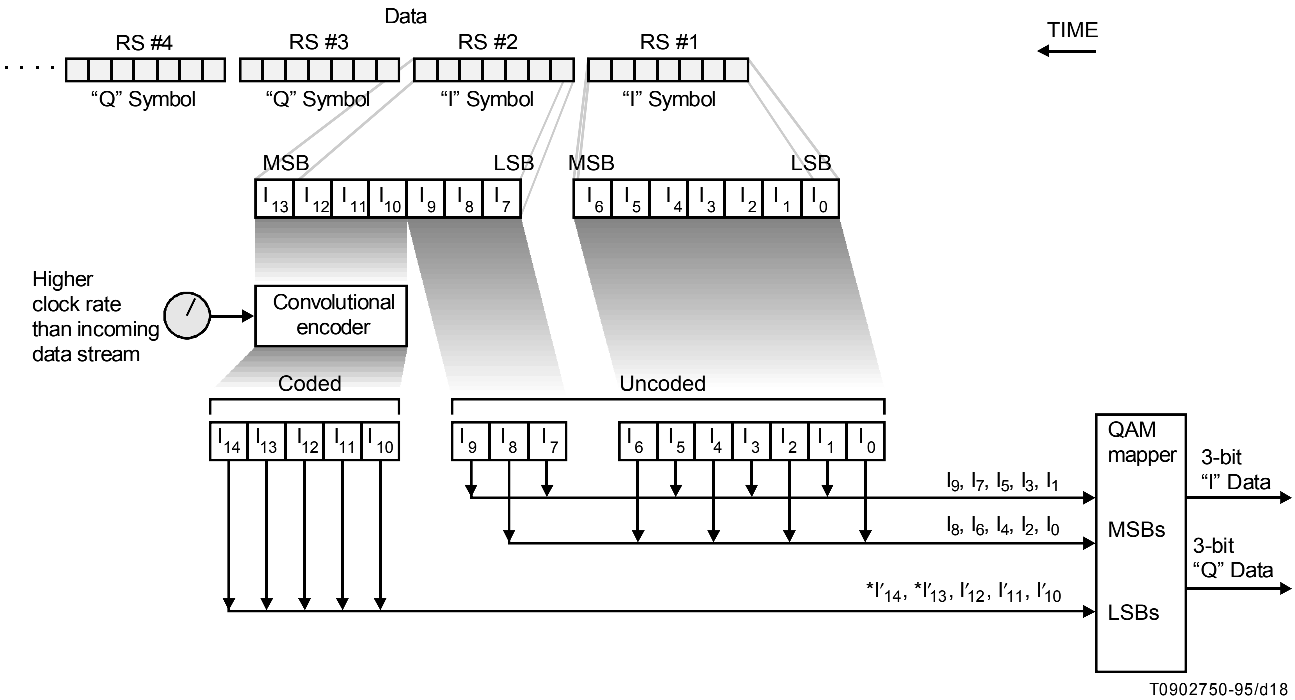
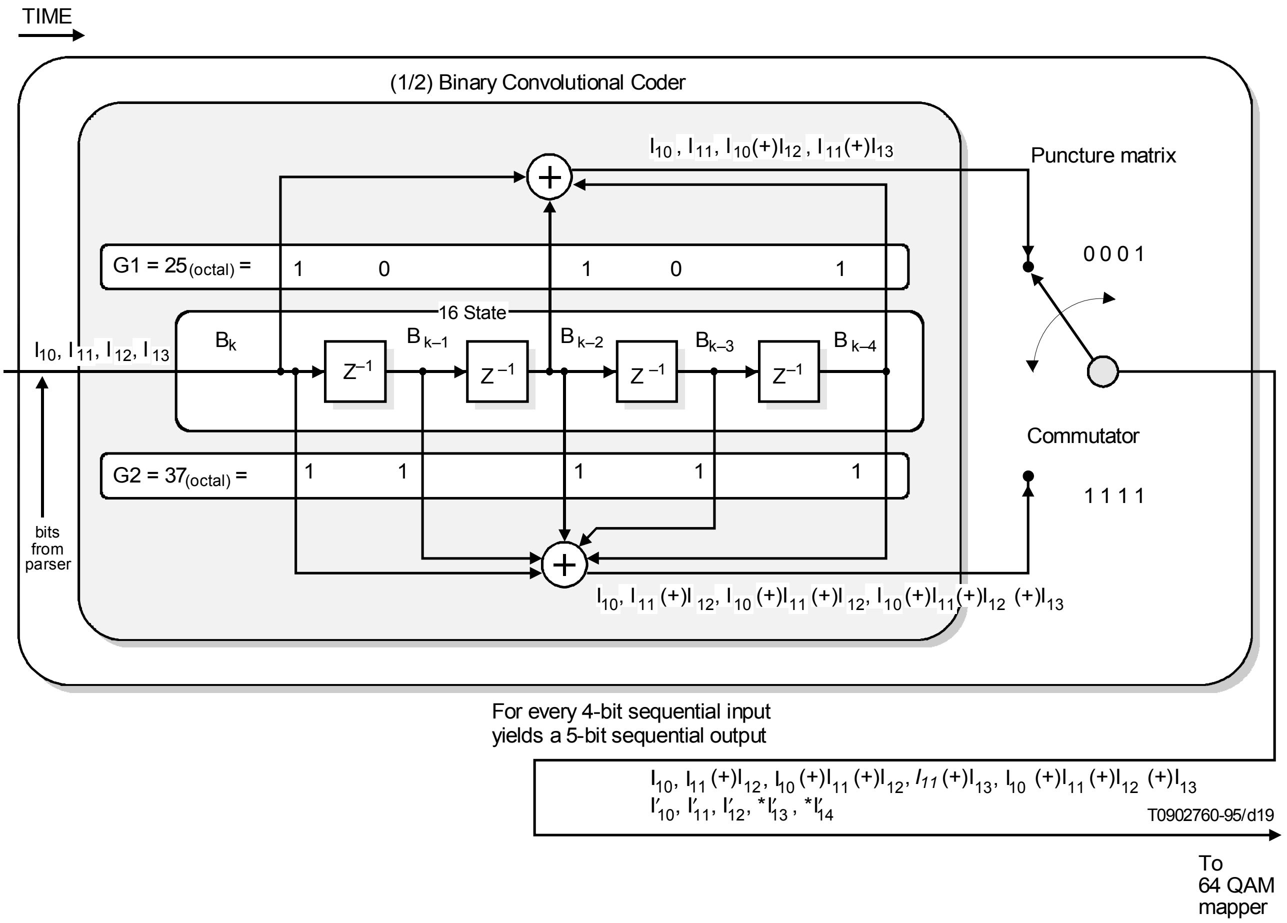


FIGURE B.10/J.83

Trellis coded modulator data flow for "I" data

The outputs of the encoder are fed into a punctured matrix: 0001 1111 ("0" denotes NO transmission, "1" denotes transmission), which produces a single serial bitstream. The puncture matrix essentially converts the rate 1/2 encoder to rate 4/5. The internal structure of the punctured encoder is illustrated in Figure B.11.

For every two Reed-Solomon symbols consisting of 14-bits, 4-bits are coded by the punctured encoder, producing 5 coded bits. Ten bits are not coded, therefore, yielding a total output of 15-bits. Thus, the overall trellis coded modulation yields a 14/15 rate.



Binary convolutional coder structure:

1) 16 state
2) 1/2 binary convolutional coder
3) Generating code: 010101, 011111 $(25, 37)_{octal}$
   or Generating Matrix of $[1(+)D^2 (+)D^4, 1(+)D(+)D^2(+)D^3(+)D^4]$ (Note 3)
4) Punctured matrix 0001 1111

NOTES

1 0 Denotes NO transmission
1 Denotes transmission.

2 (+) Denotes XOR operation.

3 D equal to Z^{-1}.

FIGURE B.11/J.83

Punctured convolutional encoder

The differential precoder, shown in Figure B.12, performs the π/2 rotationally invariant trellis coding. The key for robust modem designs is to have very fast recovery. Without rotational invariant design, a carrier timing slip will cause a major resynchronization of the FEC, causing a burst of errors at the FEC output.

The differential precoder allows the information to be carried by the change in phase, rather than by the absolute phase. The third and the sixth bits of the 6-bit symbols are differentially encoded. As illustrated in the shaded areas in Figure B.13, if the third and the sixth bits are masked out, the 90° rotational invariance of the remaining 4 bits is inherent in the symbol constellation.

The QAM mapper receives the coded and uncoded 3-bit "I" and "Q". It uses these bits to address a look-up table which produces the 6-bit constellation symbol. The 6-bit constellation symbol is then sent to the 64-QAM modem where the signal constellation illustrated in Figure B.13 is generated.

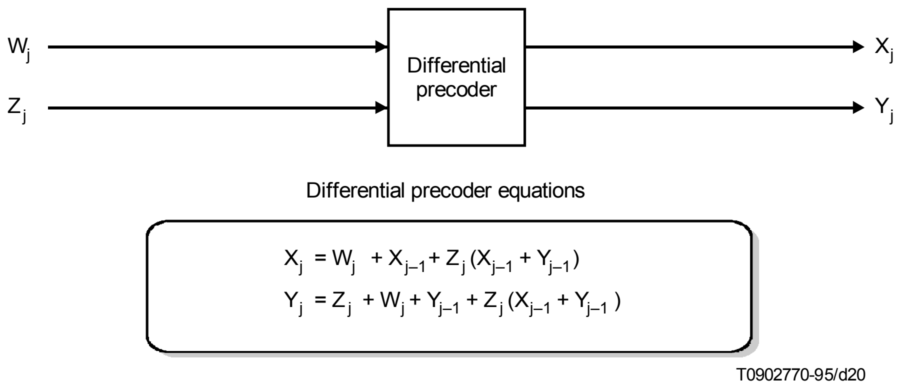


FIGURE B.12/J.83

Differential precoder

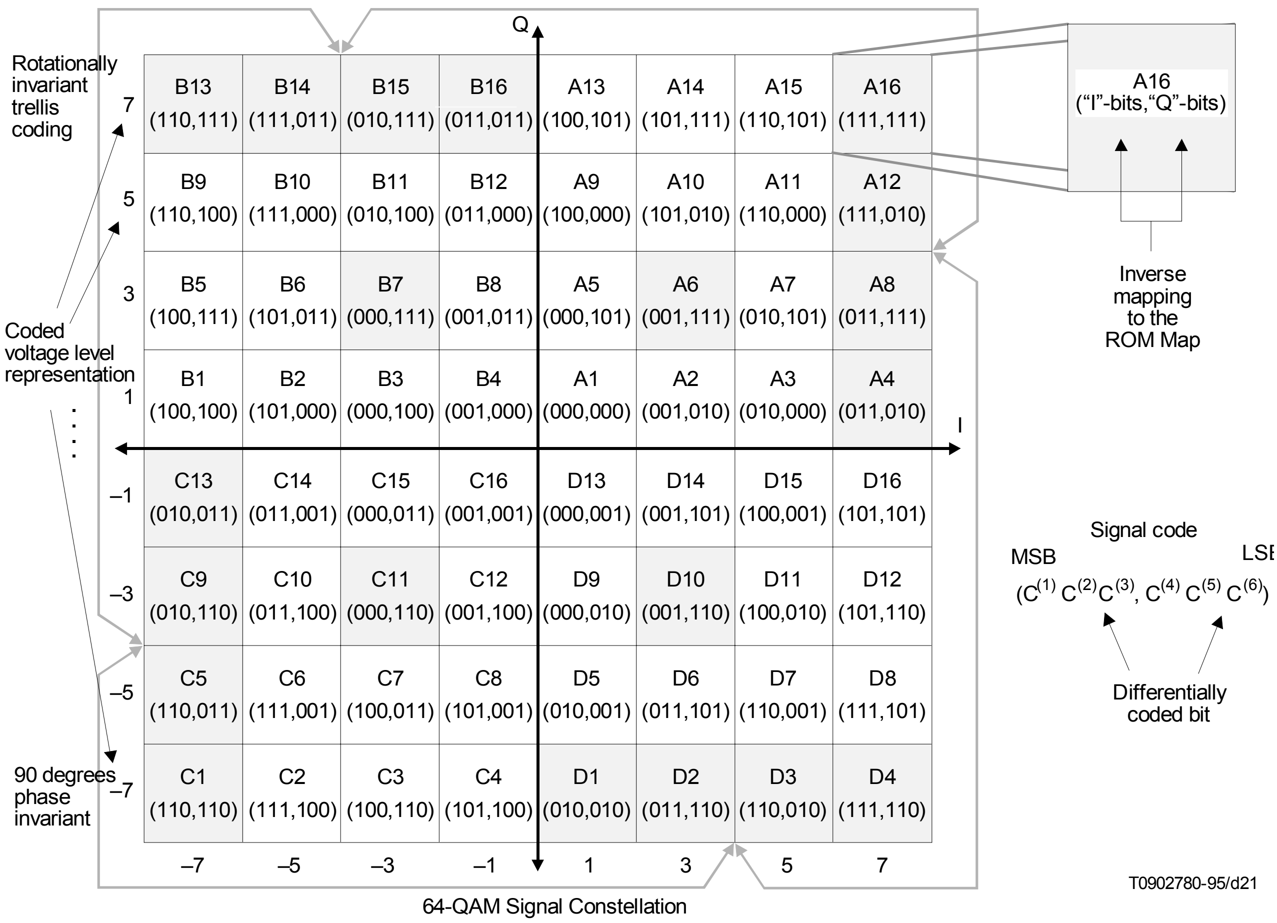


FIGURE B.13/J.83

QAM constellation

The alphanumeric code above the 6 binary bits is a code to help map the symbols. For example, an input of “I” = 001 and “Q” = 111 would yield an output of “I” = 001 and “Q” = 001, with an alphanumeric code A6. In Figure B.13, the A6 code would be mapped to the “I” = 3 and “Q” = 3 of the 64-QAM signal constellation.

B.6 Modulation and demodulation

B.6.1 QAM characteristics

The cable transmission format is summarized in Table B.1.

TABLE B.1/J.83

Cable transmission format

Parameter	Format
Modulation	64-QAM, rotationally-invariant coding
Symbol size	6 bits, 3 bits for “I” and 3 bits for “Q” dimension
Transmission band	54 to 860 MHz
Channel spacing (BW)	6 MHz (Note)
Symbol rate	5.056944 Msps ±€3 ppm (Note)
Information bit rate	26.97035 Mbps ±€3 ppm (Note)
Frequency response	Square-root raised-cosine filter (Roll-off = 0.18) (Note)
NOTE – These values are specific to 6 MHz channel spacing. Additional sets of values for differing channel spacing are under study.	

B.6.2 QAM modulator RF output

The 64-QAM modulator RF output specifications are shown in Table B.2

TABLE B.2/J.83

64 QAM modulator RF output

Parameter	Specification
I/Q phase offset	$< 1.0^{\circ}$
I/Q crosstalk	≤ -50 dB
I/Q amplitude imbalance	0.05 dB max.
I/Q timing skew	< 3.0 nsec.

Annex C

Digital multi-programme System C

(This Annex forms an integral part of this Recommendation)

C.1 Introduction

This annex describes the framing structure, channel coding and modulation of digital multi-programme system for cable distribution.

The system employs the transport multiplexing based on MPEG-2 (see Reference [2]), guaranteeing interoperability with other media such as digital broadcasting, ISDN networks or packaged media. The framing structure and the channel coding are the same as in Annex A. The modulation is 64-QAM, and the QAM symbol rate and the roll-off factor are optimized for the 6 MHz channel plan.

The field experiment using a 64-QAM receiver with an equalizer was carried out in Japan. As the results of the experiment, quasi-error-free operation was confirmed.

The system also allows for further evolution to higher order QAM constellations, and the appropriate modifications to its channel coding and symbol mapping are currently under study.

C.2 Cable system concept

The cable system shall be defined as the functional block of equipment performing the adaptation of the baseband TV signals to the cable channel characteristics.

In the cable head-end, the TV baseband signal may come from broadcasting, second distribution links, contribution links and local programme sources.

The following process shall be applied as shown in Figure C.1: System configuration.

C.2.1 Baseband interfacing and sync

This unit shall adapt the data structure to the format of the signal source. The framing structure shall be in accordance with MPEG-2 transport layer including sync bytes.

C.2.2 Sync 1 inversion and randomization

This unit shall invert the MPEG-2 Sync byte (Sync 1) every eight packets, according to the MPEG-2 framing structure, and shall randomize the data stream for spectrum shaping purposes.

C.2.3 Reed-Solomon (RS) coder

This unit shall apply a shortened Reed-Solomon (RS) code to each randomized transport packet to generate an error-protected packet. This code shall also be applied to the Sync byte itself.

C.2.4 Convolutional interleaver

This unit shall perform a depth I = 12 convolutional interleaving of the error-protected packets. The periodicity of the sync bytes shall remain unchanged.

C.2.5 Byte to m-tuple conversion

This unit shall perform a conversion of the bytes generated by the interleaver into QAM symbols.

C.2.6 Differential encoding

In order to get a rotation-invariant constellation, this unit shall apply a differential encoding of the two Most Significant Bits (MSBs) of each symbol.

C.2.7 QAM modulation and physical interface

This unit performs a square-root raised cosine filtering of the I and Q signals prior to QAM modulation. This is followed by interfacing the QAM modulated signal to the Radio Frequency (RF) cable channel.

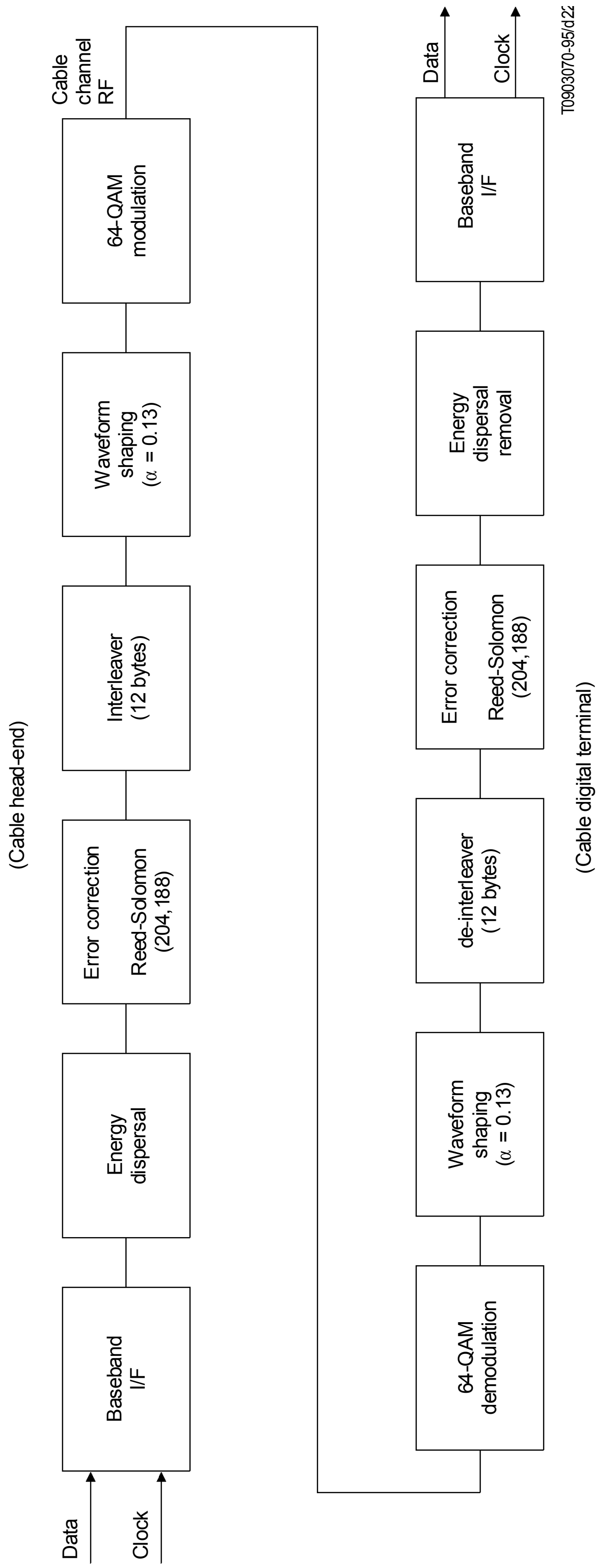


FIGURE C.1/J.83
System configuration

C.2.8 Cable receiver

A System receiver shall perform the inverse signal processing, as described for the modulation process above, in order to recover the baseband signal.

In addition, each cable receiver should install an equalizer to prevent increase of the bit-error caused by the reflection in the cable system.

C.3 MPEG-2 Transport layer

The transport layer for the digital multi-programme system is based on MPEG-2 (see Reference [2]). The transport multiplexing is performed in Transport Stream-Packet having 188 bytes, in conformance with MPEG-2.

C.4 Framing structure

The framing organization shall be based on the MPEG-2 transport packet structure. The System framing structure is shown in Figure C.2: Transmission Signal Configuration.

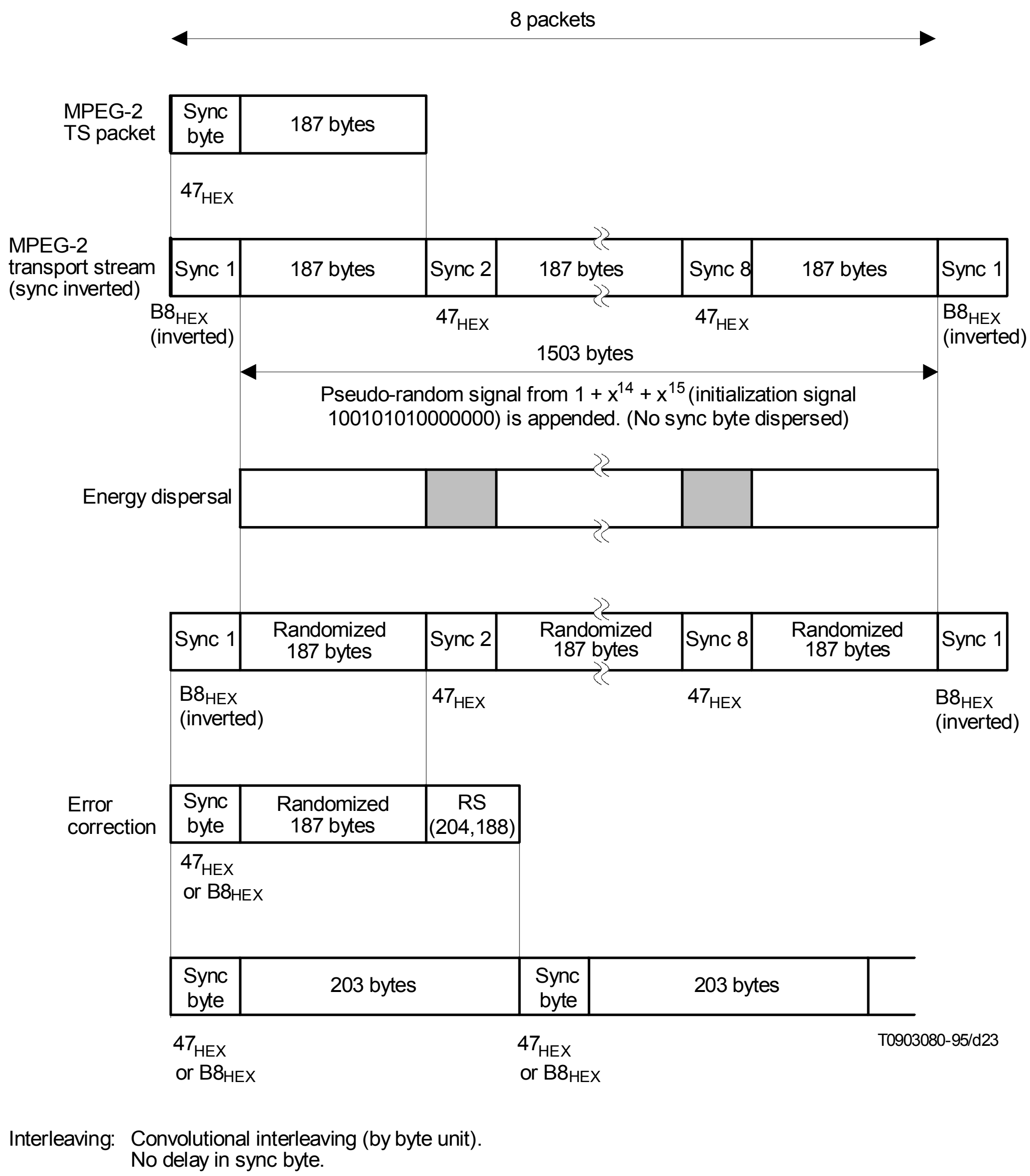


FIGURE C.2/J.83

Transmission signal configuration

C.5 Channel coding

To achieve the appropriate level of error protection required for cable transmission of digital data, a Forward Error Correction (FEC) based on Reed-Solomon encoding shall be used. Protection against burst errors shall be achieved by the use of interleaving.

C.5.1 Randomization

The System input stream shall be organized in fixed length packets (see Figure C.2), following the MPEG-2 transport multiplexer. The total packet length of the MPEG-2 transport multiplex packet is 188 bytes. This includes one sync-word byte.

In order to offer maximum compatibility with other media and to ensure adequate binary transitions for clock recovery, the data at the output of the MPEG-2 transport multiplex shall be randomized in accordance with the configuration shown in Figure C.3: Energy Dispersal Diagram.

The polynomial for the Pseudo-Random Binary Sequence (PRBS) generator shall be:

$$x^{15} + x^{14} + 1$$

Loading of the sequence "100101010000000" into the PRBS registers, as indicated in Figure C.3, shall be initiated at the start of every eight transport packets. To provide an initialization signal for the descrambler, the MPEG-2 sync byte of the first transport packet in a group of eight packets shall be bit wise inverted from 47_{HEX} to $B8_{HEX}$.

The first bit at the output of the PRBS generator shall be applied to the first bit of the first byte following the inverted MPEG-2 sync byte (i.e. $B8_{HEX}$). To aid other synchronization functions, during the MPEG-2 sync bytes of the subsequent seven transport packets, the PRBS generation continues, but its output shall be disabled, leaving these bytes unrandomized. The period of the PRBS sequence shall therefore be 1503 bytes.

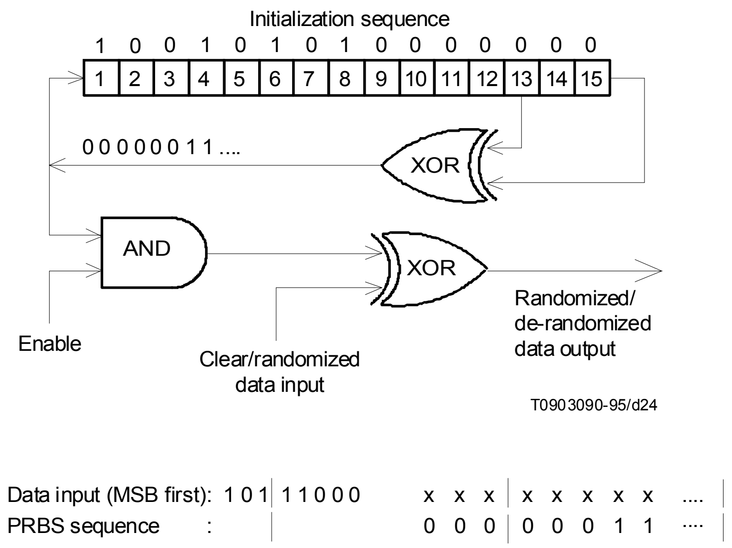


FIGURE C.3/J.83

Scrambler/descrambler schematic diagram

C.5.2 Reed-Solomon coding

The shortened Reed-Solomon (204, 188) code shall be used for the forward error correction. The Reed-Solomon coding can be organized by appending "0" of 51 bytes before the input data byte and deleting it after the coding at the general purpose of Reed-Solomon (255, 239) coding circuit.

Code Generator Polynomial:

$$g(x) = (x + \lambda^0) + (x + \lambda^1) + (x + \lambda^2) \ldots (x + \lambda^{15}), \text{where } \lambda = 02_{HEX}$$

Field Generator Polynomial:

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1$$

C.5.3 Convolutional interleaving

Following the scheme of Figure C.4, convolutional interleaving with depth I = 12 shall be applied to the error-protected packets.

The interleaver may be composed of I = 12 branches, cyclically connected to the input byte-stream by the input switch. Each branch shall be a First In First Out (FIFO) shift register, with depth (M_j) cells (where M = 17 = N/I, N = 204 = error protected frame length, I = 12 = interleaving depth, j = branch index). The cells of the FIFO shall contain one byte, and the input and output switches shall be synchronized.

For synchronization purposes, the sync bytes and the inverted sync bytes shall be always routed in the branch "0" of the interleaver (corresponding to a null delay).

NOTE – The de-interleaver is similar, in principle, to the interleaver, but the branch indexes are reversed (i.e. j = 0 corresponds to the largest delay). The de-interleaver synchronization can be carried out by routing the first recognized sync byte in the "0" branch.

C.6 Modulation

C.6.1 Byte to symbol mapping

After convolutional interleaving, an exact mapping of bytes into symbols shall be performed. The mapping shall rely upon the use of byte boundaries in the modulation system.

In each case, the MSB of symbol Z shall be taken from the MSB of byte V. Correspondingly, the next significant bit of the symbol shall be taken from the next significant bit of the byte. For the case of 2^m-QAM modulation, the process shall map k bytes into n symbols, such that;

$$8\,k = n \cdot m$$

The process is illustrated for the case of 64-QAM (when m = 6, k = 3 and n = 4) in Figure C.5.

C.6.2 Differential encoding

The two MSBs of each symbol shall then be differentially coded in order to obtain a π/2 rotation-invariant QAM constellation. The differential encoding of the two MSBs shall be given by the following expression:

$$I_k = \overline{(A_k \oplus B_k)} \cdot (A_k \oplus I_{k-1}) + (A_k \oplus B_k) \cdot (A_k \oplus Q_{k-1})$$

$$Q_k = \overline{(A_k \oplus B_k)} \cdot (B_k \oplus Q_{k-1}) + (A_k \oplus B_k) \cdot (B_k \oplus I_{k-1})$$

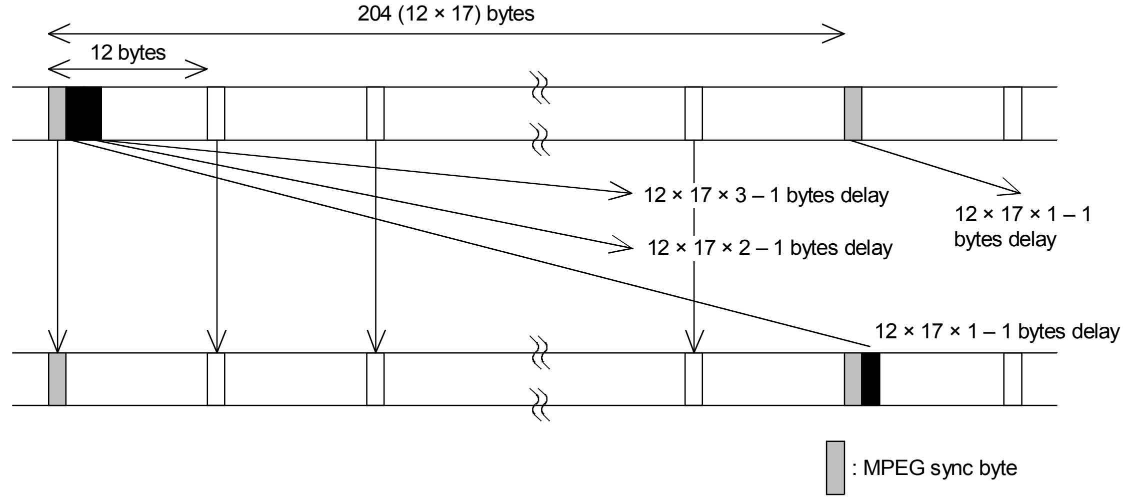
Figure C.6 gives an example of implementation of byte to symbol conversion.

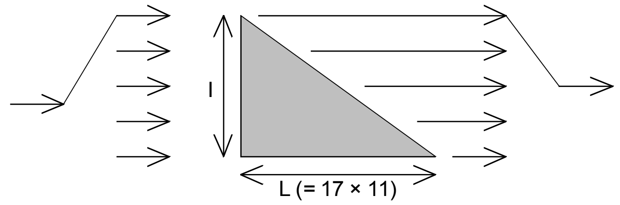
C.6.3 64-QAM constellation

The system can be adapted to 6 MHz channel spacing. The byte to modulation scheme described in this subclause is directly related to the byte to symbol mapping method given in C.6.1.

The modulation of the system shall be Quadrature Amplitude Modulation (QAM) with 64 points in the constellation chart.

The System constellation chart for 64-QAM is given in Figure C.7.



Interleaving depth	I (= 12)
Synchronization	Routing SW (Cycle I)
Required memory capacity	1/2 × I × L 

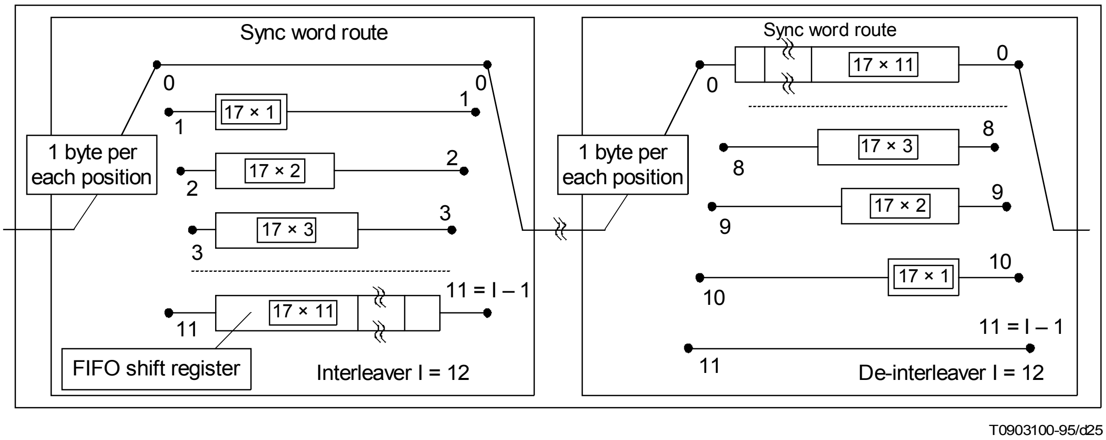
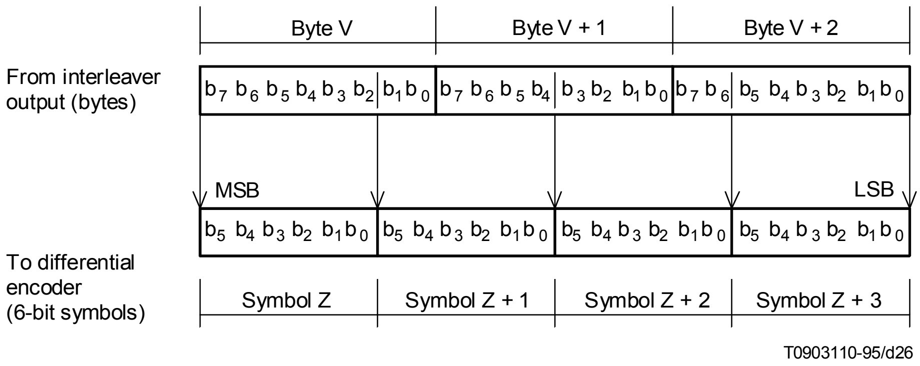


FIGURE C.4/J.83

Interleaving configuration



NOTES

1 b_0 shall be understood as being the Least Significant Bit (LSB) of each byte or m-tuple.

2 In this conversion, each byte results in more than one m-tuple, labelled Z, Z + 1, etc., with Z being transmitted before Z + 1.

FIGURE C.5/J.83

Byte to m-tuple conversion for 64-QAM

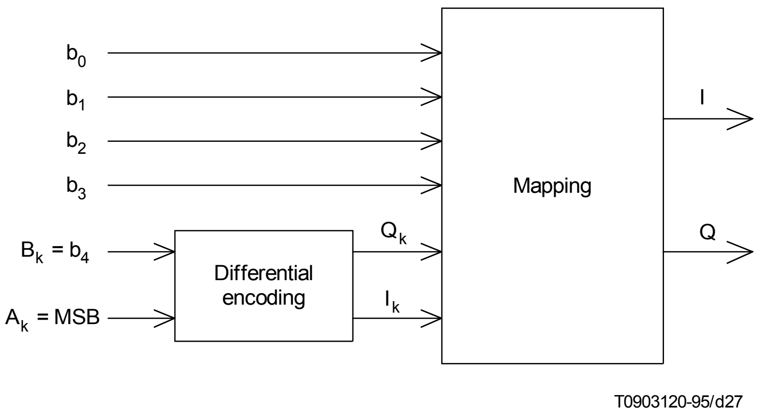


FIGURE C.6/J.83

Example of implementation of byte to symbol conversion and the differential encoding of the two MSBs

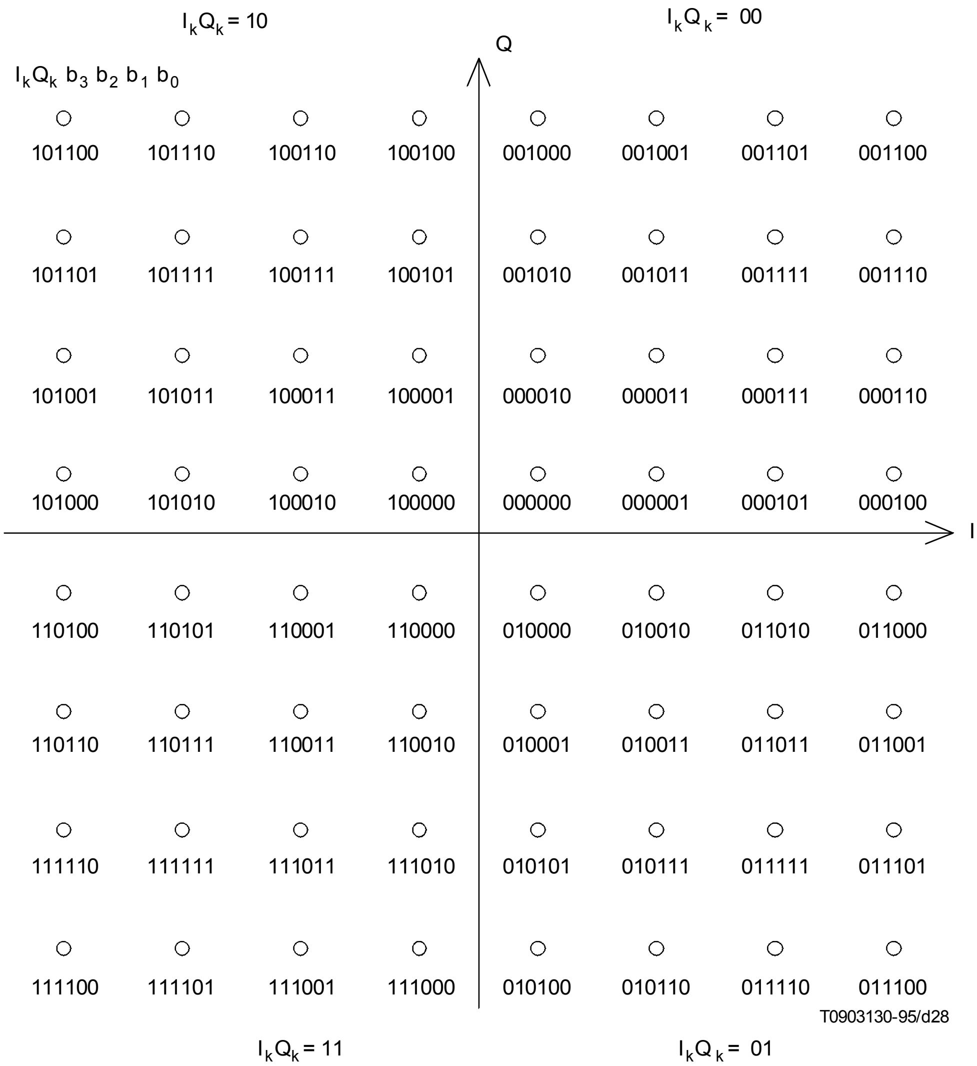


FIGURE C.7/J.83

Constellation chart for 64-QAM

C.6.4 Roll-off factor

Prior to modulation, the I and Q signals shall be square-root raised cosine filtered. The roll-off factor shall be 0.13.

The square-root raised cosine filter shall have a theoretical function defined by the following formulae:

$$H(f) = 1 \text{ for } |f| \leq f_N(1 - \alpha)$$

$$H(f) = \left[\frac{1}{2} + \frac{1}{2}\sin\frac{\pi}{2f_N}\left[\frac{f_N - |f|}{\alpha}\right]\right]^{1/2} \text{ for } f_N(1-\alpha) \leq |f| \leq f_N(1+\alpha)$$

$$H(f) = 0 \text{ for } |f| > f_N(1+\alpha),$$

where:

$$f_N = \frac{1}{2\,T_s} = \frac{R_s}{2} \text{ is the Nyquist frequency and roll-off factor } \alpha = 0.13.$$

NOTE – Transmission filter characteristics are given in the following subclause. The roll-off factor applies under the condition with adjacent channel signals interference (i.e. from TV signal etc.) and with the specified baseband filter characteristics.

C.6.5 Baseband filter characteristics

The template given in Figure C.8 shall be used a minimum requirement for hardware implementation of the Nyquist filter. This template takes into account not only the design limitations of the digital filter, but also the artifacts coming from the analogue processing components of the system (e.g. D/A conversion, analogue filtering, etc.).

The value of in-band ripple r_m in the pass-band up to $(1 – \alpha)f_N$ shall be lower than 0.4 dB. The out-band rejection shall be greater than 43 dB. The ripple r_N at the Nyquist frequency f_N shall be lower than 1.0 dB.

The filter shall be phase-linear with the group delay ripple ≤€1.0 T_s (ns) in the pass-band up to $(1 – \alpha)f_N$ and ≤€2.0 T_s (ns) at f_N

where:

$$T_S = 1/R_S \text{ is the symbol period.}$$

NOTE – The values for in-band ripple and out-of-band rejection given in this Annex are subject to the operation condition of the cable systems and may require further study.

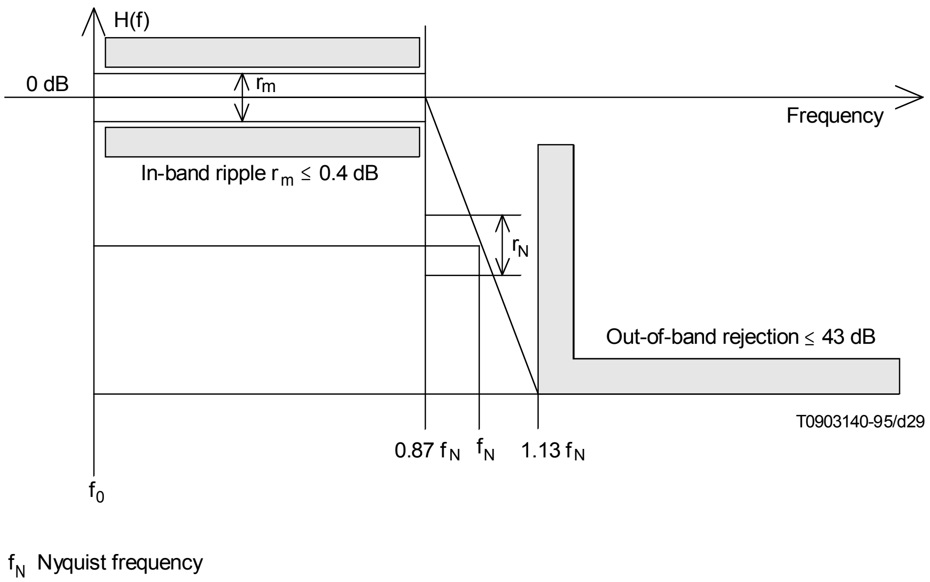


FIGURE C.8/J.83

Half-Nyquist baseband filter amplitude characteristics

Annex D

Digital multi-programme System D

(This Annex forms an integral part of this Recommendation)

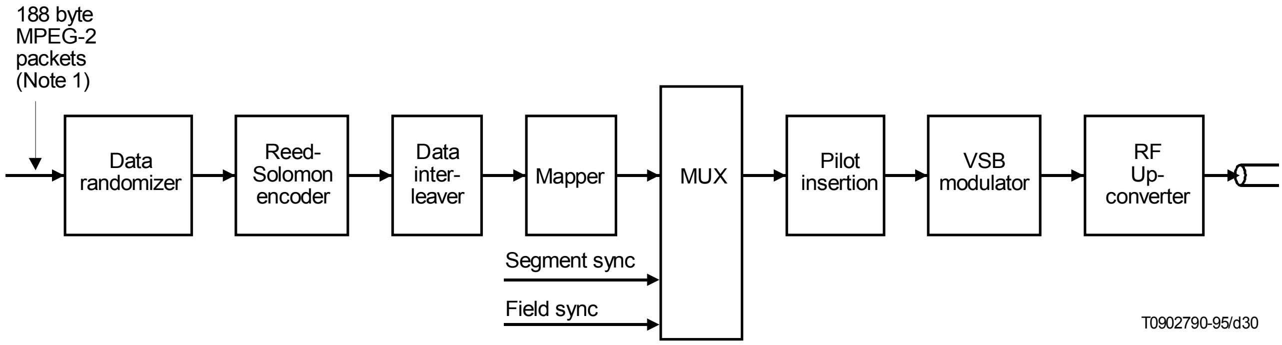
D.1 Introduction

This annex derives from work done on digital television terrestrial broadcasting in North America; it describes the framing structure, channel coding and modulation for digital multi-programme television distribution by cable, based on MPEG-2 transport multiplexing, and on 16-VSB (Vestigial SideBand) digital transmission.

D.2 Cable system concept

The 16-VSB system will support a nominal payload data rate of 38.78 Mb/s in a 6 MHz channel[2)]. A functional block diagram of a representative 16-VSB cable transmitter is shown in Figure D.1. The input to the transmission subsystem from the transport subsystem is equivalent to a nominal 38.78 Mb/s serial data stream comprised of 188-byte MPEG-compatible data packets (including a sync byte and 187 bytes of data)[2)].

The incoming data is randomized and then processed for Forward Error Correction (FEC) in the form of Reed-Solomon (RS) coding (20 RS parity bytes are added to each packet), and 1/12 data field interleaving. The randomization and FEC processes are not applied to the sync byte of the transport packet, which is represented in transmission by a Data Segment Sync signal as described below. Following randomization and forward error correction processing, convolutional byte interleaving is performed and then the data packets are formatted into Data Frames for transmission and Data Segment Sync and Data Field Sync are added.



NOTES

1 Provided by Terrestrial Broadcasts, Satellite, or Local Origination.

2 Includes Private Cable (Hotels, Apartment Buildings, Condominiums, and Schools – Wired, and MMDS [Multichannel Multipoint Distribution Service] – Wireless Microwave).

FIGURE D.1/J.83

16-VSB transmitter (cable or SMATV head-end – Note 2)

D.3 MPEG-2 transport layer

The MPEG-2 transport layer is defined in Reference [2]. The transport layer for MPEG-2 data is comprised of packets having 188 bytes, with one byte for synchronization purposes, three bytes of header containing service identification, scrambling and control information, followed by 184 bytes of MPEG-2 or auxiliary data.

D.4 Framing structure

Figure D.2 shows how the data are organized for transmission. Each Data Frame consists of two Data Fields, each containing 313 Data Segments. The first Data Segment of each Data Field is a unique synchronizing signal (Data Field Sync) and includes the training sequence used by the equalizer in the receiver. The remaining 312 Data Segments each carry the equivalent of two 188-byte transport packets plus its associated FEC overhead. The actual data in each Data Segment comes from several transport packets because of the data interleaving. Each Data Segment consists of 832 symbols. The first 4 symbols are transmitted in binary form and provide segment synchronization. This Data Segment Sync signal also represents the sync byte for each of the two 188-byte MPEG-compatible transport packets.

[2)] Parameter value for 6 MHz channel bandwidth; value can be adjusted to match other channel bandwidths.

The remaining 828 symbols of each Data Segment carry data representing two groups of 187 data bytes each followed by 20 Reed-Solomon bytes. These 828 symbols are transmitted as 16-level signals and therefore carry four bits per symbol. Thus, $828 \times 4 = 3312$ bits of data are carried in each Data Segment, which exactly matches the requirement to send two protected transport packets:

187 data bytes + 20 RS parity bytes = 207 bytes

2×207 bytes $\times$ 8 bits/byte = 3312

The exact symbol rate is given by the equation below:

S_r (MHz) = $4.5/286 \times 684$ = 10.76... MHz[3)]

The 16-level symbols combined with the binary Data Segment Sync and Data Field Sync signals are used to modulate a single carrier in suppressed-carrier mode. Before transmission, however, most of the lower sideband is removed. The resulting spectrum is flat, except for the band edges where a nominal square-root raised-cosine response results in 620 kHz transition regions. The nominal VSB transmission spectrum is shown in Figure D.3.[3)]

At the suppressed-carrier frequency, 310 kHz from the lower band edge, a small pilot is added to the signal.

The cable system may also carry standard television signals on other channels as shown in Figure D.3. The nominal average VSB signal power is 6 dB below peak sync power of standard television signals carried in adjacent channels.

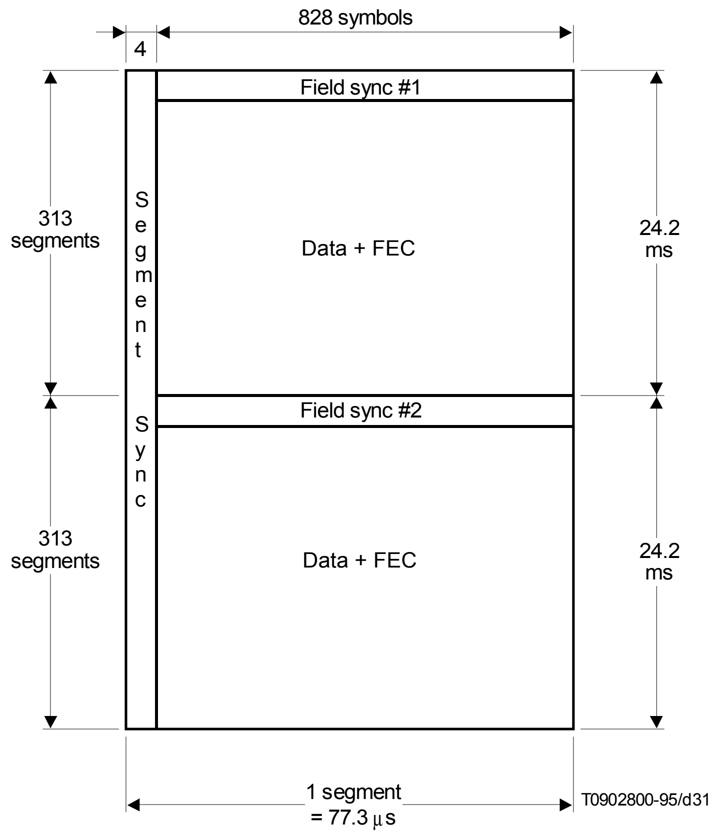


FIGURE D.2/J.83

VSB data frame

3) Parameter value for 6 MHz channel bandwidth; value can be adjusted to match other channel bandwidths.

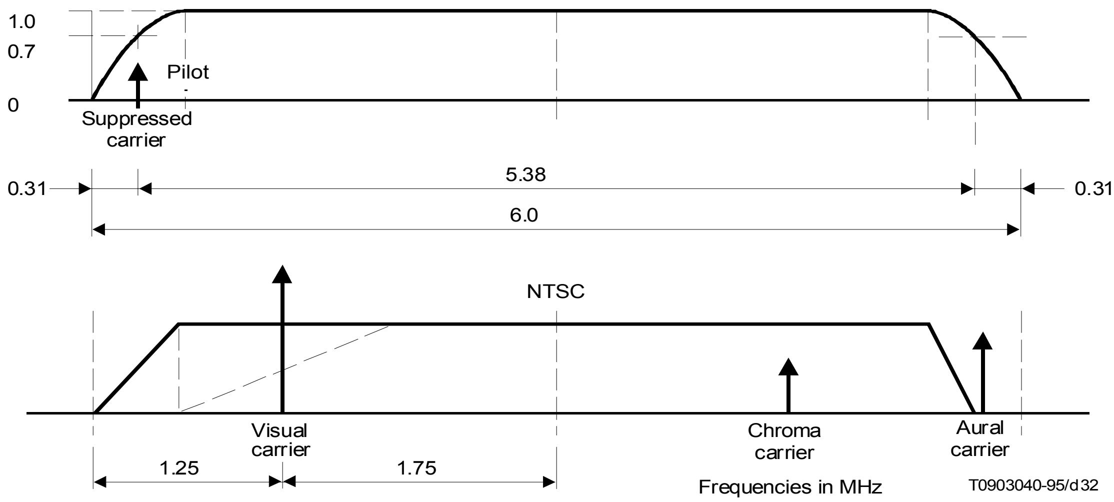


FIGURE D.3/J.83

VSB and NTSC channel occupancy

D.5 Channel coding

D.5.1 Data randomizer

A data randomizer is used on all input data to randomize the data payload (not including Data Field Sync or Data Segment Sync, or RS parity bytes). The data randomizer XOR-s all the incoming data bytes with a 16-bit maximum length Pseudo-Random Binary Sequence (PRBS) which is initialized at the beginning of the Data Field. The PRBS is generated in a 16-bit shift register that has 9 feedback taps. Eight of the shift register outputs are selected as the fixed randomizing byte, where each bit from this byte is used to individually XOR the corresponding input data bit. The data bits are XOR-ed MSB to MSB ... LSB to LSB.

The initialization (pre-load) to F180 hex (load to 1) occurs during the Data Segment Sync interval prior to the first Data Segment.

The randomizer generator polynomial and initialization are shown in Figure D.4.

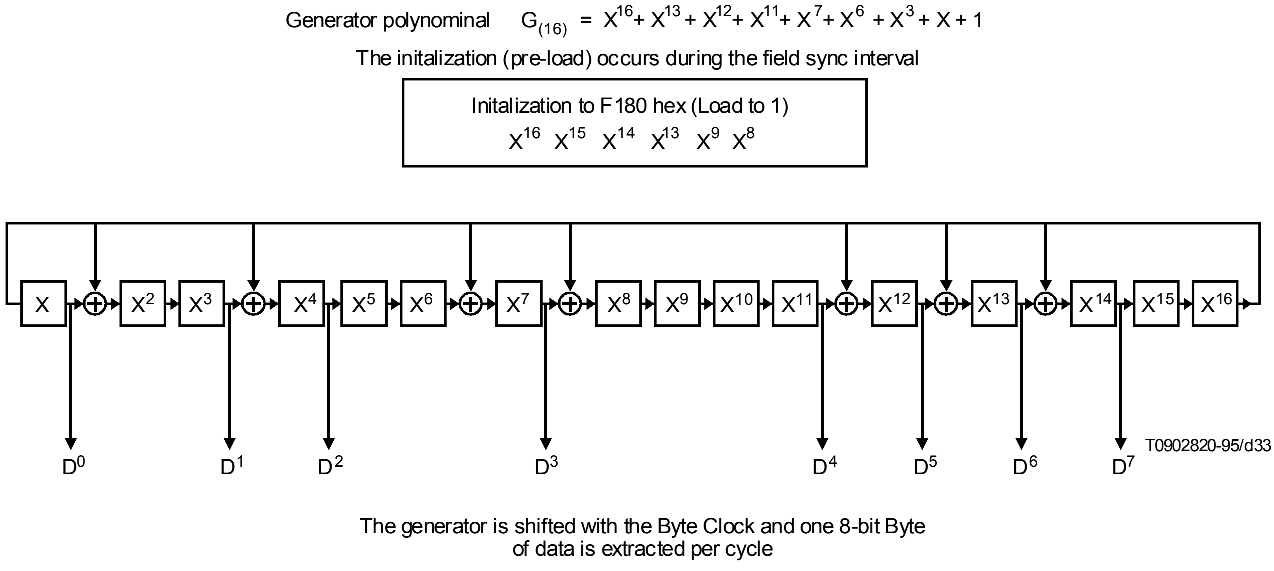


FIGURE D.4/J.83

Randomizer polynomial

D.5.2 Reed-Solomon encoder

The RS code used in the VSB transmission subsystem is t = 10 (207, 187) code. The RS data block size is 187 bytes, with 20 RS parity bytes added for error correction. Two RS blocks of 207 bytes are transmitted per Data Segment.

The 20 RS parity bytes are sent at the end of each respective group of 187 bytes. The parity generator polynomial and the primitive field generator polynomial are shown in Figure D.5.

$$\prod_{i=0}^{i=2t-1}(X+\alpha^i) = X^{20} + X^{19}\alpha^{17} + X^{18}\alpha^{60} + X^{17}\alpha^{79} + X^{16}\alpha^{50} + X^{15}\alpha^{61} + X^{14}\alpha^{163} + X^{13}\alpha^{26} + X^{12}\alpha^{187} + X^{11}\alpha^{202} + X^{10}\alpha^{180} + X^{9}\alpha^{22} + X^{8}\alpha^{225} + X^{7}\alpha^{83} + X^{6}\alpha^{239} + X^{5}\alpha^{156} + X^{4}\alpha^{164} + X^{3}\alpha^{212} + X^{2}\alpha^{212} + X^{1}\alpha^{188} + \alpha^{190}$$

$$= X^{20} + 125\,X^{19} + 185\,X^{18} + 240\,X^{17} + 5\,X^{16} + 111\,X^{15} + 99\,X^{14} + 6\,X^{13} + 220\,X^{12} + 112\,X^{11} + 150\,X^{10} + 69\,X^{9} + 36\,X^{8} + 187\,X^{7} + 22\,X^{6} + 228\,X^{5} + 198\,X^{4} + 121\,X^{3} + 121\,X^{2} + 165\,X^{1} + 174$$

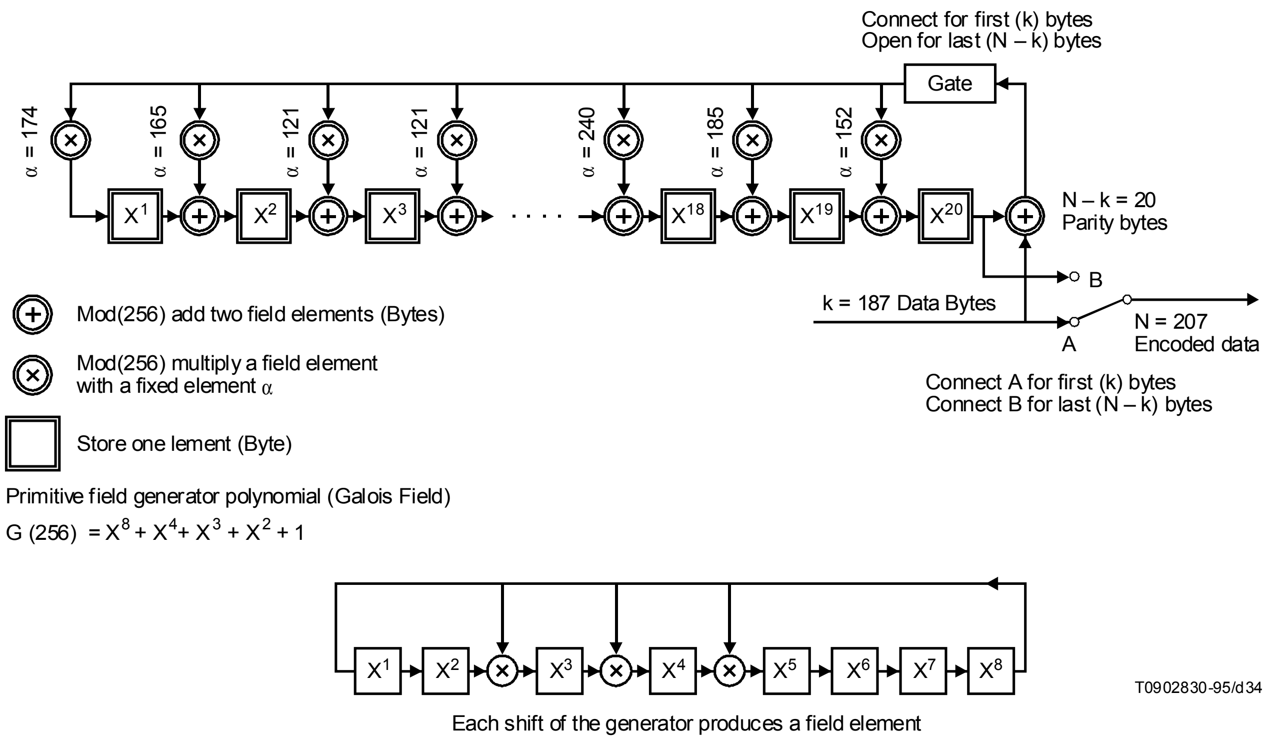
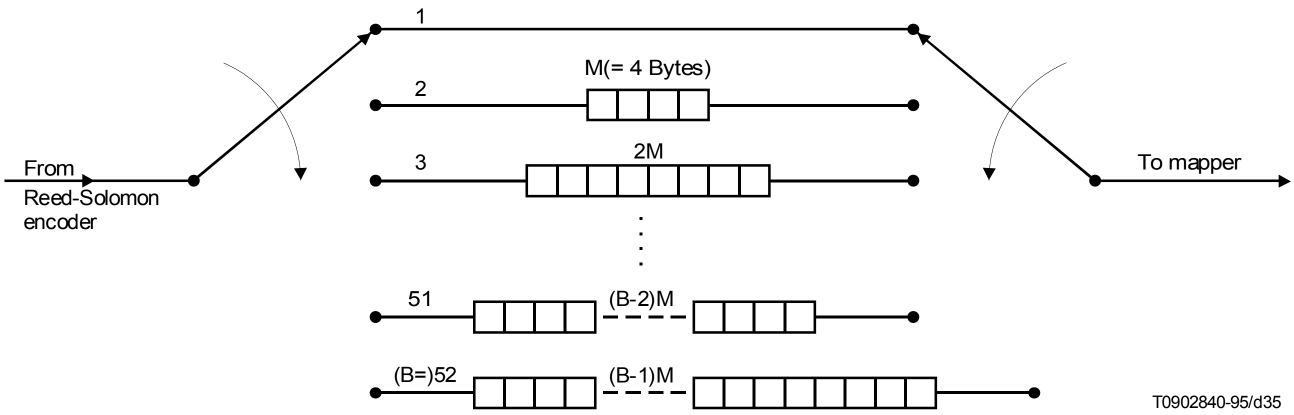


FIGURE D.5/J.83

Parity generator polynomial for Reed-Solomon (207, 187) with t = 10

D.5.3 Interleaving

The interleaver employed in the VSB transmission system is a 26 data segment (intersegment) convolutional byte interleaver. Interleaving is provided to a depth of about 1/12 of a data field (2 ms deep). Only data bytes are interleaved. The interleaver is synchronized to the first data byte of the data field. The convolutional interleaver is shown in Figure D.6.



M = 4, B = 52, N = 208, R-S Block = 207, B × M = N

FIGURE D.6/J.83

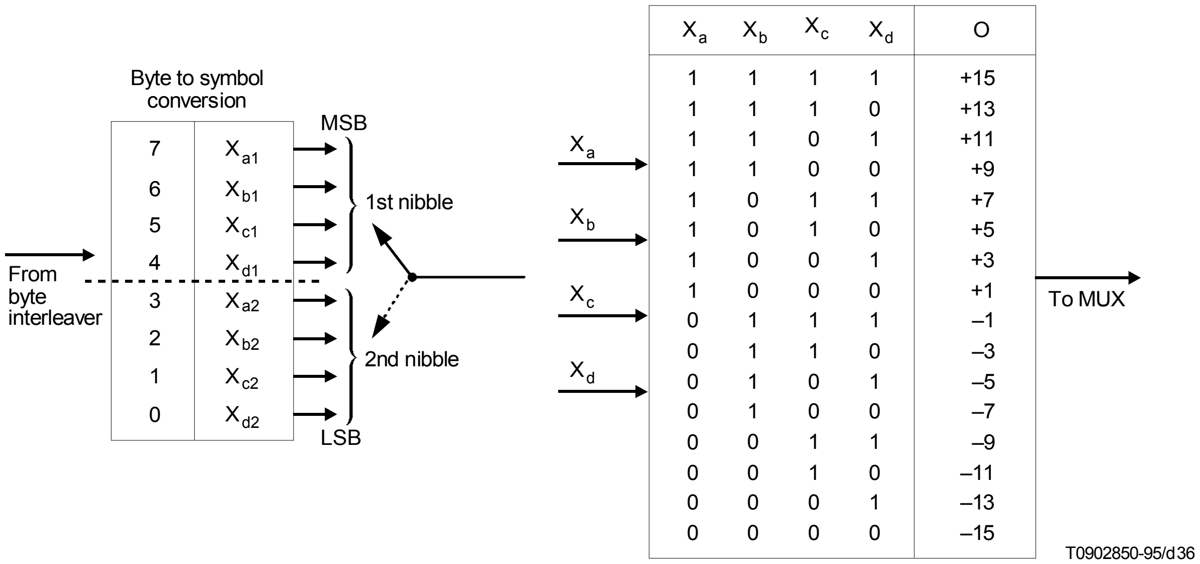
Convolutional interleaver

D.5.4 Data segment sync

The multi-level data is passed through a multiplexer that inserts the various synchronization signals (Data Segment Sync and Data Field Sync).

A two-level (binary) 4-symbol Data Segment Sync is inserted into the 16-level digital data stream at the beginning of each Data Segment. (The MPEG sync byte is replaced by Data Segment Sync.) The Data Segment Sync embedded in random data is shown in Figure D.7.

A complete segment consists of 832 symbols: 4 symbols for Data Segment Sync, and 828 data plus parity symbols. The Data Segment Sync is binary (2-level). The same sync pattern occurs regularly at 77.3 µs intervals, and is the only signal repeating at this rate. Unlike the data, the four symbols for Data Segment Sync are not Reed-Solomon encoded, nor are they interleaved. The Data Segment Sync pattern is a 1001 pattern, as shown in Figure D.8.



X_a	X_b	X_c	X_d	O
1	1	1	1	+15
1	1	1	0	+13
1	1	0	1	+11
1	1	0	0	+9
1	0	1	1	+7
1	0	1	0	+5
1	0	0	1	+3
1	0	0	0	+1
0	1	1	1	–1
0	1	1	0	–3
0	1	0	1	–5
0	1	0	0	–7
0	0	1	1	–9
0	0	1	0	–11
0	0	0	1	–13
0	0	0	0	–15

FIGURE D.7/J.83

16-VSB mapper

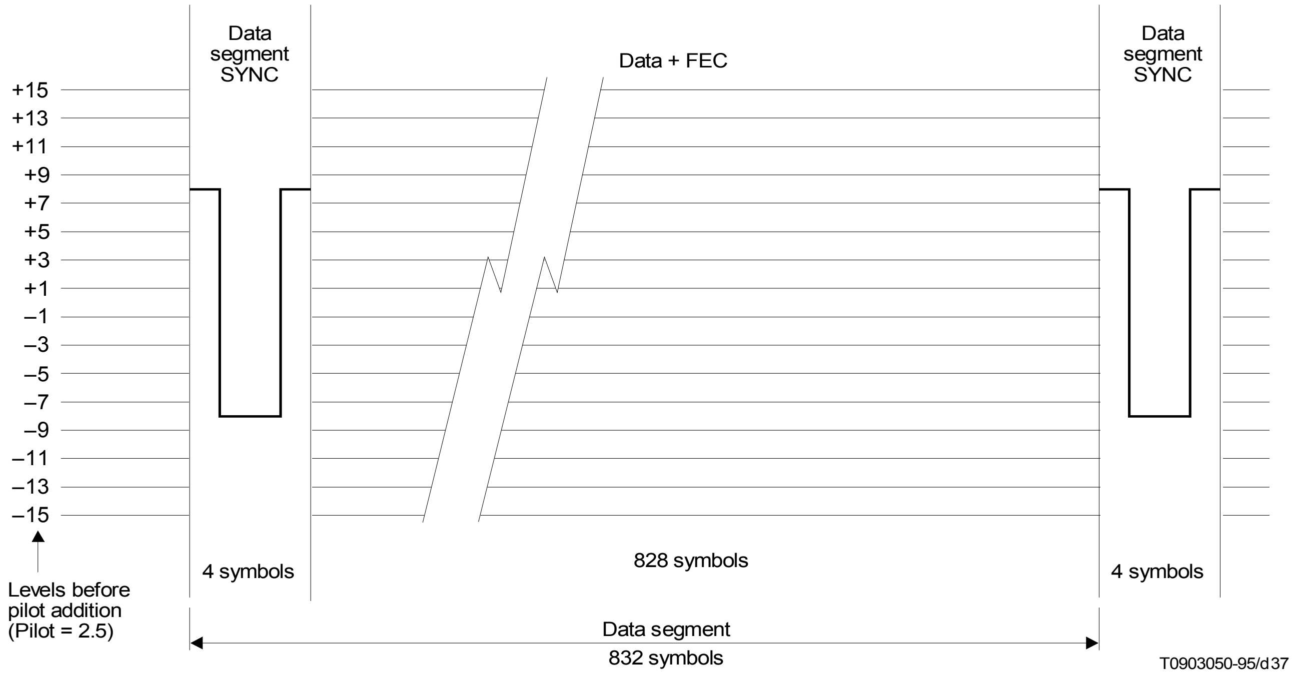


FIGURE D.8/J.83

VSB data segment

D.5.5 Data field sync

The data are not only divided into Data Segments, but also into Data Fields, each consisting of 313 segments. Each Data Field (24.2 ms) starts with one complete Data Segment of Data Field Sync, as shown in Figure D.9. Each symbol represents one bit of data (2-level). The 832 symbols in this segment are defined below. See Figure D.9.

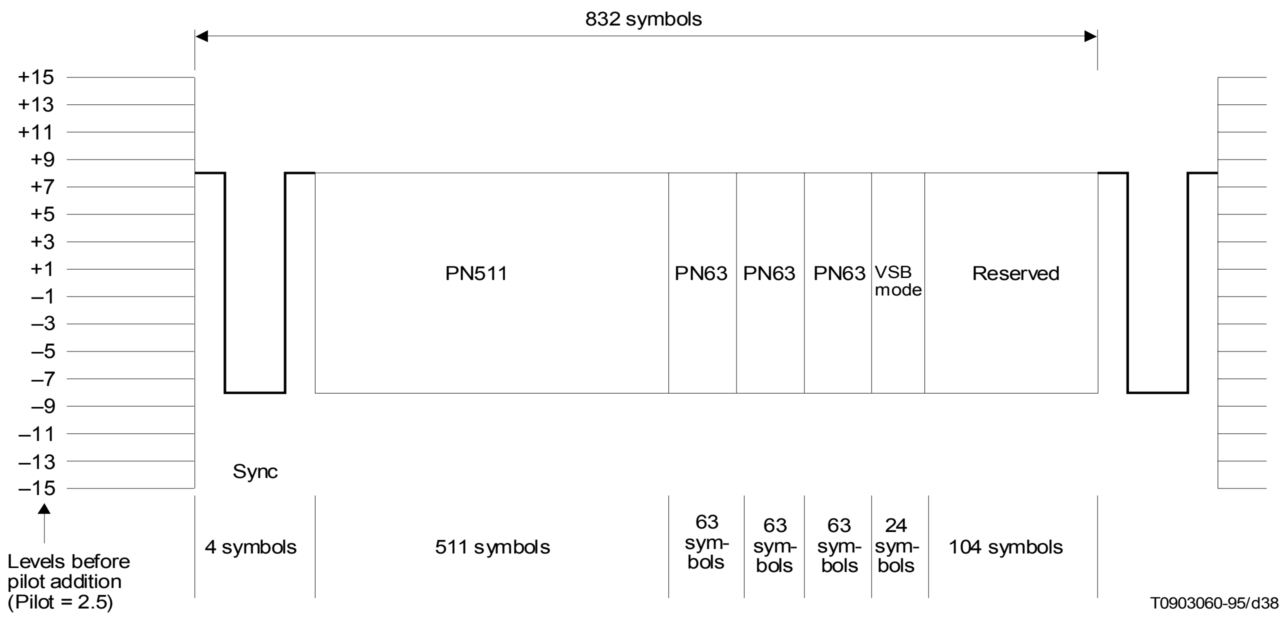


FIGURE D.9/J.83

VSB data field sync

D.5.5.1 Sync

This corresponds to Data Segment Sync and is defined as 1001.

D.5.5.2 PN511[4)]

This pseudo-random sequence is defined as $X^9 + X^7 + X^6 + X^4 + X^3 + X + 1$ with a pre-load value of 010000000.

D.5.5.3 PN63[4)]

This pseudo-random sequence is repeated three times. It is defined as $X^6 + X + 1$ with a pre-load value of 100111. The middle PN63 is inverted on every other Data Field Sync.

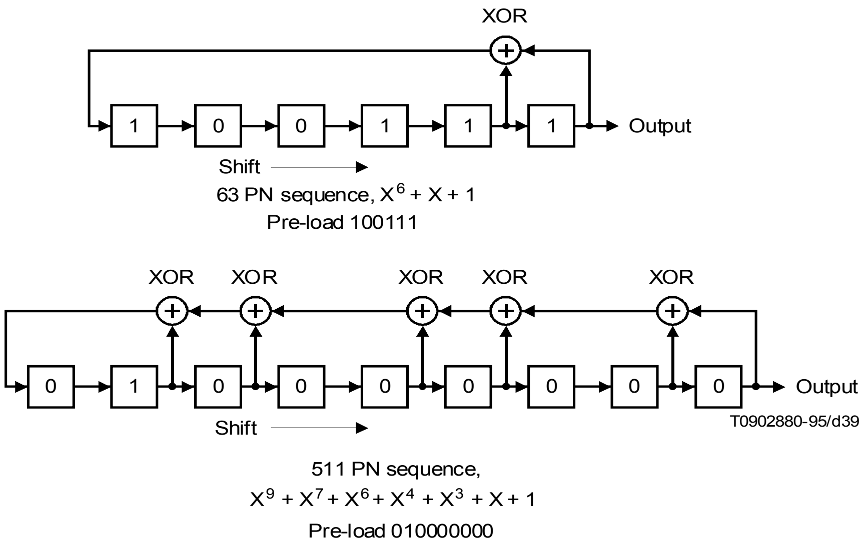


FIGURE D.10/J.83

Field sync PN sequence generators

D.5.5.4 VSB mode

These 24 bits determine the VSB mode for the data in the frame. The first two bytes are reserved. The suggested fill pattern is 0000111100001111. The next byte is defined as:

$$\text{P A B C } \overline{\text{P A B C}}$$

where P is the even parity bit, the MSB of the byte, and A, B, C are the actual mode bits.

P A B C	
0 0 0 0	Reserved
1 0 0 1	Reserved
1 0 1 0	Reserved
0 0 1 1	Reserved
1 1 0 0	16-VSB Cable
0 1 0 1	8-VSB Terrestrial (Note)
0 1 1 0	Reserved
1 1 1 1	Reserved

NOTE – In the 8-VSB terrestrial mode, the preceding bits are defined as:

$$\text{0 0 0 0 } \overline{\text{P A B C}} \text{ P A B C 1 1 1 1}$$

---

4) The generators for the PN63 and PN511 sequences are shown in Figure D.10.

D.5.5.5 Reserved

The last 104 bits is reserved space. It is suggested that this be filled with a continuation of the PN63 sequence.

All sequences are pre-loaded before the beginning of the Data Field Sync.

Like the Data Segment Sync, the Data Field Sync is not Reed-Solomon encoded, nor is it interleaved.

D.6 Modulation

D.6.1 Bit-to-symbol mapping

Figure D.7 shows the mapping of the outputs of the interleaver to the nominal signal levels of (±1, ±3, ±5, ±7, ±9, ±11, ±13, ±15). As shown in Figures D.8 and D.9, the nominal levels of Data Segment Sync and Data Field Sync are –9 and +9.

D.6.2 Pilot addition

A small in-phase pilot is added to the data signal. The frequency of the pilot is the same as the suppressed-carrier frequency as shown in Figure D.3. This may be generated in the following manner. A small (digital) DC level (2.5) is added to every symbol (data and syncs) of the digital baseband data plus sync signal (±1, ±3, ±5, ±7, ±9, ±11, ±13, ±€15). The power of the pilot is 11.3 dB below the average data signal power.

D.6.3 16-VSB modulation method

The VSB modulator receives the 10.76 Msymbols/s, 16-level composite data signal (pilot and syncs added). The digital multi-programme system performance is based on a linear-phase raised-cosine Nyquist filter response in the concatenated transmitter and receiver, as shown in Figure D.11. See Footnote 3. The system filter response is essentially flat across the entire band, except for the transition regions at each end of the band. Nominally, the roll-off in the transmitter has the response of a linear-phase square-root raised-cosine filter. Tolerances, both in-band and out-of-band, are under study.

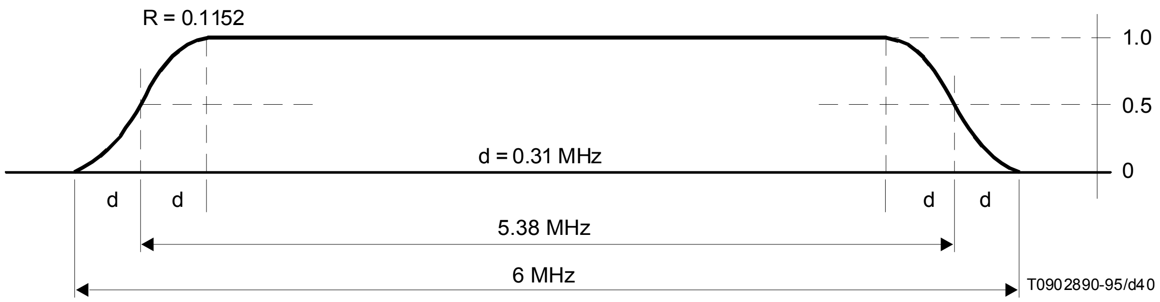


FIGURE D.11/J.83

Nominal VSB system channel response (linear-phase raised-cosine Nyquist filter)

D.6.4 Up-conversion

The modulation process is usually accomplished at an IF frequency. The modulated IF is then up-converted to the final frequency carried by the cable system.

D.7 16-VSB cable receiver

The 16-VSB cable receiver is shown in Figure D.12. All of the inverse functions of the transmitter are performed in the receiver: down conversion (tuner), detection, sync and timing recovery, de-interleaving, Reed-Solomon forward error correction, and data de-randomization.

In addition, an equalizer removes intersymbol interference making use of the data field sync as a training reference signal, and a phase tracker reduces the effect of phase-noise of the local oscillator of the tuner. Following the phase tracker is the slicer to recover the data from the multi-level symbols.

The demodulating carrier is recovered from the pilot and the sync and clock are recovered from the segment sync.

The receiver may be fed with cable mode signals from the cable distribution system or, if the receiver is a terrestrial broadcast receiver, may also be fed from 8-VSB trellis-coded terrestrial broadcasts, or from private cable sources (SMATV or MMDS, or other).

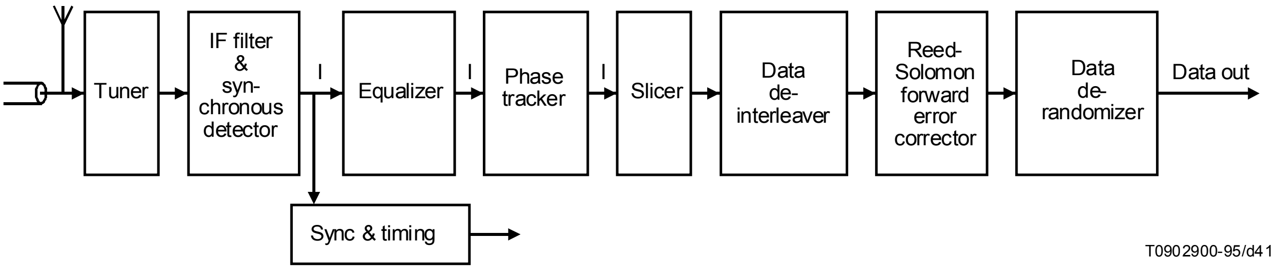


FIGURE D.12/J.83

16-VSB receiver

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