



ENGN4521/6521

Embedded Wireless

Wireless Communications via Digital Video Broadcast
over Satellite (DVB-S)

V3.0

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1 Foreword

In this phase of the project we look at the wireless signal processing aspects of the satellite digital video broadcast standard (DVB-S). The details of this standard can be found in the appendix. We look at C-code that implements some of the processing blocks specified in the standard.

2 Assessment

This part of the project is worth 20% of the course mark. All crucial aspects of the project will be carried out in the lab.

3 Procedure

The information contained in this description and the solutions to a few short exercises provide the basis for a 5-10 page report. The aim of the project is to investigate and experiment with a dvb-s transmitter. Several items of software are provided as tools for the project but in this project we are only concerned with the dvb-s transmitter itself and not the receiver.

4 Description of the subsystems

4.1 The MPEG2-TS Transport Stream

The aim of dvb-s is to communicate mpeg2-ts (mpeg2-transport stream) source encoded data over a satellite wireless channel. Mpeg2-ts packets are byte (8 bit words) sequences of length 188 bytes. The first byte in each packet is always a 47HEX or 0100_0111 = 47H (or 0x47 in C-language notation). Its purpose is to provide a mechanism for the video playback device to maintain timing and synchronisation. The broadcast standard, dvb-s exploits this synchronisation character for its own synchronisation purposes. The remaining 187 bytes form the payload consisting of mpeg2-ts encoded data that must have the proper format to be decodable by the video playback device. The frame structure of an mpeg2-ts stream is shown in Fig. 1.

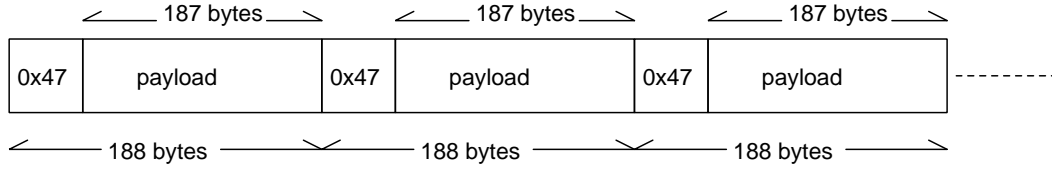


Figure 1: Frame format of mpeg2-ts

The mpeg2-ts video format is an example of *source coding*. It follows however that *any* type of data can be transported over dvb-s by encapsulating it inside a mpeg2-ts packet stream. That does not imply that arbitrary data can be played back like video, but provided the data is output to the right application at the receiver (for example a web server for a http request) then dvb-s can transport general wireless data.

4.2 The DVB-S Transmitter

The blocks of a simplified dvb-s transmitter are shown in Fig. 2. These blocks are responsible for processing the mpeg2-ts stream for transmission over a wireless channel. This function is referred to as *channel coding*. We now summarise these functions. Further details can be found in the dvb-s standard (*en_300421v010102p*) reproduced in the appendix and in the comments and implementation of the *dvbs_transmit_file.c* source code supplied in *linux.zip*.

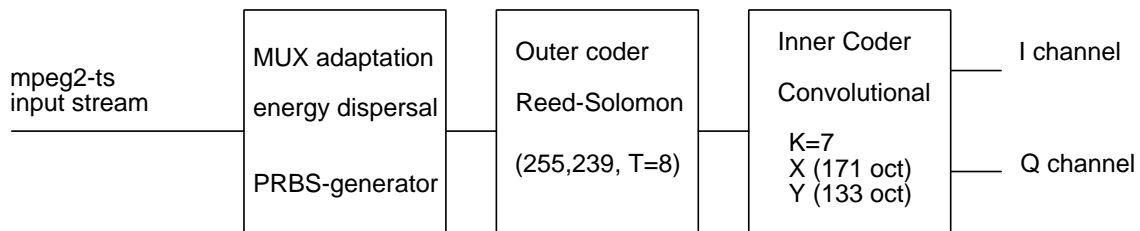


Figure 2: Block diagram diagram of the dvbs transmitter.

We will not consider the optional *convolutional encoder* nor the *baseband shaping*. Our purpose here is to create a working wireless link (using the appropriate receiver: *dvbs_receive_stream.c* and to get a feel for how wireless communications can be performed in the c-programming language.

4.3 Mux Adaptation and Randomization

In order to aid in synchronisation over the wireless link, the first step is MUX adaptation which allows the mpeg2-ts data to be aggregated into larger packets. In MUX adaptation, mpeg2-ts packets are grouped into blocks of 8 packets. The sync byte $0x47$ at the start of each block of 8 packets is bitwise inverted to give $0xB8$. Fig. 3 shows the format of the resultant MUX adapted transport stream.

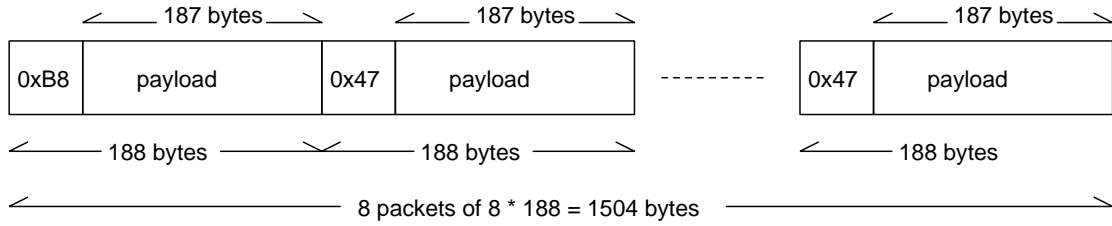


Figure 3: MUX adapted mpeg2-ts stream

Arbitrarily source encoded data may not have enough transitions between ones and zeros. In order to noise-whiten the incoming data stream so that there are adequate numbers of bit transitions, the MUX adapted signal is passed through a *pseudo random bit sequence* generator as shown in Fig. 4.

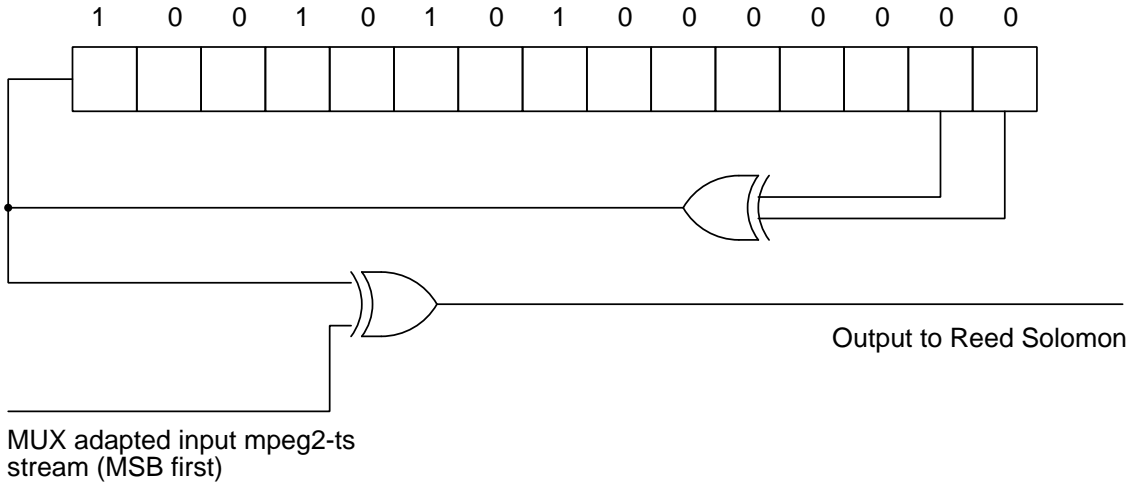


Figure 4: Circuit schematic of the PRBS sequence generator.

When a new MUX adapted frame arrives, the prbs generator bit-shift registers are preset to 100_1010_1000_0000. The prbs then cyclically performs the operations shown while

Xoring with the incoming MUX adapted sequence bits. MUX adapted bytes are entered in most significant bit order first (MSB). The prbs sequence does not act on the sync bytes, `0xB8` and `0x47`. It starts on the first byte after `0xB8` and jumps over `0x47` without processing it. In this way the sync bytes remain in tact over the wireless link.

Note that the prbs sequence doesnot involve input data in its memory - its output does not depend on previous MUX adapted input. Consequently, the same process can be applied at the receiver to recover the original MUX adapted stream.

4.4 Outer coding

The outer forward error correcting (FEC) code is a cyclic Reed-Solomon (R-S) code. The actual code is based on the original $N=255$, $K=239$ code where N is the number of bytes in a code word and K in the information word. Note that R-S codes are maximum distance separable (MDS) codes that operate on bytes by treating these as numbers over a Galois field. The MDS property implies that the R-S codes can correct $T = (N - K)/2$ byte errors. For the $N=255$, $K=239$ code, $T = 8$ and we write (255,239,T=8).

Since our input stream is slotted into 188 byte chunks, the original (255,239,8) is shortened by padding with 55 zero bytes to give a (204,188,T=8) code. Look at the source code `rs_encode()` to see how this works.

In the actual implentation, Phil Karn's optimised *fec - 3.0.1.zip* has been used so that the receiver's FEC decoder can run fast enough on a desktop to do DVB-S reception¹.

4.5 Inner coding

Inner coding consists of a 171 octal and 133 octal convolutional encoder as shown in (Fig. 5). From the structure it can be seen that this is a 1/2-rate code: the number of code bits is twice the number of information bits. See the source code of *dvbs_transmit_file.c* for details of how this inputs bytes from the R-S encoder output and converts these to QPSK symbols. Note that in dvb-s, *puncturing* is used to increase the code rate and hence improve link performance under conditions of high SNR. Puncturing is not performed here.

¹<https://github.com/OpenDigitalRadio/ka9q-fec>

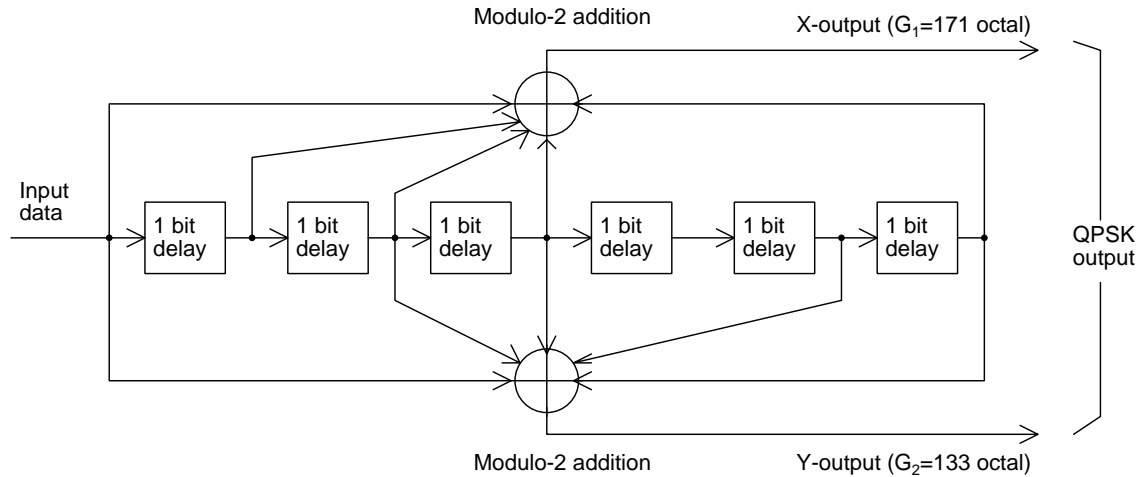


Figure 5: Inner coder.

5 The Software

The following software is provided for the exercises.

bin2hex.c : converts binary data into a list of double-nibble (8 bit) hexadecimal data.

dvbs_transmit_file.c : reads a video file *stuxnet.ts* and encodes this to a dvb-s QPSK stream.

dvbs_receive_stream.c : reads an input dvb-s QPSK stream from **dvbs_transmit_file.c** and decodes it to an mpeg2-ts stream. To use it you will have to install *mpv* or a suitable command-line video player on your system.

The folder also contains a pair of 'make' files for the transmitter and the receiver. The script *run.sh* contains examples of how to compile the code. If you run the script file by executing *sh run.sh* at the unix command-line, all of the code will be compiled and a demo will run of dvb-s encoding and decoding. In the demo, *stuxnet.ts* is read by **dvbs_receive_stream.c** which encodes it and pipes to the receiver **dvbs_transmit_file.c**. The receiver decodes the dvb-s stream and pipes it to *mpv*-video player for playback. In the receiver there is also code to allow BER-testing of the FEC codecs.

6 Exercises (20 marks)

1. Demonstrate the following by taking a screen shot of your work.

(a) Produce a stuxnet.DVBS file by redirecting the output of `dvbs_transmit_file.c`. (2 marks)

(b) Install the *mpv* video player and play the movie by redirecting the .DVBS file to `dvbs_receive_stream.c` and piping the output to *mpv*. (2 marks)

2. Devise an algorithm to communicate arbitrary data (such http) over the dvb-s connection (4 marks)

hint: What should you do about the 0x47 sync characters used in mpeg2-ts?

3. Eliminate the viterbi decoder from the DVB-S chain so that only the MUX adaptation PRBS and the (Reed Solomon) R-S codes are active. (3 marks)

4. Using the code from question 3, check that the R-S code achieves the predicted Bit-Error-Rate (BER) performance by introducing byte errors into the code. (2 marks)

hint: Add byte errors to the output of the R-S encoder and see how many can be corrected.

5. Alter the R-S code to correct 30 bytes errors. Check that your R-S code achieves the predicted Bit-Error-Rate (BER) performance. (2 marks)

6. Implement a messaging app over dvb-s to send messages to a recipient. (5 marks)

hint: You have to alter the IO structure of `dvbs_receive_stream.c` and `dvbs_transmit_file.c` and you will have to read in at least 187 characters at a time.

APPENDIX B: EN 300 421

EN 300 421 V1.1.2 (1997-08)

European Standard (Telecommunications series)

Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services

European Broadcasting Union



Union Européenne de Radio-Télévision

DVB
Digital Video
Broadcasting



European Telecommunications Standards Institute

Reference

REN/JTC-00DVB-41 (3wc00idc.PDF)

Keywords

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Foreword

This second edition, previously as an ETS now an EN, contains changes of an entirely editorial nature as follows:

- 1) add the DVB logo to the front page of the deliverable;
- 2) change the title from: "Digital broadcasting systems for television, sound and data services; etc." to "Digital Video Broadcast (DVB); etc.";
- 3) add in the foreword the DVB acknowledgement.

This European Standard (Telecommunications series) has been produced by the Joint Technical Committee (JTC) of the European Broadcasting Union (EBU), Comité Européen de Normalisation ELECTrotechnique (CENELEC) and the European Telecommunications Standards Institute (ETSI).

NOTE: The EBU/ETSI JTC was established in 1990 to co-ordinate the drafting of standards in the specific field of broadcasting and related fields. Since 1995 the JTC became a tripartite body by including in the Memorandum of Understanding also CENELEC, which is responsible for the standardization of radio and television receivers. The EBU is a professional association of broadcasting organizations whose work includes the co-ordination of its members' activities in the technical, legal, programme-making and programme-exchange domains. The EBU has active members in about 60 countries in the European broadcasting area; its headquarters is in Geneva *.

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Digital Video Broadcasting (DVB) Project

Founded in September 1993, the DVB Project is a market-led consortium of public and private sector organizations in the television industry. Its aim is to establish the framework for the introduction of MPEG-2 based digital television services. Now comprising over 200 organizations from more than 25 countries around the world, DVB fosters market-led systems, which meet the real needs, and economic circumstances, of the consumer electronics and the broadcast industry.

Proposed national transposition dates	
Date of adoption:	15 August 1994
Date of latest announcement of this EN (doa):	30 November 1997
Date of latest publication of new National Standard or endorsement of this EN (dop/e):	31 May 1998
Date of withdrawal of any conflicting National Standard (dow):	31 May 1998

1 Scope

The present document describes the modulation and channel coding system (denoted the "System" for the purposes of the present document) for satellite digital multi-programme Television (TV)/High Definition Television (HDTV) services to be used for primary and secondary distribution in Fixed Satellite Service (FSS) and Broadcast Satellite Service (BSS) bands. The System is intended to provide Direct-To-Home (DTH) services for consumer Integrated Receiver Decoder (IRD), as well as collective antenna systems (Satellite Master Antenna Television (SMATV)) and cable television head-end stations, with a likelihood of remodulation, see EN 300 429 (bibliography).

The System uses Quaternary Phase Shift Keying (QPSK) modulation and concatenated error protection strategy based on a convolutional code and a shortened Reed-Solomon (RS) code.

The System is suitable for use on different satellite transponder bandwidths.

Compatibility with Moving Pictures Experts Group-2 (MPEG-2) coded TV services (see ISO/IEC DIS 13818-1 [1]), with a transmission structure synchronous with the packet multiplex, is provided. Exploitation of the multiplex flexibility allows the use of the transmission capacity for a variety of TV service configurations, including sound and data services. All service components are Time Division Multiplexed (TDM) on a single digital carrier.

The present document:

- gives a general description of the System for satellite digital TV transmission;
- specifies the digitally modulated signal in order to allow compatibility between pieces of equipment developed by different manufacturers. This is achieved by describing in detail the signal processing principles at the modulator side, while the processing at the receive side is left open to different implementation solutions. However, it is necessary in the present document to refer to certain aspects of reception;
- identifies the global performance requirements and features of the System, in order to meet the service quality targets.

2 Normative references

References may be made to:

- a) specific versions of publications (identified by date of publication, edition number, version number, etc.), in which case, subsequent revisions to the referenced document do not apply; or
- b) all versions up to and including the identified version (identified by "up to and including" before the version identity); or
- c) all versions subsequent to and including the identified version (identified by "onwards" following the version identity); or
- d) publications without mention of a specific version, in which case the latest version applies.

A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

- | | |
|-----|--|
| [1] | ISO/IEC DIS 13818-1 (June 1994): "Coding of moving pictures and associated audio". |
| [2] | Forney, G.D. IEEE Trans. Comm. Tech., COM-19, pp. 772-781, (October 1971): "Burst-correcting codes for the classic bursty channel". |
| [3] | Intelsat Earth Station Standards (IESS) No. 308, revision 6 (26 October 1990): "Performance characteristics for Immediate Data Rate (IDR) digital carriers". |

3 Symbols and abbreviations

3.1 Symbols

For the purposes of the present document, the following symbols apply:

α	Roll-off factor
C/N	Signal-to-noise ratio
d_{free}	Convolutional code free distance
E_b/N_0	Ratio between the energy per useful bit and twice the noise power spectral density
f_N	Nyquist frequency
G_1, G_2	Convolutional code generators
$g(x)$	RS code generator polynomial
I	Interleaving depth [bytes]
I, Q	In-phase, Quadrature phase components of the modulated signal
j	Branch index of the interleaver
K	Convolutional code constraint length
M	Convolutional interleaver branch depth for $j = 1$, $M = N/I$
N	Error protected frame length (bytes)
$p(x)$	RS field generator polynomial
r_m	In-band ripple (dB)
R_s	Symbol rate corresponding to the bilateral Nyquist bandwidth of the modulated signal
R_u	Useful bit rate after MPEG-2 [1] transport multiplexer
R_u'	Bit rate after RS outer coder
T	Number of bytes which can be corrected in RS error protected packet
T_s	Symbol period
X, Y	Di-bit stream after rate 1/2 convolutional coding

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AWGN	Additive White Gaussian Noise
BB	BaseBand
BER	Bit Error Ratio
BSS	Broadcast Satellite Service
BW	BandWidth
DTH	Direct To Home
FDM	Frequency Division Multiplex
FEC	Forward Error Correction
FIFO	First-In, First-Out shift register
FIR	Finite Impulse Response
FSS	Fixed Satellite Service
HEX	Hexadecimal notation
HDTV	High Definition Television
IF	Intermediate Frequency
IMUX	Input Multiplexer - Filter
IRD	Integrated Receiver Decoder
MPEG	Moving Pictures Experts Group
MSB	Most Significant Bit
MUX	Multiplex
OBO	Output Back Off
OCT	Octal notation
OMUX	Output Multiplexer - Filter
P	Puncturing
PDH	Plesiochronous Digital Hierarchy
PSK	Phase Shift Keying
PRBS	Pseudo Random Binary Sequence

QEF	Quasi-Error-Free
QPSK	Quaternary PSK
R	Randomized sequence
RF	Radio Frequency
RS	Reed-Solomon
SMATV	Satellite Master Antenna Television
TBD	To Be Defined
TDM	Time Division Multiplex
TV	Television
TWTA	Travelling Wave Tube Amplifier

4 Transmission system

4.1 System definition

The System is defined as the functional block of equipment performing the adaptation of the baseband TV signals, from the output of the MPEG-2 transport multiplexer (see ISO/IEC DIS 13818-1 [1]), to the satellite channel characteristics. The following processes shall be applied to the data stream (see figure 1):

- transport multiplex adaptation and randomization for energy dispersal;
- outer coding (i.e. Reed-Solomon);
- convolutional interleaving;
- inner coding (i.e. punctured convolutional code);
- baseband shaping for modulation;
- modulation.

The System functional description is given in annex B.

DTH services via satellite are particularly affected by power limitations, therefore, ruggedness against noise and interference, shall be the main design objective, rather than spectrum efficiency. To achieve a very high power efficiency without excessively penalizing the spectrum efficiency, the System shall use QPSK modulation and the concatenation of convolutional and RS codes. The convolutional code is able to be configured flexibly, allowing the optimization of the system performance for a given satellite transponder bandwidth (see annex C).

Although the System is optimized for single carrier per transponder Time Division Multiplex (TDM), it is able to be used for multi-carrier Frequency Division Multiplex (FDM) type applications.

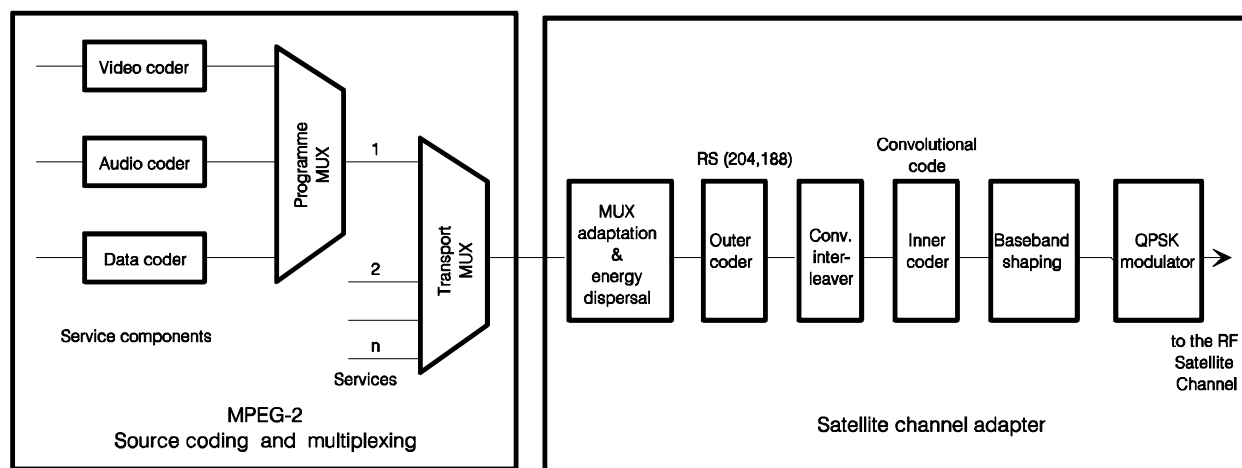


Figure 1: Functional block diagram of the System

The System is directly compatible with MPEG-2 coded TV signals (see ISO/IEC DIS 13818-1 [1]). The modem transmission frame is synchronous with the MPEG-2 multiplex transport packets.

If the received signal is above C/N and C/I threshold, the Forward Error Correction (FEC) technique adopted in the System is designed to provide a "Quasi Error Free" (QEF) quality target. The QEF means less than one uncorrected error-event per transmission hour, corresponding to Bit Error Ratio (BER) = 10^{-10} to 10^{-11} at the input of the MPEG-2 demultiplexer.

4.2 Adaptation to satellite transponder characteristics

Transmissions of digital multi-programme TV services will use satellites in both the FSS and the BSS bands. The choice of transponder bandwidth is a function of the satellite used and the data rates required by the service.

The symbol rate shall be matched to given transponder characteristics. Examples based on computer simulations for a hypothetical satellite chain, not including interference effects, are given in annex C.

4.3 Interfacing

The System, as defined in the present document, shall be delimited by the following interfaces given in table 1:

Table 1: System interfaces

Location	Interface	Interface type	Connection
Transmit station	Input	MPEG-2 [1] transport multiplex	from MPEG-2 multiplexer
	Output	70/140 MHz IF	to RF devices
Receive installation	Output	MPEG-2 transport multiplex	to MPEG-2 demultiplexer
	Input	TBD	from RF devices (indoor unit)

4.4 Channel coding

4.4.1 Transport multiplex adaptation and randomization for energy dispersal

The System input stream shall be organized in fixed length packets (see figure 3), following the MPEG-2 transport multiplexer (see ISO/IEC DIS 13818-1 [1]). The total packet length of the MPEG-2 transport Multiplex (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 ITU Radio Regulations and to ensure adequate binary transitions, the data of the input MPEG-2 multiplex shall be randomized in accordance with the configuration depicted in figure 2.

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 2, 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 is bit-wise inverted from 47_{HEX} to B8_{HEX}. This process is referred to as the "Transport Multiplex Adaptation".

The first bit at the output of the PRBS generator shall be applied to the first bit (i.e. MSB) 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 shall continue, but its output shall be disabled, leaving these bytes unrandomized. Thus, the period of the PRBS sequence shall be 1 503 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.

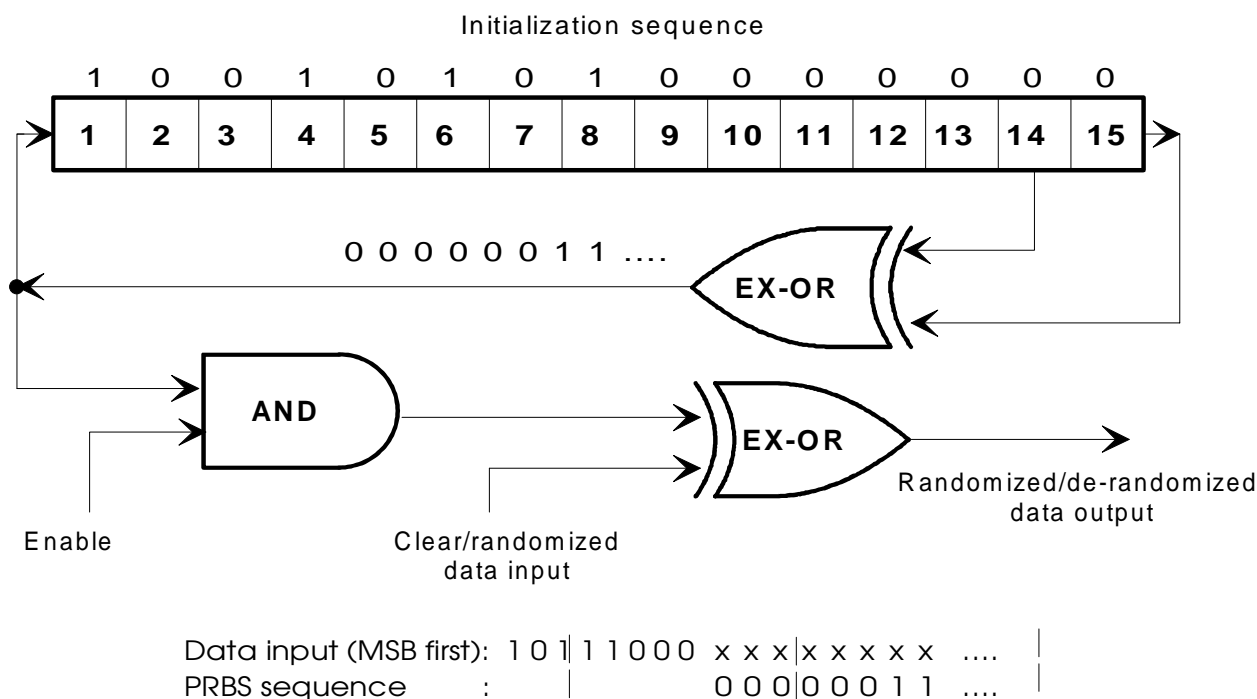


Figure 2: Randomizer/de-randomizer schematic diagram

4.4.2 Outer coding (RS), interleaving and framing

The framing organization shall be based on the input packet structure (see figure 3a).

Reed-Solomon RS (204,188, T = 8) shortened code, from the original RS(255,239, T = 8) code, shall be applied to each randomized transport packet (188 bytes) of figure 3b to generate an error protected packet (see figure 3c). Reed-Solomon coding shall also be applied to the packet sync byte, either non-inverted (i.e. 47HEX) or inverted (i.e. B8HEX).

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

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

The shortened Reed-Solomon code may be implemented by adding 51 bytes, all set to zero, before the information bytes at the input of a (255,239) encoder. After the RS coding procedure these null bytes shall be discarded.

Following the conceptual scheme of figure 4, convolutional interleaving with depth $I = 12$ shall be applied to the error protected packets (see figure 3c). This results in an interleaved frame (see figure 3d).

The convolutional interleaving process shall be based on the Forney approach [2] 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 inverted or non-inverted MPEG-2 [1] 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 $(M \cdot j)$ 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 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.

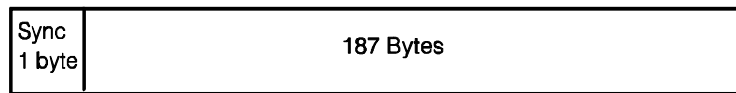


Figure 3a) MPEG-2 transport MUX packet

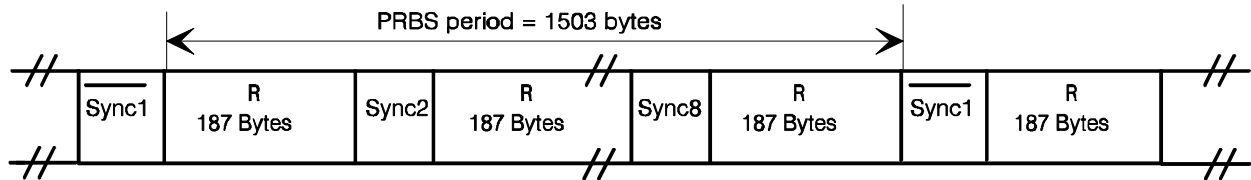


Figure 3b) Randomized transport packets: Sync bytes and randomized sequence R

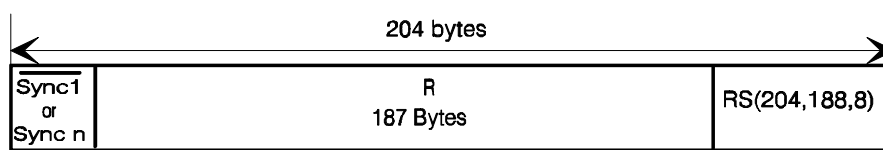
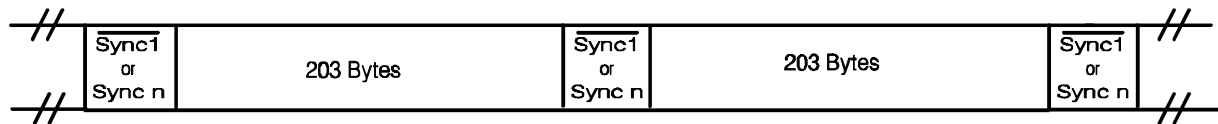


Figure 3c) Reed-Solomon RS (204,188, T=8) error protected packet

Figure 3d) Interleaved frames; interleaving depth $l=12$ bytes

Sync1 = not randomized complemented sync byte
 Sync n = not randomized sync byte, $n = 2, 3, \dots, 8$

Figure 3: Framing structure

4.4.3 Inner coding (convolutional)

The System shall allow for a range of punctured convolutional codes, based on a rate 1/2 convolutional code with constraint length $K = 7$. This will allow selection of the most appropriate level of error correction for a given service or data rate. The System shall allow convolutional coding with code rates of 1/2, 2/3, 3/4, 5/6 and 7/8.

The punctured convolutional code shall be used as given in table 2. See also figure 5.

NOTE: At the receiver, each of the code rates and puncturing configurations is in a position to be tried until lock is acquired. π phase ambiguity in the demodulator is able to be resolved by decoding the MPEG-2 sync byte delimiting the interleaved frame (see ISO/IEC DIS 13818-1 [1]).

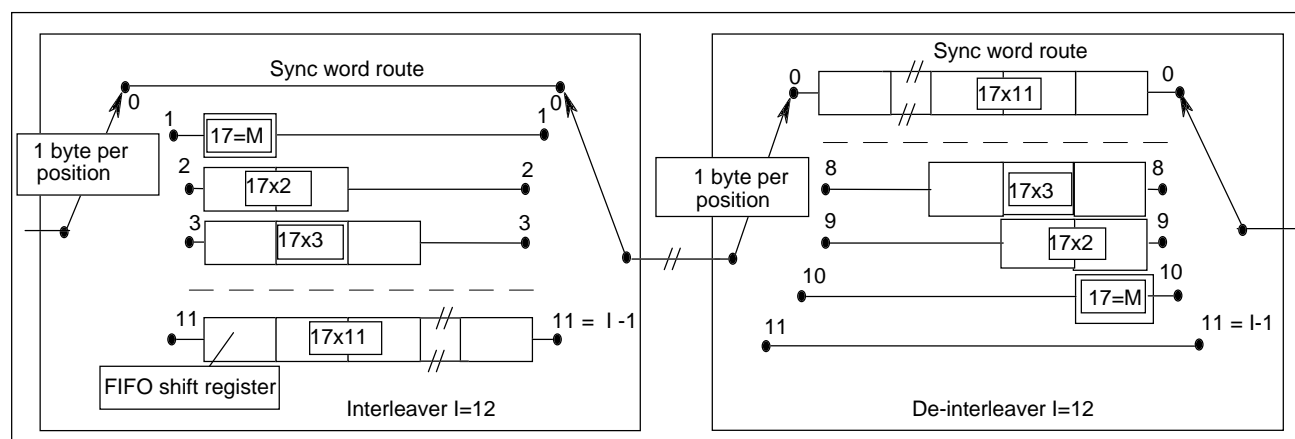


Figure 4: Conceptual diagram of the convolutional interleaver and de-interleaver

Table 2: Punctured code definition

Original code			Code rates									
			1/2		2/3		3/4		5/6		7/8	
K	G ₁ (X)	G ₂ (Y)	P	d _{free}	P	d _{free}	P	d _{free}	P	d _{free}	P	d _{free}
7	171 _{OCT}	133 _{OCT}	X: 1 Y: 1 I=X ₁ Q=Y ₁	10	X: 1 0 Y: 1 1 I=X ₁ Y ₂ Y ₃ Q=Y ₁ X ₃ Y ₄	6	X: 1 0 1 Y: 1 1 0 I=X ₁ Y ₂ Q=Y ₁ X ₃	5	X: 1 0 1 0 1 Y: 1 1 0 1 0 I=X ₁ Y ₂ Y ₄ Q=Y ₁ X ₃ X ₅	4	X: 1 0 0 0 1 0 1 Y: 1 1 1 1 0 1 0 I=X ₁ Y ₂ Y ₄ Y ₆ Q=Y ₁ Y ₃ X ₅ X ₇	3

NOTE: 1 = transmitted bit
0 = non transmitted bit

4.5 Baseband shaping and modulation

The System shall employ conventional Gray-coded QPSK modulation with absolute mapping (no differential coding). Bit mapping in the signal space as given on figure 5 shall be used.

Prior to modulation, the I and Q signals (mathematically represented by a succession of Dirac delta functions spaced by the symbol duration $T_s = 1/R_s$, with appropriate sign) shall be square root raised cosine filtered. The roll-off factor α shall be 0,35.

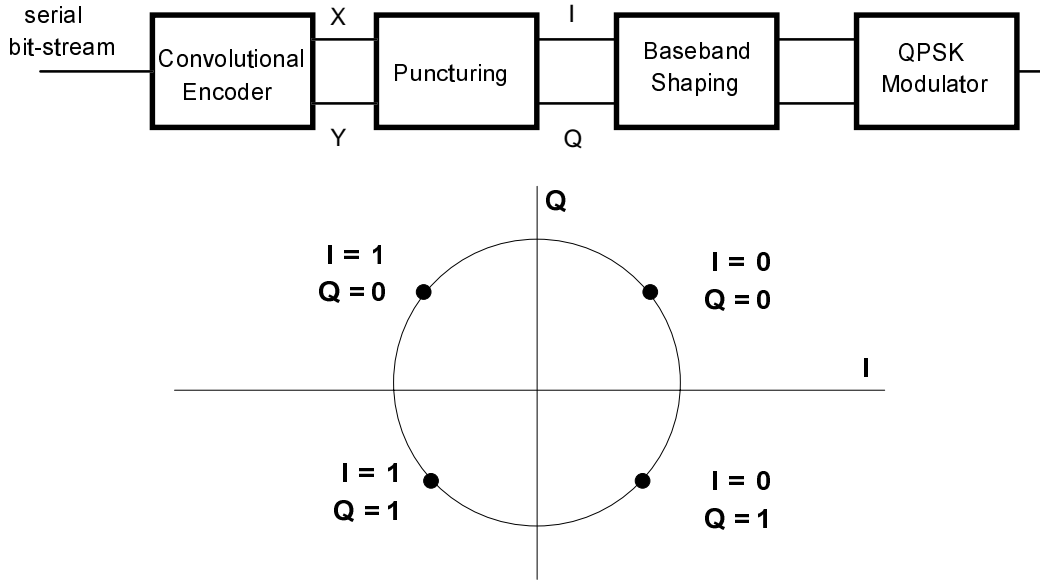


Figure 5: QPSK constellation

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

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

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

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

where

$$f_N = \frac{1}{2T_s} = \frac{R_s}{2} \text{ is the Nyquist frequency and}$$

α is the roll-off factor, $\alpha = 0,35$.

A template for the signal spectrum at the modulator output is given in annex A.

5 Error performance requirements

The modem, connected in the IF loop, shall meet the BER versus E_b/N_0 performance requirements given in table 3.

Table 3: IF-Loop performance of the System

Inner code rate	Required E_b/N_0 for BER = 2×10^{-4} after Viterbi QEF after Reed-Solomon
1/2	4,5
2/3	5,0
3/4	5,5
5/6	6,0
7/8	6,4

NOTE 1: The figures of E_b/N_0 refer to the useful bit-rate before RS coding and include a modem implementation margin of 0,8 dB and the noise bandwidth increase due to the outer code ($10 \log 188/204 = 0,36$ dB).

NOTE 2: Quasi-Error-Free (QEF) means less than one uncorrected error event per hour, corresponding to BER = 10^{-10} to 10^{-11} at the input of the MPEG-2 demultiplexer.

Indicative figures of the System performance by satellite are given in annex D.

Annex A (normative): Signal spectrum at the modulator output

Figure A.1 gives a template for the signal spectrum at the modulator output.

Figure A.1 also represents a possible mask for a hardware implementation of the Nyquist modulator filter as specified in subclause 4.5. The points A to S shown on figures A.1 and A.2 are defined in table A.1. The mask for the filter frequency response is based on the assumption of ideal Dirac delta input signals, spaced by the symbol period $T_s = 1/R_s = 1/2f_N$, while in the case of rectangular input signals a suitable $x/\sin x$ correction shall be applied on the filter response.

Figure A.2 gives a mask for the group delay for the hardware implementation of the Nyquist modulator filter.

Figures A.1 and A.2 are based on Intelsat Earth Station Standards (IESS) No. 308 [3], with slight modification due to different roll off.

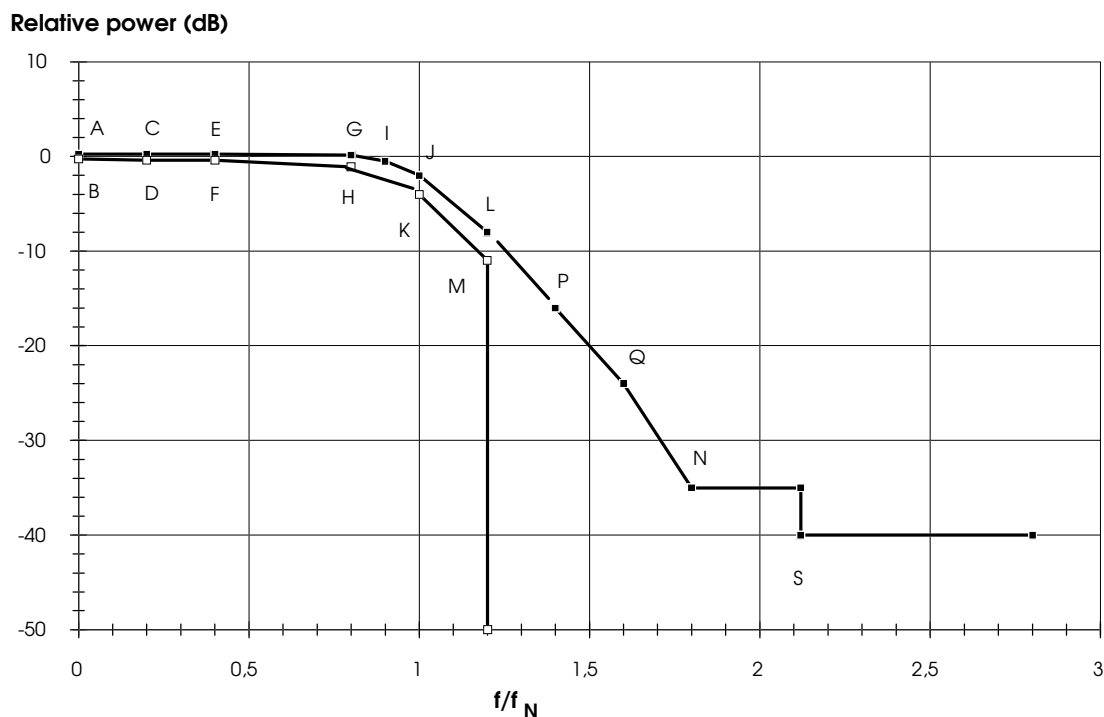


Figure A.1: Template for the signal spectrum mask at the modulator output represented in the baseband frequency domain

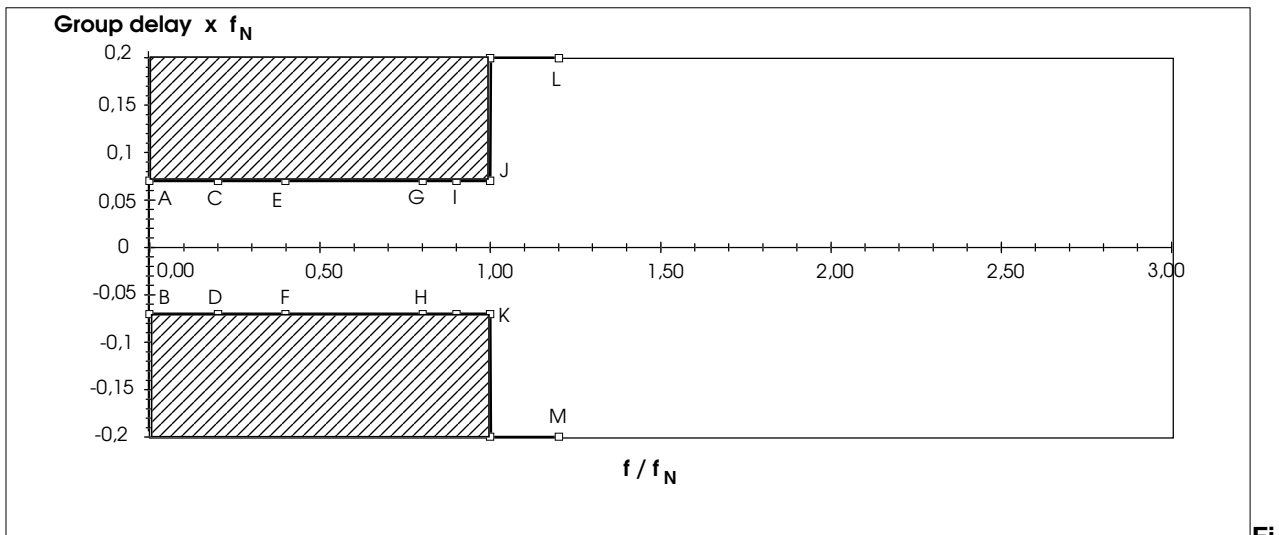


Figure A.2: Template of the modulator filter group delay

Table A.1: Definition of points given in figure A.1

Point	Frequency	Relative power (dB)	Group delay
A	0,0 f _N	+0,25	+0,07 / f _N
B	0,0 f _N	-0,25	-0,07 / f _N
C	0,2 f _N	+0,25	+0,07 / f _N
D	0,2 f _N	-0,40	-0,07 / f _N
E	0,4 f _N	+0,25	+0,07 / f _N
F	0,4 f _N	-0,40	-0,07 / f _N
G	0,8 f _N	+0,15	+0,07 / f _N
H	0,8 f _N	-1,10	-0,07 / f _N
I	0,9 f _N	-0,50	+0,07 / f _N
J	1,0 f _N	-2,00	+0,07 / f _N
K	1,0 f _N	-4,00	-0,07 / f _N
L	1,2 f _N	-8,00	-
M	1,2 f _N	-11,00	-
N	1,8 f _N	-35,00	-
P	1,4 f _N	-16,00	-
Q	1,6 f _N	-24,00	-
S	2,12 f _N	-40,00	-

Annex B (informative): Conceptual System description

The modulator and demodulator may perform the functions indicated in the block diagrams of figure B.1.

Due to the similarity of the modulator and demodulator block diagrams, only the latter is described as follows:

- **IF interface and QPSK demodulator:** this unit performs the quadrature coherent demodulation function and the analogue to digital conversion, providing "soft decision" I and Q information to the inner decoder.
- **Matched filter:** this unit performs the complementary pulse shaping filtering of raised cosine type according to the roll-off. The use of a Finite Impulse Response (FIR) digital filter could provide equalization of the channel linear distortions in the IRD.
- **Carrier/clock recovery unit:** this device recovers the demodulator synchronization. The probability of slips generation over the full C/N range of the demodulator should be very low.
- **Inner decoder:** this unit performs first level error protection decoding. It should operate at an input equivalent "hard decision" BER in the order of between 10^{-1} and 10^{-2} (depending on the adopted code rate), and should produce an output BER of about 2×10^{-4} or lower. This output BER corresponds to QEF service after outer code correction. It is possible that this unit makes use of "soft decision" information. This unit is in a position to try each of the code rates and puncturing configurations until lock is acquired. Furthermore, it is in a position to resolve $\pi/2$ demodulation phase ambiguity.

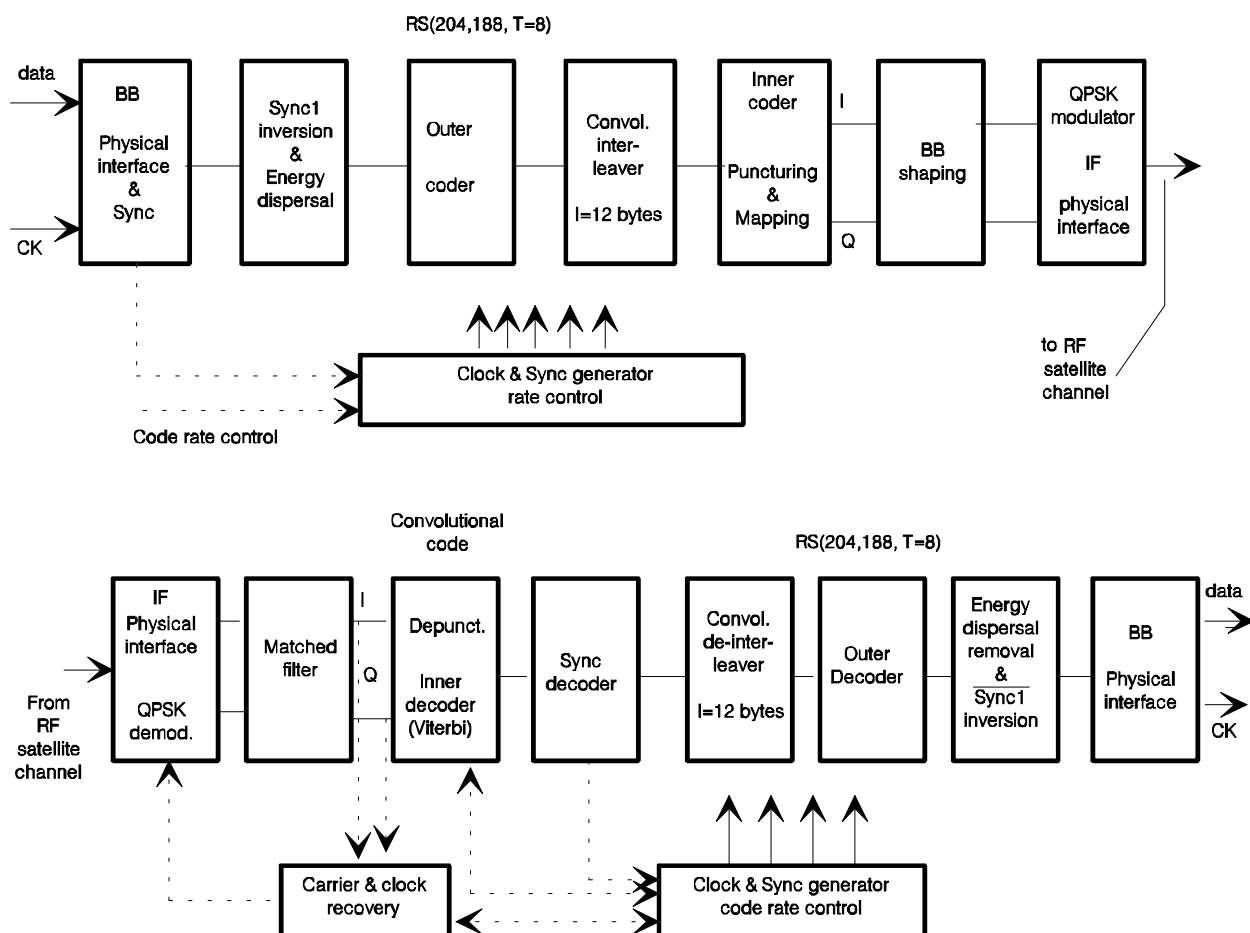


Figure B.1: Conceptual block diagram of the System at the transmitting and receiving side

- **Sync byte decoder:** by decoding the MPEG-2 [1] sync bytes, this decoder provides synchronization information for the de-interleaving. It is also in a position to recover π ambiguity of QPSK demodulator (not detectable by the Viterbi decoder).

- **Convolutional de-interleaver:** this device allows the error bursts at the output of the inner decoder to be randomized on a byte basis in order to improve the burst error correction capability of the outer decoder.
- **Outer decoder:** this unit provides second level error protection. It is in a position to provide QEF output (i.e. BER of about 10^{-10} to 10^{-11}) in the presence of input error bursts at a BER of about 7×10^{-4} or better with infinite byte interleaving. In the case of interleaving depth $I = 12$, $BER = 2 \times 10^{-4}$ is assumed for QEF.
- **Energy dispersal removal:** this unit recovers the user data by removing the randomizing pattern used for energy dispersal purposes and changes the inverted sync byte to its normal MPEG-2 sync byte value.
- **Baseband physical interface:** this unit adapts the data structure to the format and protocol required by the external interface.

NOTE: A possibility is provided by the MPEG-2 [1] system to set on the error flag bit in the packet header if the correction capability of the outer code is exceeded.

Annex C (informative):

Examples of bit rates versus transponder bandwidth

The transmission symbol rate R_s can be matched to given transponder characteristics, to achieve the maximum transmission capacity compatible with the acceptable signal degradation due to transponder bandwidth limitations. Table C.1 gives examples of the useful bit rate capacity R_u achievable on a satellite transponder with bandwidth BW corresponding to $BW/R_s = 1,28$.

Other BW/R_s values may be adopted for different service requirements, depending on the trade-off between transmission capacity and E_b/N_0 degradation.

Figures C.1 and C.2 show the IMUX and OMUX filter characteristics adopted in the computer simulations, with a 33 MHz (-3dB) total bandwidth.

Figure C.3 gives an example of the E_b/N_0 degradation on a computer simulated satellite transponder (Travelling Wave Tube Amplifier Output Back Off (TWTA OBO) = 0 dB) due to bandwidth limitations on IMUX and OMUX (see figures C.1 and C.2), for a ratio BW/R_s between 1 and 1,35. The reference 0 dB degradation refers to the case of a satellite transponder without bandwidth limitations ($BW = \infty$, TWTA OBO = 0 dB). The results are obtained by computer simulations, with inner code rates 2/3 and 7/8, at $BER = 2 \times 10^{-4}$. Other results could be obtained for different transponder filter characteristics. When using the results of figure C.3, suitable margins should be allowed to take into account thermal and ageing instabilities of the transponder characteristics.

Table C.1: Examples of bit rates versus transponder bandwidth

BW (at -3 dB)	BW' (at -1 dB)	R_s (for $BW/R_s=1.28$)	R_u (for QPSK + 1/2 convol)	R_u (for QPSK + 2/3 convol)	R_u (for QPSK + 3/4 convol)	R_u (for QPSK + 5/6 convol)	R_u (for QPSK + 7/8 convol)
[MHz]	[MHz]	[Mbaud]	[Mbit/s]	[Mbit/s]	[Mbit/s]	[Mbit/s]	[Mbit/s]
54	48,6	42,2	38,9	51,8	58,3	64,8	68,0
46	41,4	35,9	33,1	44,2	49,7	55,2	58,0
40	36,0	31,2	28,8	38,4	43,2	48,0	50,4
36	32,4	28,1	25,9	34,6	38,9	43,2	45,4
33	29,7	25,8	23,8	31,7	35,6	39,6	41,6
30	27,0	23,4	21,6	28,8	32,4	36,0	37,8
27	24,3	21,1	19,4	25,9	29,2	32,4	34,0
26	23,4	20,3	18,7	25,0	28,1	31,2	32,8

NOTE 1: R_u stands for the useful bit rate after MPEG-2 MUX. R_s (symbol rate) corresponds to the -3dB bandwidth of the modulated signal.

NOTE 2: The figures of table C.1 correspond to an E_b/N_0 degradation of 1,0 dB (with respect to AWGN channel) for the case of 0,35 roll-off and 2/3 code rate, including the effects of IMUX, OMUX and TWTA.

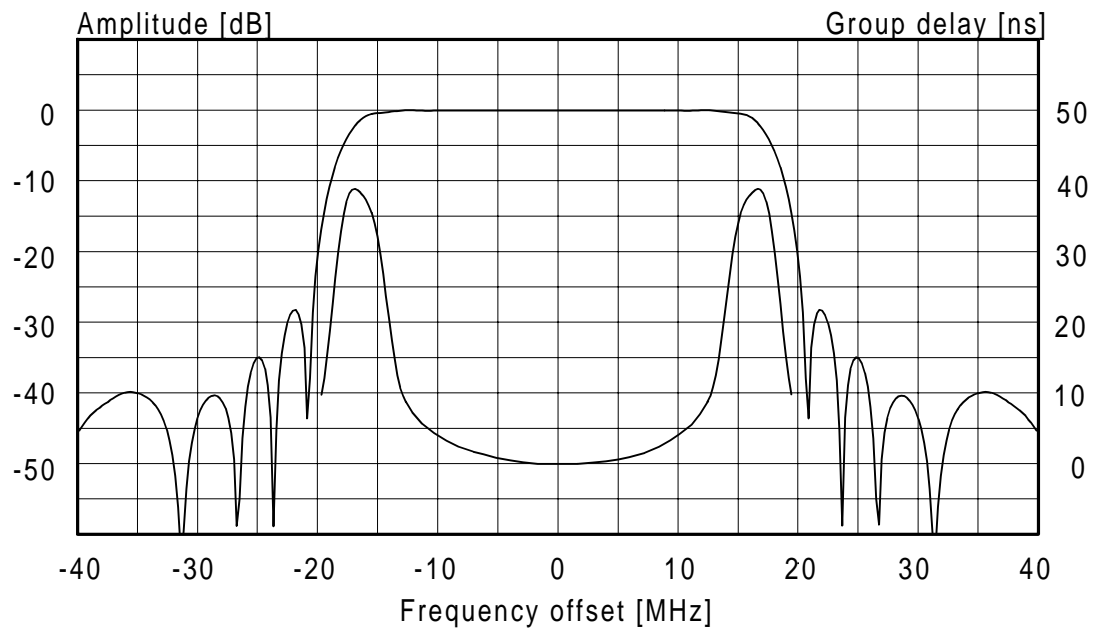


Figure C.1: Hypothetical IMUX filter characteristic

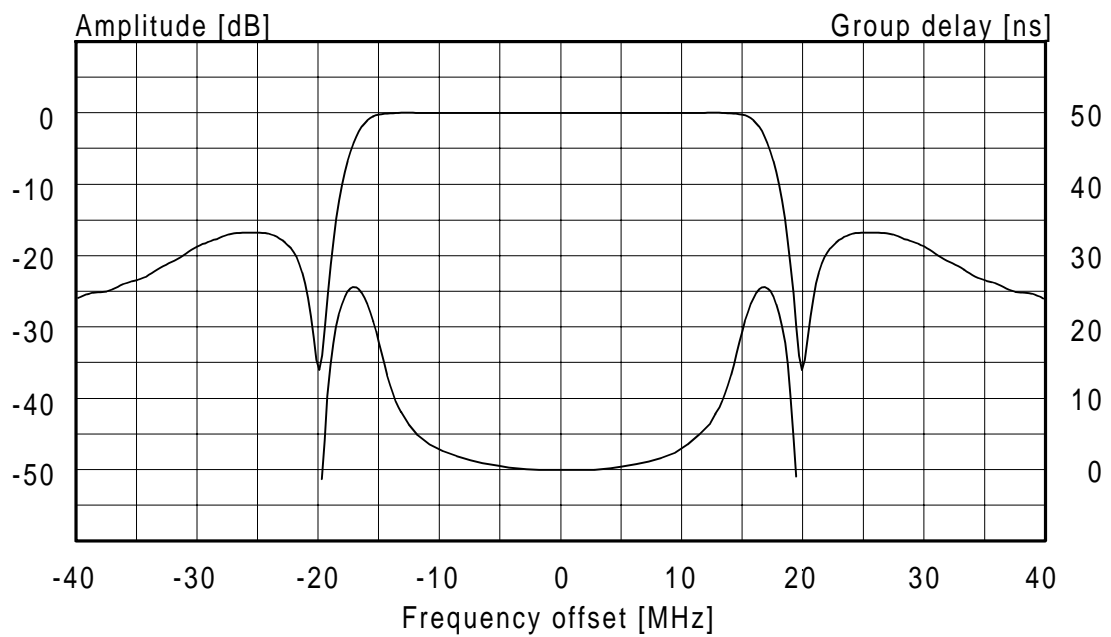


Figure C.2: Hypothetical OMUX filter characteristic

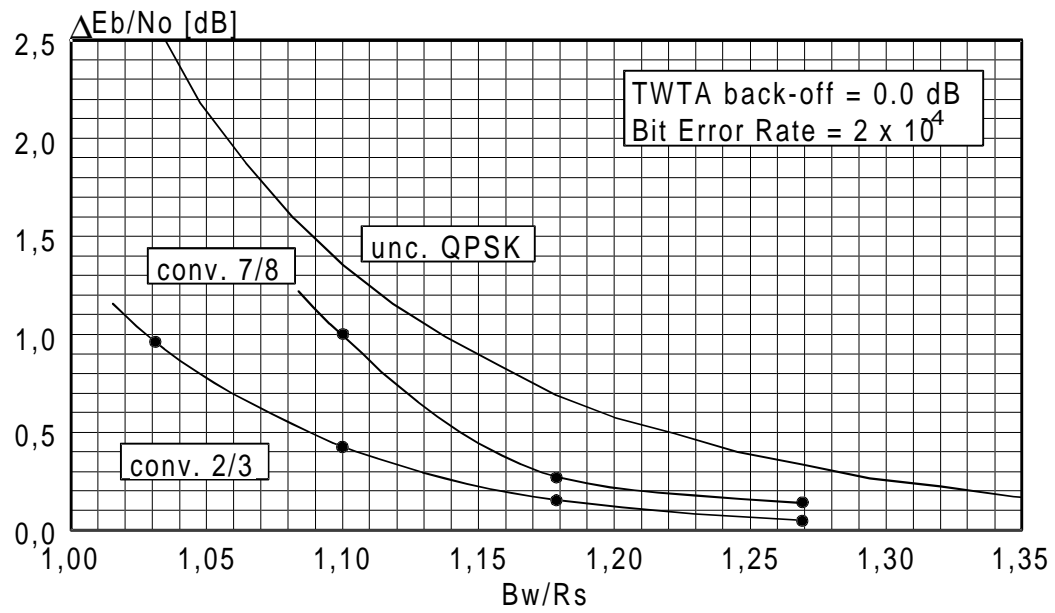


Figure C.3: Example degradation due to transponder bandwidth limitation

Annex D (informative): Examples of possible use of the System

Table D.1 considers possible examples of use of the System for a nominal transponder bandwidth (-3dB) of 33 MHz. Different inner code rates are given with the relevant bit rates.

Figure D.1 shows that the example highlighted in table D.1 with rate 2/3 inner code would be suitable for connection to a Plesiochronous Digital Hierarchy (PDH) terrestrial network at 34,368 Mbit/s, including the same Reed-Solomon error protection used by satellite.

Table D.1: Example of System performance over 33 MHz transponder

Bit Rate R_u (after MUX) [Mbit/s]	Bit Rate R'_u (after RS) [Mbit/s]	Symbol Rate [Mbaud]	Convolut. Inner Code Rate	RS Outer Code Rate	C/N (33 MHz) [dB]
23,754	25,776	25,776	1/2	188/204	4,1
31,672	34,368	25,776	2/3	188/204	5,8
35,631	38,664	25,776	3/4	188/204	6,8
39,590	42,960	25,776	5/6	188/204	7,8
41,570	45,108	25,776	7/8	188/204	8,4

NOTE 1: The figures in table D.1 refer to computer simulation results achieved on a hypothetical satellite chain, including IMUX, TWTA and OMUX (see figures C.1 and C.2), with modulation roll-off of 0,35. The C/N figures are based on the assumption of soft-decision Viterbi decoding in the receiver. The ratio $BW/R_s = 1,28$ has been adopted.

NOTE 2: The figures for C/N include a calculated degradation of 0,2 dB due to bandwidth limitations on IMUX and OMUX filters, 0,8 dB non-linear distortion on TWTA at saturation and 0,8 dB modem degradation. The figures apply to $BER = 2 \times 10^{-4}$ before RS(204,188), which corresponds to "Quasi Error Free" at the RS coder output. Degradation due to interference is not taken into account.

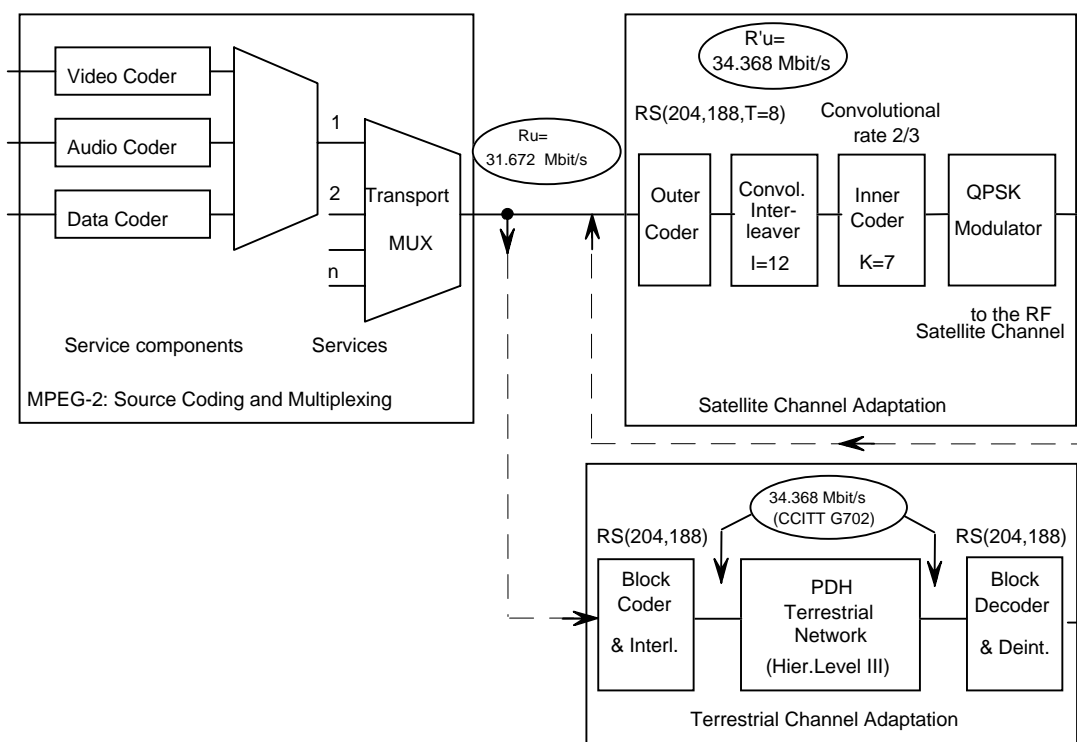


Figure D.1: Example of connection of the System with the terrestrial PDH network

Annex E (informative): Bibliography

For the purposes of the present document, the following informative references apply:

- DTVB 1163/GT V4/MOD 269 2nd revised version (November 1993): "Potential applications of the baseline modulation/channel coding system for digital multi-programme television by satellite" (Contribution from V4/MOD).
- Reimers, U. NAB'93, (EBU V4/MOD 249): "The European perspectives on Digital Television Broadcasting".
- Cominetti, M., Morello, A., Visintin, M. EBU Review - Technical, Summer '93, (EBU V4/MOD 235 rev.): "Satellite digital multi-programme TV/HDTV".
- DTVB 1110/GT V4/MOD 252/ DTVC 18, 7th revised version, January 1994: "Baseline modulation/channel coding system for digital multi-programme television by satellite" (Contribution from V4/MOD-B).
- EN 300 429: "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems".

History

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