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MODULATION AND CODING REQUIREMENTS FOR DIGITAL TV (DTV) APPLICATIONS OVER SATELLITE

ATSC STANDARD

ADVANCED TELEVISION SYSTEMS COMMITTEE

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ATSC STANDARD

1. SCOPE

1.1 Purpose

This document defines a standard for modulation and coding of data delivered over satellite for digital television (DTV) applications. The data can be a collection of program material including video, audio, data, multimedia or other material generated in a digital format. It includes digital multiplex bit streams constructed in accordance with ISO/IEC 13818-1 (MPEG-2 systems), but is not limited to these and makes provision for arbitrary types of data, as well.

The modulation and coding of data for satellite transmission and reception is the main focus of this standard. It entails the transformation of data using error correction, signal mapping and modulation to produce a digital carrier suitable for satellite transmission. In particular, quadrature phase shift modulation (QPSK), eight phase shift modulation (8PSK) and sixteen quadrature amplitude modulation (16QAM) schemes are specified. The main distinction between QPSK, 8PSK and 16QAM is the amount of bandwidth and power required for transmission. Generally, for the same data rate, progressively less bandwidth is consumed by QPSK, 8PSK and 16QAM, respectively, but the improved bandwidth efficiency is accompanied by an increase in power to deliver the same level of signal quality.

A second parameter, coding, also influences the amount of bandwidth and power required for transmission. Coding, or in this instance, forward error correction (FEC) adds information to the data stream that reduces the amount of power required for transmission and improves reconstruction of the data stream received at the demodulator. While the addition of more correction bits improves the quality of the received signal, it also consumes more bandwidth in the process. So, the selection of FEC serves as another tool to balance bandwidth and power in the satellite transmission link. Other parameters exist, as well, such as transmit filter shape factor (commonly known as "α"), which have an effect on bandwidth and power efficiency of the system.

System operators optimize the transmission parameters of a satellite link by carefully considering a number of tradeoffs. In a typical scenario for a broadcast network, material is generated at multiple locations and requires delivery to multiple destinations by transmitting one

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NOTE: The user's attention is called to the possibility that compliance with this standard may require use of an invention covered by patent rights. By publication of this standard, no position is taken with respect to the validity of this claim, or of any patent rights in connection therewith. The patent holder has, however, filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license. Details may be obtained from the publisher.

or more carriers over satellite, as dictated by the application. Faced with various size antennas, available satellite bandwidth, satellite power and a number of other variables the operator will tailor the system to efficiently deliver the data payload. The important tools available to the operator for dealing with this array of system variables include the selection of the modulation, FEC, and “α” value for transmission.

1.2 Services / Applications

The need for this standard arises from applications that require satellite transmission to deliver program material and/or associated data. Two distinct types of services are considered in this standard:

- **Contribution** - transmission of programming/data from a programming source to a broadcast center. Examples include such program material as digital satellite news gathering (DSNG), sports and special events;
- **Distribution** - transmission of material (programming and/or data) from a broadcast center to its affiliate or member stations;

The applications were the primary interest to the industry participants of the ATSC Specialist Group on Satellite Transmission (T3/S14).[1] There was an immediate need for the ATSC to address technical standards for satellite transmission that was driven by the ambitious schedule for the introduction of DTV services in the United States.[2]

1.3 Industry Standards

This document relies heavily upon previous work done by the Digital Video Broadcasting (DVB) Project of the European Broadcast Union (EBU) for satellite transmission. Where applicable this standard sets forth requirements by reference to those standards, particularly EN 300 421 (QPSK) and prEN 301 210 (QPSK, 8PSK and 16QAM).

1.4 Modulation And Coding Compliance

The modulation and coding defined in this standard have mandatory and optional provisions. QPSK is considered mandatory as a mode of transmission, while 8PSK and 16QAM are optional. Whether equipment implements optional features is a decision for the manufacturer. However, when optional features are implemented they shall be in accordance with this standard in order to be compliant with it.

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[1] The industry responses are summarized in document T3/S14-043, *ATSC T3/S14 Specialist Group On Satellite Communications, RFI Response Summaries*.

[2] The development of a Direct-To-Home (DTH) satellite transmission standard by the ATSC is, at the time of this writing, a future work item.

2. REFERENCES

The following documents are applicable to this standard:

Normative:

1) EN 300 421 (v1.1.2, 1997-08), Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/12 GHz satellite services.[*]

Informative:

1) IESS-308 (Rev 9, 30 Nov 1998), Intelsat Earth Station Standards, Performance Characteristics For Intermediate Data Rate Digital Carriers Using Convolutional Encoding/Viterbi Encoding and QPSK Modulation.[**]
2) IESS-310 (Rev 1, 30 Nov 1998), Intelsat Earth Station Standards, Performance Characteristics For Intermediate Data Rate Digital Carriers Using Rate 2/3 TCM / 8PSK And Reed-Solomon Outer Coding.[**]
3) EN 301 210 (v1.1.1, 1999-03), Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for Digital Satellite News Gathering (DSNG) and other contribution applications by satellite *(portions of this document may become normative)*.[*]

[*] EN documents: European Telecommunications Standards Institute (ETSI), Nice, France. <www.etsi.org>

[**] IESS documents: INTELSAT, Washington, D.C., USA. <www.intelsat.com>

3. DEFINITIONS

3.1 Compliance Notation

As used in this document, *"shall"* or *"will"* denotes a mandatory provision of the standard. *"Should"* denotes a provision that is recommended but not mandatory. *"May"* denotes a feature whose presence does not preclude compliance, that may or may not be present at the option of the implementer.

3.2 Acronyms and Abbreviations

The following acronyms and abbreviations are used within this standard:

16QAM	Sixteen Quadrature Amplitude Modulation
1CBPS	1 Coded Bit Per Symbol
2CBPS	2 Coded Bits Per Symbol
8PSK	Eight Phase Shift Keying
ASCII	American Standard Code for Information Interchange
ATSC	Advanced Television Systems Committee
AWGN	Additive White Gaussian Noise
BER	Bit Error Ratio
BW_S	Slot bandwidth (for a given service, within a transponder)
BW_T	Transponder bandwidth
DSNG	Digital Satellite News Gathering
DTH	Direct To Home
DTV	Digital Television
DVB	Digital Video Broadcasting
DVB-SI	Digital Video Broadcasting – Service Information
EBU	European Broadcasting Union
ETS	European Telecommunication Standard
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FIFO	First-In, First-Out shift register
FIR	Finite Impulse Response
GHz	Gigahertz (10^9 cycles per second)
HDTV	High Definition Television
HEX	Hexadecimal notation
HPA	High power amplifier
I/O	Input/Output
IBO	Input Back Off
IDR	Intermediate data rate
IEC	International Electrotechnical Commission
IESS	Intelsat Earth Station Standard
IF	Intermediate Frequency

ISO	International Standards Organization
LNA	Low-noise amplifier
LNB	Low-noise block downconverter
Mbps	Megabits per second (10^6 bits per second)
MCPC	Multiple Channels Per Carrier
MHz	Megahertz (10^6 cycles per second)
MPEG	Moving Picture Experts Group
MSB	Most Significant Bit
MUX	Multiplex
OBO	Output Back Off
OCT	Octal notation
P	Puncturing
PAT	Program Association Table
PMT	Program Map Table
PRBS	Pseudo Random Binary Sequence
PSK	Phase Shift Keying
QEF	Quasi-Error-Free
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RFI	Request For Information
RS	Reed-Solomon
SCPC	Single Channel Per Carrier
SI	Service Information
SNG	Satellite News Gathering
TBD	To Be Determined
TCM	Trellis Coded Modulation
TDM	Time Division Multiplex
TSDT	Transport Stream Descriptor Table
TV	Television
TWTA	Traveling Wave Tube Amplifier
uimsbf	Unsigned integer most significant bit first

3.3 Symbols

For the purposes of this standard, the following symbols apply:

0x	Denotes hexadecimal format (e.g., 0xFF)
α	Roll-off factor
C/N	Carrier-to-noise ratio
C1, C2	Outputs of punctured convolutional encoder (QPSK)
d_{free}	Convolutional code free distance
E_b/N_0	Ratio of the energy per useful bit to 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
k/n	Rate of the punctured convolutional code
m	number of transmitted bits per constellation symbol
M	Convolutional interleaver branch depth for j = 1, M = N/I
η	Bandwidth shaping factor (=1+α)
N	Error protected frame length (bytes)
p(x)	RS field generator polynomial
$\mathbf{r_m}$	In-band ripple (dB)
$\mathbf{R_{TCM}}$	Rate of the trellis code
$\mathbf{R_s}$	Symbol rate corresponding to the bilateral Nyquist bandwidth of the modulated signal
$\mathbf{R_u}$	Useful bit rate after MPEG-2 [1] transport multiplexer, referred to the 188 byte format
$\mathbf{R_u(204)}$	Bit rate after RS outer coder, referred to the 204 byte format
T	Number of bytes which can be corrected in RS error protected packet
$\mathbf{T_s}$	Symbol period
X,Y	Bit streams after rate 1/2 convolutional coding

4. SYSTEM DEFINITION - OVERVIEW

A digital satellite transmission system is capable of delivering data from one location to one or more destinations. A block diagram of a simple system is shown in Figure 4.1. It depicts a data source and data sink which might represent a video encoder/multiplexer or decoder/demultiplexer for ATSC applications, but can also represent a variety of other sources which produce a digital data stream.

This particular point, the accommodation of arbitrary data streams, is a distinguishing feature between the systems supported by this standard and those supported by the DVB specifications EN 300 421 and prEN 301 210, which deal solely with MPEG transport streams. ATSC-compliant satellite transmission systems, for contribution and distribution applications, will accommodate arbitrary data streams as outlined in the sections which follow.

The subject of this standard is the segment between the dashed lines designated by the reference points, and includes the modulator and demodulator. Only the modulation parameters are specified, and the receive equipment is designed to recover the transmitted signal. This standard does not preclude combining equipment outside the dashed lines with the modulator or demodulator, but it sets a logical demarcation between functions.

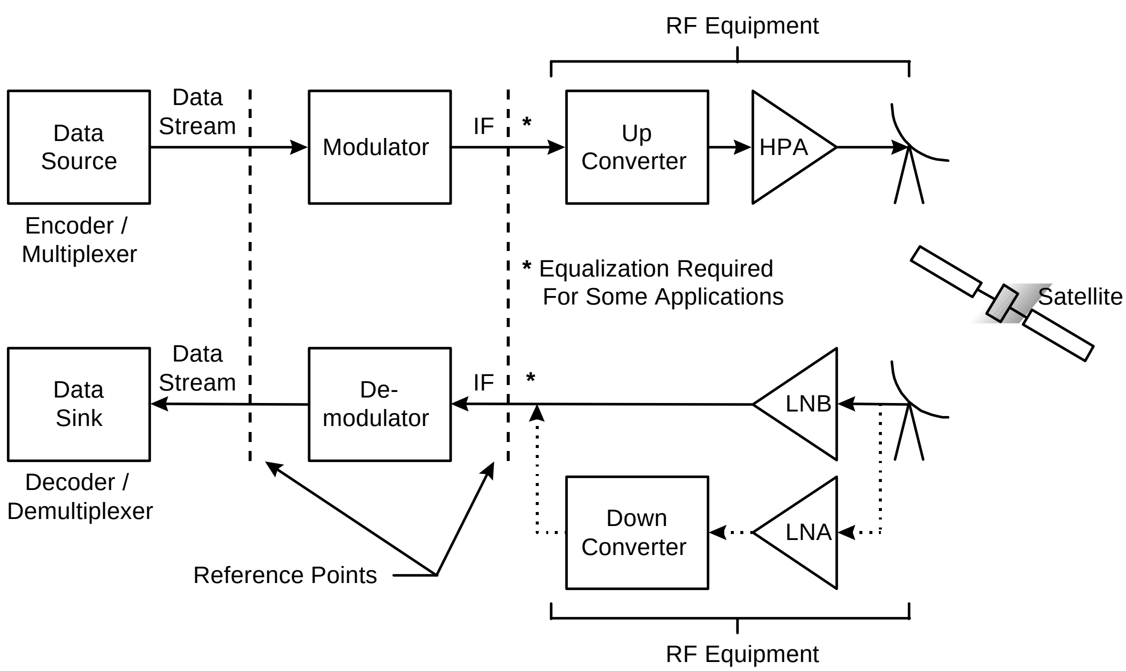


Figure 4.1 System Block Diagram

In the diagram the modulator accepts a data stream and operates upon it to generate an intermediate frequency (IF) carrier suitable for satellite transmission. The data are acted upon by forward error correction (FEC), interleaving and mapping to QPSK, 8PSK or 16QAM, frequency conversion and other operations to generate the IF carrier. The selection of the modulation type and FEC affects the bandwidth of the IF signal produced by the modulator. Selecting QPSK, 8PSK or 16QAM consumes successively less bandwidth as the modulation type changes from QPSK to 8PSK to 16QAM. So, it is possible to use less bandwidth for the same data rate or increase the data rate through the available bandwidth by altering the modulation type.

Coding or FEC has a similar impact on bandwidth. More powerful coding adds more information to the data stream and increases the occupied bandwidth of the IF signal emitted by the modulator. There are two types of coding applied in the modulator. An outer Reed Solomon code is concatenated with an inner convolutional/trellis code to produce error correction capability exceeding the ability of either coding method used alone. The amount of coding is referred to as the *code rate*, quantified by a dimensionless fraction (k/n) where n indicates the number of bits out of the encoder given k input bits (e.g., rate 1/2 or rate 7/8). The Reed Solomon code rate is fixed at 188 / 204, but the inner convolutional/trellis code rate is selectable offering the opportunity to modify the transmitted IF bandwidth. For example, choosing a higher inner code rate, say 7/8 instead of 1/2, also reduces the occupied bandwidth for a given information rate.

One consequence of selecting a more bandwidth efficient modulation or a higher inner code rate is an increase in the amount of power required to deliver the same level of performance. The key measure of power is the Eb/No (energy per useful bit relative to the noise power per Hz), and the key performance parameter is the bit error ratio (BER) delivered at a particular Eb/No. For digital video, a BER of about 10^{-10} is necessary to produce high quality video. So, noting the Eb/No required to produce a given BER provides a way of comparing modulation and coding schemes. It also provides a relative measure of the power required from a satellite transponder, at least for a linear transponder operation.

5. TRANSMISSION SYSTEM

5.1 System definition

The requirements for the modulation and coding processes performed on the input data stream are specified in this section. For this standard, these requirements are defined only for the modulator, which is sufficient to permit design of a receiver to recover the transmitted data stream. The following processes shall be applied to the data stream (also refer to Figure 5.1, which expands the “modulator” segment shown between the dashed lines in the system block diagram, Figure 4.1):

- Packetizing & energy dispersal;
- Reed Solomon outer coding;
- Interleaving;
- Convolutional inner coding;
- Baseband shaping for modulation;
- Modulation.

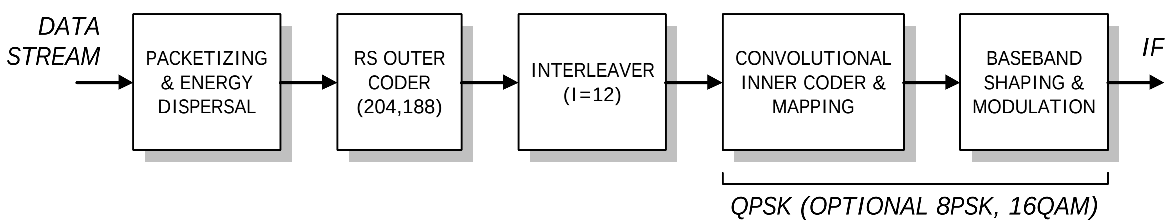


Figure 5.1 Baseband And Modulator Block Diagram

5.2 Adaptation to satellite transponder characteristics

This standard was designed to accommodate a variety of bit rates and transponder characteristics and as such, does not restrict the bit rate ranges or transponder bandwidths to which it applies. Examples of possible uses of the described system are discussed in Annex B, and refer to specific rates and bandwidths.

5.3 Interfacing

The input to the modulator is a data stream delivered to the modulator. The physical and electrical properties of the data interface are outside the scope of this standard.[3]

[3] Work is currently underway in the ATSC and other industry forums to define appropriate data interfaces.

The output of the modulator is an IF signal which is modulated by the processed input data stream. This is the signal delivered to RF equipment for transmission to the satellite. Table 5.1 shows the system inputs and outputs.

Table 5.1 System Interfaces

Location	System Inputs/Outputs	Type	Connection
Transmit station	Input	MPEG-2 transport (Note 1) or arbitrary	From MPEG-2 multiplexer or other
	Output	70/140 MHz IF, L-band IF, RF (Note 2)	To RF devices
Receive installation	Input	70/140 MHz IF, L-band IF (Note 2)	From RF devices
	Output	MPEG-2 transport (Note 1) or arbitrary	To MPEG-2 de-multiplexer or other

Notes:

(1) In accordance with ISO/IEC 13838-1;

(2) The IF bandwidth may impose a limitation on the maximum symbol rate.

5.3.1 Data streams

The data stream is the digital input applied to the modulator. This standard does not specify the interface, so the data stream presented to the packetizing and energy dispersal block is shown conceptually as a serial data stream, although a parallel bit stream is equally valid. There shall be two types of packet structures supported by this standard:

Table 5.2 Input Data Stream Structures

Type	Description
1	The packet structure shall be a constant rate MPEG-2 transport per ISO/IEC 13818-1 (188 or 204 bytes per packet including 0x47 sync, MSB first).
2	The input shall be a constant rate data stream that is arbitrary. In this case, the modulator takes successive 187 byte portions from this stream and prepends a 0x47 sync byte to each portion, to create a 188 byte MPEG-2 like packet. (The demodulator will remove this packetization so as to deliver the original, arbitrary stream at the demodulator output.)

5.4 QPSK modes

5.4.1 Packetization and randomization for energy dispersal

Shall be per EN 300 421, Section 4.4.1.

“Fixed length packets,” as referred to in EN 300 421, shall either represent the actual structure of the input data stream itself (for Type 1 data streams as described in Table 5.2 above), or the (constant data rate) data stream whose structure is altered by the modulator as described for Type 2 data in Table 5.2 above. In these cases (i.e. for Type 2 data), the comments in EN 300 421 specifying the MPEG-2 transport as the data source, do not apply.

5.4.2 Outer coding (RS), interleaving, and framing

Shall be per EN 300 421, Section 4.4.2.

5.4.3 Inner coding (convolutional)

Shall be per EN 300 421, Section 4.4.3.

5.4.4 Bit mapping to QPSK constellation

Bit mapping into the symbol constellation shall be in accordance with EN 300 421, Section 4.5, as summarized below.

The serial bit stream (see Figure 5.2) shall be directly fed into the convolutional encoder. The outputs C1 and C2 of the punctured convolutional encoder shall be directly sent to the QPSK mapper.

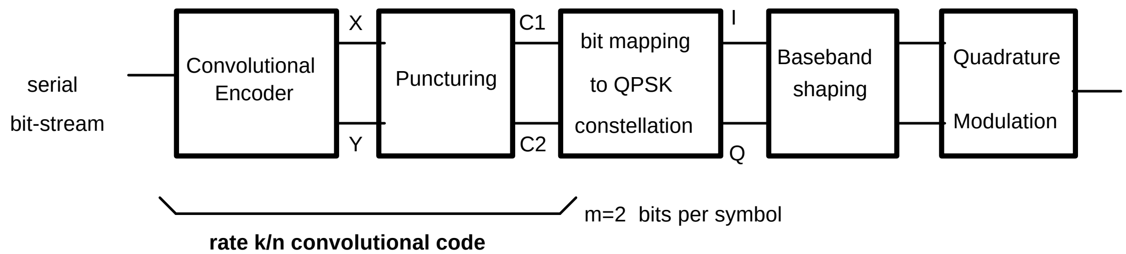


Figure 5.2 Inner coding principle for QPSK

The system shall employ conventional Gray-coded QPSK modulation with absolute mapping (no differential coding). Bit mapping in the QPSK constellation shall follow Figure 5.3. If the normalization factor $1/\sqrt{2}$ is applied to the I and Q components, the corresponding average energy per symbol becomes equal to 1.

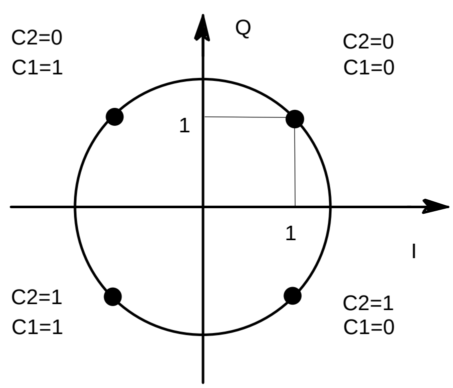


Figure 5.3 Bit mapping into QPSK constellation

5.4.5 Baseband shaping

Baseband shaping shall be in accordance with EN 300 421, Section 4.5, as summarized below.

Prior to modulation, the I and Q signals (mathematically represented by a succession of Dirac delta functions, multiplied by the amplitudes I and Q, spaced by the symbol duration $T_s = 1/R_s$) shall be square root raised cosine filtered. The roll-off factor shall be $\alpha = 0.35$.

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

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

$$H(f) = \left\{ \frac{1}{2} + \frac{1}{2} sin \frac{p}{2 f_N} \left[\frac{f_N - |f|}{a} \right] \right\}^{1/2} \quad \text{for} \quad f_N(1 - a) \le |f| \le f_N(1 + a)$$

$$H(f) = 0 \; for |f| > f_N (1 + a),$$

where

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

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

5.5 Optional 8PSK modes

5.5.1 Packetization and randomization for energy dispersal

Shall be per EN 300 421, Section 4.4.1.

"Fixed length packets," as referred to in EN 300 421, shall either represent the actual structure of the input data stream itself (for Type 1 data streams as described in Table 5.2 above), or the (constant data rate) data stream whose structure has been altered by the modulator as described for Type 2 data in Table 5.2 above. In these cases (i.e. for Type 2 data), the comments in EN 300 421 specifying the MPEG-2 transport multiplexer as the data source, do not apply.

5.5.2 Outer coding (RS), interleaving, and framing

Shall be per EN 300 421, Section 4.4.2.

5.5.3 Inner coding ("pragmatic" trellis coding type)

Shall be per prEN 301 210, Section 4.6.3.

5.5.4 Bit mapping to constellations

Shall be per prEN 301 210, Section 4.7.1.

5.5.4.1 Inner coding and constellation for 8PSK 2/3 (2CBPS)

Shall be per prEN 301 210, Section 4.7.1.1.

5.5.4.2 Inner coding and constellation for 8PSK 5/6 and 8/9 (1CBPS)

Shall be per prEN 301 210, Section 4.7.1.2.

5.5.5 Baseband shaping

Shall be per prEN 301 210, Section 4.7.2.

5.6 Optional 16QAM modes

5.6.1 Packetization and randomization for energy dispersal

Shall be per EN 300 421, Section 4.4.1.

"Fixed length packets," as referred to in EN 300 421, shall either represent the actual structure of the input data stream itself (for Type 1 data streams as described in Table 5.2 above), or the (constant data rate) data stream whose structure has been altered by the modulator as described for Type 2 data in Table 5.2 above. In these cases (i.e. for Type 2 data), the comments in EN 300 421 specifying the MPEG-2 transport multiplexer as the data source, do not apply.

5.6.2 Outer coding (RS), interleaving, and framing

Shall be per EN 300 421, Section 4.4.2.

5.6.3 Inner coding ("pragmatic" trellis coding type)

Shall be per prEN 301 210, Section 4.6.3.

5.6.4 Bit mapping to constellations

Shall be per prEN 301 210, Section 4.7.1.

5.6.4.1 Inner coding and constellation for 16QAM 3/4 and 7/8 (2CBPS)

Shall be per prEN 301 210, Section 4.7.1.3.

5.6.5 Baseband shaping

Shall be per prEN 301 210, Section 4.7.2.

6. ERROR PERFORMANCE REQUIREMENTS

6.1 QPSK modes

Shall be per EN 300 421, Section 5 (specified for IF loopback connection). This requirement is also presented below in Table 6.1.

Table 6.1 IF-loop performance of the system (QPSK modes)

Inner Code Rate	Spectral Efficiency (bit/symbol)	Modem Implementation Margin (dB)	Required Eb/No (Note 1) for BER = $2x10^{-4}$ before RS; QEF (Note 2) after RS (dB)
1/2	0.92	0.8	4.5
2/3	1.23	0.8	5.0
3/4	1.38	0.8	5.5
5/6	1.53	0.8	6.0
7/8	1.61	0.8	6.4

Notes:

(1) The figures of E_b/N_o are referred to the useful bit-rate R_u (188 byte format, before RS coding), taking into account the noise bandwidth increase due to the RS outer code, equaling 10 Log (188/204) ≈ 0.36 dB, and including the modem implementation margin;

(2) Quasi-Error-Free (QEF) means less than one uncorrected error event per hour, corresponding to a BER of $1x10^{-10}$ to $1x10^{-11}$ at the output of the RS decoder.

6.2 Optional 8PSK modes

Shall be per prEN 301 210, Section 5 (specified for IF loopback connection). This requirement is also presented below in Table 6.2.

Table 6.2 Loop performance of the system (optional 8PSK modes)

Inner Code Rate	Spectral Efficiency (bit/symbol)	Modem Implementation Margin (dB)	Required Eb/No (Note 1) for BER = $2x10^{-4}$ before RS; QEF (Note 2) after RS (dB)
2/3	1.84	1.0	6.9
5/6	2.30	1.4	8.9
8/9 (Note 3)	2.46	1.5	9.4

Notes:

(1) The figures of E_b/N_o are referred to the useful bit-rate R_u (188 byte format, before RS coding), taking into account the noise bandwidth increase due to the RS outer code, equaling 10 Log (188/204) ≈ 0.36 dB, and including the modem implementation margin. Modem implementation margins which increase with the spectrum efficiency are adopted, to cope with the larger sensitivity associated with these schemes;

(2) Quasi-Error-Free (QEF) means approximately less than one uncorrected error event per hour at the output of the RS decoder. The BER of $2x10^{-4}$ before RS decoding corresponds

approximately to a *byte* error ratio of between 7x10^{-4} and 2x10^{-3}, depending on the coding scheme. This corresponds approximately to a BER of 1x10^{-10} to 1x10^{-11} at the output of the RS decoder;

(3) 8PSK 8/9 is suitable for satellite transponders driven near saturation, while 16QAM 3/4 offers better spectrum efficiency for quasi-linear transponders, in FDMA configuration.

6.3 Optional 16QAM modes

Shall be per prEN 301 210, Section 5 (specified for IF loopback connection). This requirement is also presented below in Table 6.3.

Table 6.3 IF-Loop performance of the system (optional 16QAM modes)

Inner Code Rate	Spectral Efficiency (bit/symbol)	Modem Implementation Margin (dB)	Required Eb/No (Note 1) for BER = 2x10^{-4} before RS; QEF (Note 2) after RS (dB)
3/4 (Note 3)	2.76	1.5	9.0
7/8	3.22	2.1	10.7

Notes:

(1) The figures of E_b/N_o are referred to the useful bit-rate R_u (188 byte format, before RS coding), taking into account the noise bandwidth increase due to the RS outer code, equaling 10 Log (188/204) ≈ 0.36 dB, and including the modem implementation margin. Modem implementation margins which increase with the spectrum efficiency are adopted, to cope with the larger sensitivity associated with these schemes;

(2) Quasi-Error-Free (QEF) means approximately less than one uncorrected error event per hour at the output of the RS decoder. The BER of 2x10^{-4} before RS decoding corresponds approximately to a *byte* error ratio of between 7x10^{-4} and 2x10^{-3}, depending on the coding scheme. This corresponds approximately to a BER of 1x10^{-10} to 1x10^{-11} at the output of the RS decoder;

(3) 8PSK 8/9 is suitable for satellite transponders driven near saturation, while 16QAM 3/4 offers better spectrum efficiency for quasi-linear transponders, in FDMA configuration.

ANNEX A

(Normative)

SIGNAL SPECTRUM AT THE MODULATOR OUTPUT

For QPSK modulation, the signal spectrum at the modulator output shall be in accordance with EN 300 421, relevant to a roll-off factor $\alpha = 0.35$. Figure A.1 gives a template for the signal spectrum at the modulator output for a roll-off factor $\alpha = 0.35$.

Figure A.1 also represents a possible mask for a hardware implementation of the Nyquist modulator filter. The points A through S shown on Figures A.1 and A.2 are defined in Table A.1 for roll-off factors $\alpha = 0.35$ and $\alpha = 0.25$. 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 a hardware implementation of the Nyquist modulator filter.

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

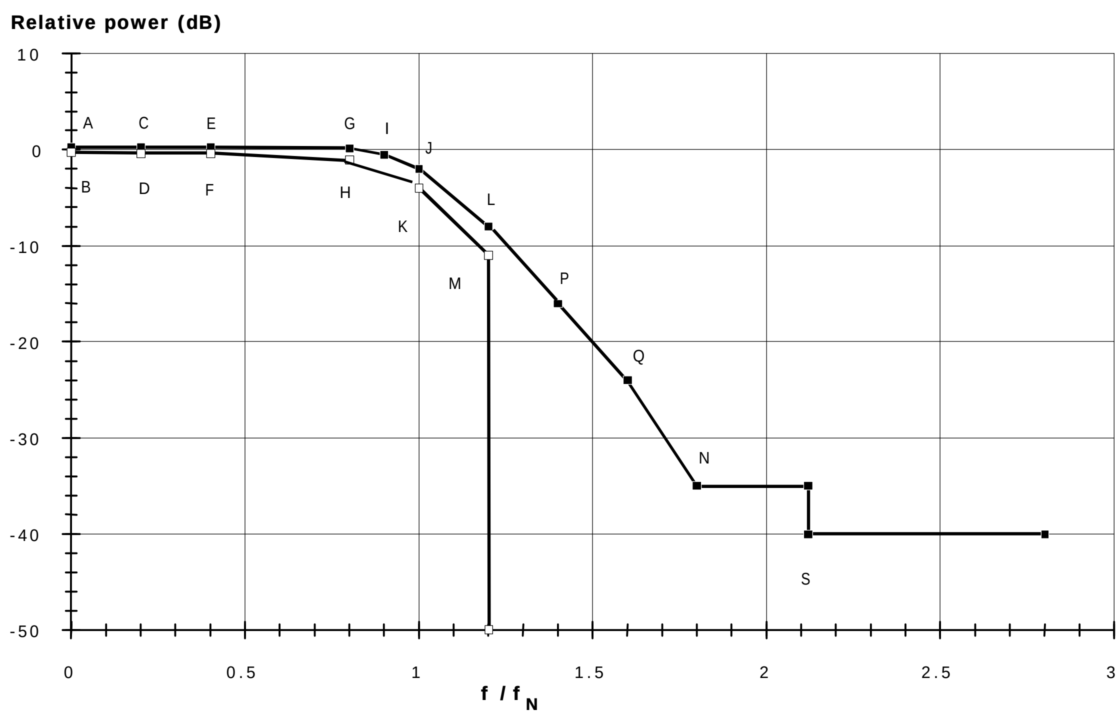


Figure A.1 Template for the signal spectrum mask at the modulator output represented in the baseband frequency domain (roll-off factor $\alpha = 0.35$).

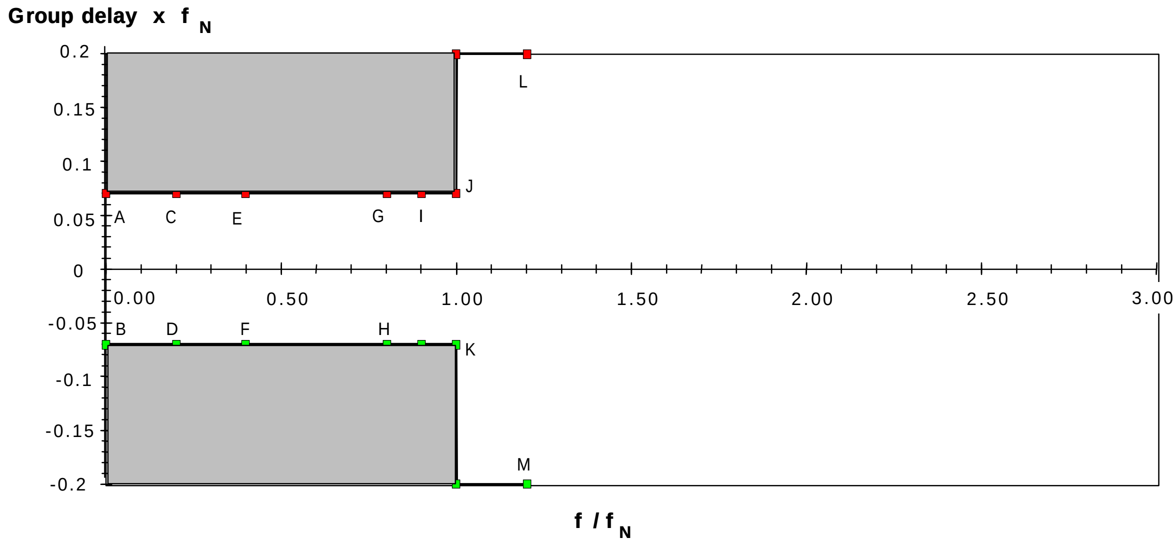


Figure A.2 Template of the modulator filter group delay (roll-off factors α = 0.35 and α = 0.25)

Table A.1 Definition of points given in figures A.1 and A.2

Point	Frequency for α = 0.35	Frequency for α = 0.25 *	Relative power (dB)	Group delay
A	0.0 f_N	0.0 f_N	+0.25	+0.07 / f_N
B	0.0 f_N	0.0 f_N	-0.25	-0.07 / f_N
C	0.2 f_N	0.2 f_N	+0.25	+0.07 / f_N
D	0.2 f_N	0.2 f_N	-0.40	-0.07 / f_N
E	0.4 f_N	0.4 f_N	+0.25	+0.07 / f_N
F	0.4 f_N	0.4 f_N	-0.40	-0.07 / f_N
G	0.8 f_N	0.86f_N	+0.15	+0.07 / f_N
H	0.8 f_N	0.86 f_N	-1.10	-0.07 / f_N
I	0.9 f_N	0.93 f_N	-0.50	+0.07 / f_N
J	1.0 f_N	1.0 f_N	-2.00	+0.07 / f_N
K	1.0 f_N	1.0 f_N	-4.00	-0.07 / f_N
L	1.2 f_N	1.13 f_N	-8.00	-
M	1.2 f_N	1.13 f_N	-11.00	-
N	1.8 f_N	1.60 f_N	-35.00	-
P	1.4 f_N	1.30 f_N	-16.00	-
Q	1.6 f_N	1.45 f_N	-24.00	-
S	2.12 f_N	1.83 f_N	-40.00	-

(*) The roll-off factor α = 0.25 is optional and applicable to 8PSK and 16QAM only.

Equalization of the RF equipment and the transmission channel usually becomes necessary for higher symbol rate carriers. It is possible to compensate the RF equipment and the transmission channel using an equalizer or a modulator with equalizer settings for system applications.

ANNEX B

(Informative)

EXAMPLES OF POSSIBLE USE OF THE SYSTEM

In single carrier per transponder configurations, the transmission symbol rate R_s can be matched to a given transponder bandwidth, BW_T, to achieve the maximum transmission capacity compatible with acceptable signal degradation. To take into account possible thermal and aging characteristics, reference is made to the frequency response mask of the transponder.

In a multi-carrier (i.e. frequency division multiplex or FDM) configuration, R_s can be matched to a frequency slot bandwidth, BW_S (allocated to the service by a frequency plan), to optimize the transmission capacity while keeping the mutual interference between adjacent carriers at an acceptable level.

Tables B.1 and B.2 give examples of the maximum useful bit rate capacity R_u achievable by the system versus the allocated bandwidths BW_T (i.e. transponder bandwidth) or BW_S (i.e. slot bandwidth, less than the transponder bandwidth by definition), for Type 1 and Type 2 data as defined in the standard (Table 5.2). The figures for very low and very high bit-rates may be irrelevant for specific applications. In these two tables, the adopted BW_T / R_s or BW_S / R_s ratios are $\eta = (1+\alpha) = 1.35$ where α is the roll-off factor of the modulation. This choice allows for a negligible E_b/N_o degradation due to transponder bandwidth limitations, and also due to adjacent channel interference for a linear channel.

Higher bit-rates can be achieved with the narrower roll-off factor $\alpha=0.25$ (optional for 8PSK and 16QAM) and BW_T / R_s or BW_S / R_s equal to $\eta = (1+\alpha) = 1.25$. Tables B.3 and B.4 provide examples of the maximum useful bit rate capacity R_u in these cases, again, for Type 1 and Type 2 data, respectively. The adoption of BW_T / R_s or BW_S / R_s significantly lower than this, in order to improve the spectrum exploitation, should be carefully studied on a case-by-case basis, since severe performance degradations may arise due to bandwidth limitations and/or adjacent channel interference, especially with optional 8PSK and 16QAM modulations and higher coding rates.

Table B.1 Examples of Maximum Usable Bit Rate for the Type 1 Data Stream Structure ($\alpha = 0.35$)

Available bandwidth	Maximum transmission symbol rate (α = 0.35)	Maximum usable bit rate, Mbps									
		QPSK					8PSK			16QAM	
(MHz)	*(Msps)*	*rate 1/2*	*rate 2/3*	*rate 3/4*	*rate 5/6*	*rate 7/8*	*rate 2/3*	*rate 5/6*	*rate 8/9*	*rate 3/4*	*rate 7/8*
72	53.3333	49.1503	65.5338	73.7255	81.9172	86.0131	98.3007	122.8758	131.0675	147.4510	172.0261
54	40.0000	36.8627	49.1503	55.2941	61.4379	64.5098	73.7255	92.1569	98.3007	110.5882	129.0196
46	34.0741	31.4016	41.8688	47.1024	52.3360	54.9528	62.8032	78.5040	83.7376	94.2048	109.9056
41	30.3704	27.9884	37.3178	41.9826	46.6473	48.9797	55.9768	69.9710	74.6357	83.9651	97.9593
36	26.6667	24.5752	32.7669	36.8627	40.9586	43.0065	49.1503	61.4379	65.5338	73.7255	86.0131
33	24.4444	22.5272	30.0363	33.7908	37.5454	39.4227	45.0545	56.3181	60.0726	67.5817	78.8453
30	22.2222	20.4793	27.3057	30.7190	34.1322	35.8388	40.9586	51.1983	54.6115	61.4379	71.6776
27	20.0000	18.4314	24.5752	27.6471	30.7190	32.2549	36.8627	46.0784	49.1503	55.2941	64.5098
18	13.3333	12.2876	16.3834	18.4314	20.4793	21.5033	24.5752	30.7190	32.7669	36.8627	43.0065
15	11.1111	10.2397	13.6529	15.3595	17.0661	17.9194	20.4793	25.5991	27.3057	30.7190	35.8388
12	8.8889	8.1917	10.9223	12.2876	13.6529	14.3355	16.3834	20.4793	21.8446	24.5752	28.6710
9	6.6667	6.1438	8.1917	9.2157	10.2397	10.7516	12.2876	15.3595	16.3834	18.4314	21.5033
6	4.4444	4.0959	5.4611	6.1438	6.8264	7.1678	8.1917	10.2397	10.9223	12.2876	14.3355
4.5	3.3333	3.0719	4.0959	4.6078	5.1198	5.3758	6.1438	7.6797	8.1917	9.2157	10.7516
3	2.2222	2.0479	2.7306	3.0719	3.4132	3.5839	4.0959	5.1198	5.4611	6.1438	7.1678
1.5	1.1111	1.0240	1.3653	1.5359	1.7066	1.7919	2.0479	2.5599	2.7306	3.0719	3.5839

Notes:

(1) Relative to the introductory paragraphs of this Annex, maximum usable bit rate corresponds to R_u for Type 1 data (MPEG-2 transport, 188 byte format); maximum transmission symbol rate corresponds to R_s; and available bandwidth corresponds to either BW_T or BW_S as appropriate;

(2) Values in table calculated using the following formula: $R_u = R_s$ x (188/204) x (FEC) x m;

(3) 8PSK rate 8/9 is suitable for satellite transponders driven near saturation, while 16QAM rate 3/4 offers better spectrum efficiency for quasi-linear transponders, in FDMA configuration.

Table B.2 Examples of Maximum Usable Bit Rate for the Type 2 Data Stream Structure ($\alpha = 0.35$)

Available bandwidth (MHz)	Maximum transmission symbol rate (α = 0.35) (Msps)	Maximum usable bit rate, Mbps QPSK rate 1/2	QPSK rate 2/3	QPSK rate 3/4	QPSK rate 5/6	QPSK rate 7/8	8PSK rate 2/3	8PSK rate 5/6	8PSK rate 8/9	16QAM rate 3/4	16QAM rate 7/8
72	53.3333	48.8889	65.1852	73.3333	81.4815	85.5556	97.7778	122.2222	130.3704	146.6667	171.1111
54	40.0000	36.6667	48.8889	55.0000	61.1111	64.1667	73.3333	91.6667	97.7778	110.0000	128.3333
46	34.0741	31.2346	41.6461	46.8519	52.0576	54.6605	62.4691	78.0864	83.2922	93.7037	109.3210
41	30.3704	27.8395	37.1193	41.7593	46.3992	48.7191	55.6790	69.5988	74.2387	83.5185	97.4383
36	26.6667	24.4444	32.5926	36.6667	40.7407	42.7778	48.8889	61.1111	65.1852	73.3333	85.5556
33	24.4444	22.4074	29.8765	33.6111	37.3457	39.2130	44.8148	56.0185	59.7531	67.2222	78.4259
30	22.2222	20.3704	27.1605	30.5556	33.9506	35.6481	40.7407	50.9259	54.3210	61.1111	71.2963
27	20.0000	18.3333	24.4444	27.5000	30.5556	32.0833	36.6667	45.8333	48.8889	55.0000	64.1667
18	13.3333	12.2222	16.2963	18.3333	20.3704	21.3889	24.4444	30.5556	32.5926	36.6667	42.7778
15	11.1111	10.1852	13.5802	15.2778	16.9753	17.8241	20.3704	25.4630	27.1605	30.5556	35.6481
12	8.8889	8.1481	10.8642	12.2222	13.5802	14.2593	16.2963	20.3704	21.7284	24.4444	28.5185
9	6.6667	6.1111	8.1481	9.1667	10.1852	10.6944	12.2222	15.2778	16.2963	18.3333	21.3889
6	4.4444	4.0741	5.4321	6.1111	6.7901	7.1296	8.1481	10.1852	10.8642	12.2222	14.2593
4.5	3.3333	3.0556	4.0741	4.5833	5.0926	5.3472	6.1111	7.6389	8.1481	9.1667	10.6944
3	2.2222	2.0370	2.7160	3.0556	3.3951	3.5648	4.0741	5.0926	5.4321	6.1111	7.1296
1.5	1.1111	1.0185	1.3580	1.5278	1.6975	1.7824	2.0370	2.5463	2.7160	3.0556	3.5648

Notes:

(1) Relative to the introductory paragraphs of this Annex, maximum usable bit rate corresponds to R_u for Type 2 data (arbitrary); maximum transmission symbol rate corresponds to R_s; and available bandwidth corresponds to either BW_T or BW_S as appropriate;

(2) Values in table calculated using the following formula: $R_u = R_s$ x (187/204) x (FEC) x m;

(3) 8PSK rate 8/9 is suitable for satellite transponders driven near saturation, while 16QAM rate 3/4 offers better spectrum efficiency for quasi-linear transponders, in FDMA configuration.

Table B.3 Examples of Maximum Usable Bit Rate for the Type 1 Data Stream Structure (α = 0.25)

Available bandwidth *(MHz)*	Maximum transmission symbol rate (α = 0.25) *(Msps)*	Maximum usable bit rate, Mbps				
		8PSK			16QAM	
		rate 2/3	*rate 5/6*	*rate 8/9*	*rate 3/4*	*rate 7/8*
72	57.6000	106.1647	132.7059	141.5529	159.2471	185.7882
54	43.2000	79.6235	99.5294	106.1647	119.4353	139.3412
46	36.8000	67.8275	84.7843	90.4366	101.7412	118.6980
41	32.8000	60.4549	75.5686	80.6065	90.6824	105.7961
36	28.8000	53.0824	66.3529	70.7765	79.6235	92.8941
33	26.4000	48.6588	60.8235	64.8784	72.9882	85.1529
30	24.0000	44.2353	55.2941	58.9804	66.3529	77.4118
27	21.6000	39.8118	49.7647	53.0824	59.7176	69.6706
18	14.4000	26.5412	33.1765	35.3882	39.8118	46.4471
15	12.0000	22.1176	27.6471	29.4902	33.1765	38.7059
12	9.6000	17.6941	22.1176	23.5922	26.5412	30.9647
9	7.2000	13.2706	16.5882	17.6941	19.9059	23.2235
6	4.8000	8.8471	11.0588	11.7961	13.2706	15.4824
4.5	3.6000	6.6353	8.2941	8.8471	9.9529	11.6118
3	2.4000	4.4235	5.5294	5.8980	6.6353	7.7412
1.5	1.2000	2.2118	2.7647	2.9490	3.3176	3.8706

Notes:

(1) Relative to the introductory paragraphs of this Annex, maximum usable bit rate corresponds to R_u for Type 1 data (MPEG-2 transport, 188 byte format); maximum transmission symbol rate corresponds to R_s; and available bandwidth corresponds to either BW_T or BW_S as appropriate;

(2) Values in table calculated using the following formula:

$$R_u = R_s \times (188/204) \times (FEC) \times m;$$

(3) 8PSK rate 8/9 is suitable for satellite transponders driven near saturation, while 16QAM rate 3/4 offers better spectrum efficiency for quasi-linear transponders, in FDMA configuration.

Table B.4 Examples of Maximum Usable Bit Rate for the Type 2 Data Stream Structure ($\alpha = 0.25$)

Available bandwidth *(MHz)*	Maximum transmission symbol rate (α = 0.25) *(Msps)*	Maximum usable bit rate, Mbps				
		8PSK			**16QAM**	
		rate 2/3	*rate 5/6*	*rate 8/9*	*rate 3/4*	*rate 7/8*
72	57.6000	105.6000	132.0000	140.8000	158.4000	184.8000
54	43.2000	79.2000	99.0000	105.6000	118.8000	138.6000
46	36.8000	67.4667	84.3333	89.9556	101.2000	118.0667
41	32.8000	60.1333	75.1667	80.1778	90.2000	105.2333
36	28.8000	52.8000	66.0000	70.4000	79.2000	92.4000
33	26.4000	48.4000	60.5000	64.5333	72.6000	84.7000
30	24.0000	44.0000	55.0000	58.6667	66.0000	77.0000
27	21.6000	39.6000	49.5000	52.8000	59.4000	69.3000
18	14.4000	26.4000	33.0000	35.2000	39.6000	46.2000
15	12.0000	22.0000	27.5000	29.3333	33.0000	38.5000
12	9.6000	17.6000	22.0000	23.4667	26.4000	30.8000
9	7.2000	13.2000	16.5000	17.6000	19.8000	23.1000
6	4.8000	8.8000	11.0000	11.7333	13.2000	15.4000
4.5	3.6000	6.6000	8.2500	8.8000	9.9000	11.5500
3	2.4000	4.4000	5.5000	5.8667	6.6000	7.7000
1.5	1.2000	2.2000	2.7500	2.9333	3.3000	3.8500

Notes:

(1) Relative to the introductory paragraphs of this Annex, maximum usable bit rate corresponds to R_u for Type 2 data (arbitrary); maximum transmission symbol rate corresponds to R_s; and available bandwidth corresponds to either BW_T or BW_S as appropriate;

(2) Values in table calculated using the following formula:

$$R_u = R_s \times (187/204) \times (FEC) \times m;$$

(3) 8PSK rate 8/9 is suitable for satellite transponders driven near saturation, while 16QAM rate 3/4 offers better spectrum efficiency for quasi-linear transponders, in FDMA configuration.

Also of interest, for applications involving Type 1 data, is the number of 19.39 Mbps ATSC terrestrial data streams which can be placed into a typical 36 MHz transponder assuming ideal conditions. Table B.5 describes specific examples for accommodating 2, 3, and 4 data streams per 36 MHz transponder; others exist, as well.

Table B.5 Examples of Multiple 19.39 Mbps data streams in a 36 MHz Transponder

# OF DATA STREAMS	MODULATION TYPE	CODE RATE	"α" VALUE
2	QPSK	5/6	0.35 or 0.25
3	8PSK	5/6	0.35 or 0.25
4	16QAM	3/4	0.25

In MCPC cases, the complete transponder bandwidth is used and it is driven near saturation. The QPSK and 8PSK modulation and coding systems are constant envelope modulation schemes and as such are best suited for this kind of application.

In multiple SCPC cases, care should be taken to keep the mutual interference between multiple adjacent carriers at an acceptable level. In many cases this OBO requirement will comply with the linearity requirement for 16QAM modulation schemes.

The system, when operating in the optional 8PSK and 16QAM modes, is more sensitive to phase noise than in QPSK modes. Figure B.1 shows an example transmit phase noise mask for carriers with information rates <2,048 Mbps, taken from the Intelsat IESS-310 specification for pragmatic trellis coded 8PSK modulations.

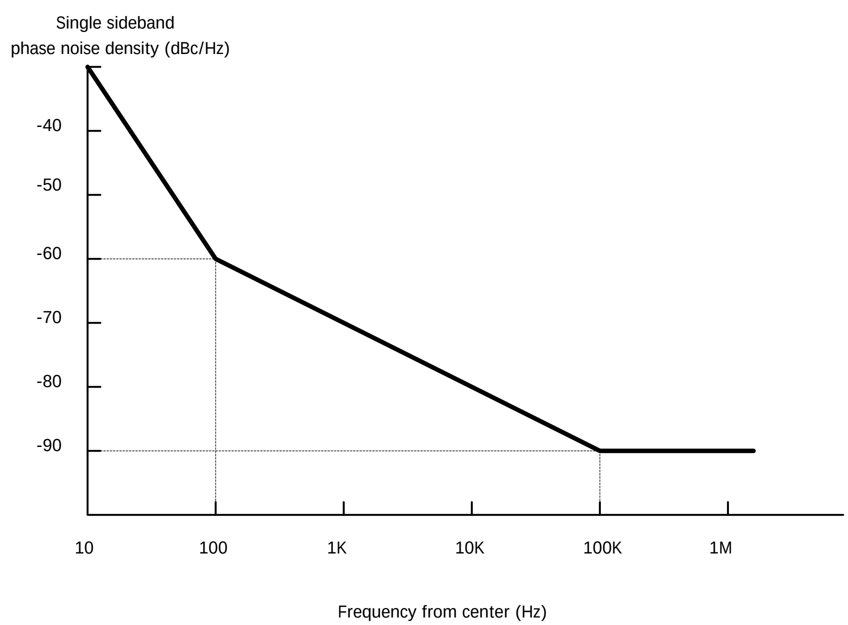


Figure B.1 Example of continuous single sideband phase noise mask (for carriers with information rates less than or equal to 2.048 Mbps)

Note: Equipment designers should take account of the total system phase noise requirements, that is arising in the modulator, up/down converters, satellite and the receiver oscillators.

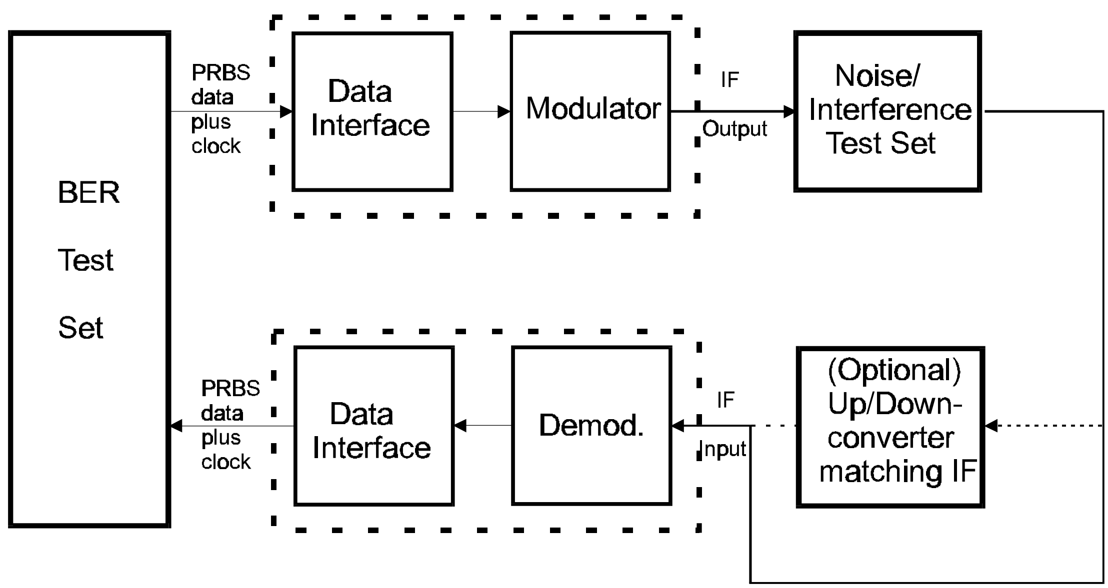
ANNEX C

(Informative)

BASELINE (IF LOOPBACK) MODEM TESTING

Baseline (“IF loopback”) testing of modulators and demodulators should be conducted with commercially-available Bit Error Rate (BER) test sets (as opposed to special test equipment provided by the manufacturer of the modem under test); a calibrated noise insertion source/apparatus; and an optional up/down converter in cases where the IF frequencies of the modulator and demodulator are not the same. Figure C.1 illustrates the generic block diagram of such a test setup.

Figure C.1 Baseline test configuration

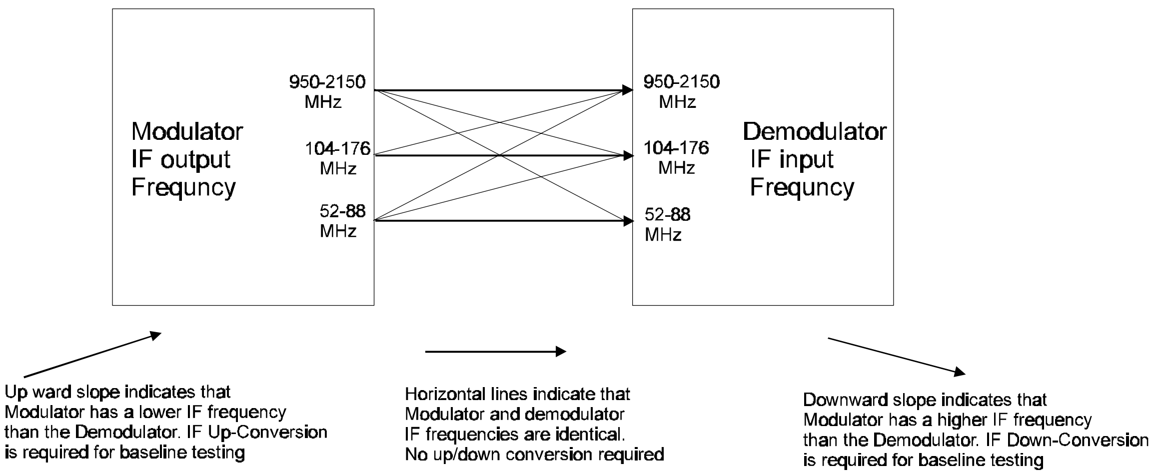


The BER test set provides a Pseudo-Random Binary Sequence (PRBS) to the modulator, and compares the received data stream for the purpose of counting bit errors and calculating the BER of the modem under test. A data interface on both the modulator and demodulator, compatible with the data interface on the BER test set, is needed for physical and electrical interconnection.

The modulator and demodulator IF frequencies are typically in the following ranges: 52-88 MHz; 104-176 MHz; or, L-Band (including 950-1450 MHz, 950-1525 MHz, 950-1750 MHz, 950-2050 MHz and 950-2150 MHz) as stated in Table 5.1 of the standard (System Interfaces). For IF loopback testing, the IF output of the modulator should match the input frequency range of the demodulator, or, the output IF frequency from the modulator should be either up or down converted to an IF frequency that the demodulator can accept. Figure C.2 illustrates the possible up/down IF conversion combinations.

The Noise/Interference test set (shown in Figure C.1) is a device that measures the power level of the modulator IF output, and based upon a programmed data rate, inserts noise on a calibrated basis to correspond to a defined S/N or E_b/N_0. The Noise/Interference test set establishes the baseline S/N or E_b/N_0 for which the BER is measured by the (separate) BER test set.

Figure C.2 Possible IF frequency combinations in IF loopback test setup



Since the purpose of baseline BER measurements is to determine the "back-to-back" i.e. IF loopback performance capability of a modulator/demodulator pair, it is essential to minimize any external sources of degradation in the test set-up. The IF interfaces on the modulator and demodulator will commonly be either 75 or 50 Ohm impedance, coaxial connections. Similarly, the I/O ports on the up/down converter and the Noise/Interference test set can also be either 75 or 50 Ohm impedance. To minimize the potential distortion of the IF signal between the modulator and demodulator, appropriate impedance converters are essential at dissimilar impedance junctions, cable lengths should be kept under 2 meters, and the use of coaxial adapters should be minimized.

When an up/down converter is used in the baseline test configuration, the performance of the up/down converter should be such as to contribute no distortions in the ideal case and a minimum of distortion in the practical case. Practical distortion limits on the up/down converter should include:

<u>Amplitude linearity</u>: <0.5 dB gain variation, peak to peak across the bandwidth of interest;

<u>Group delay variation</u>: <2 nanoseconds of group delay across the bandwidth of interest;

<u>Phase noise characteristics</u>: Should be >6 dB better than the phase noise characteristics of the modulator under test.

Measurement credibility is an issue that cannot be overemphasized for baseline testing conditions. External BER and Noise/Interference test sets with calibration traceability to a recognized bureau of standards organization, should be the only basis for such testing. Internally generated PRBS data, and associated BER, S/N, and E_b/N_0 measurements, should only be considered as qualitative, and in principle, not used as the basis of a quantitative measurement of modem performance.

ANNEX D

(Informative)

CORRESPONDENCE TO DVB STANDARDS DOCUMENTS

As noted in Section 1.3 of the standard, this document relies heavily upon previous work done by the Digital Video Broadcasting (DVB) Project of the European Broadcast Union (EBU) for satellite transmission. Given below in Tables D.1 and D.2 are the section numbers in EN 300 421 (QPSK) and prEN 301 210 (QPSK, 8PSK and 16QAM), respectively, which correspond to the section numbers in this ATSC standard.

Table D.1. Corresponding Section Numbers in EN 300 421 (QPSK)

DVB SECTION NO.	ATSC SECTION NO.	COMMENTS
4.1	5.1	ATSC document contains references to optional 8PSK and 16 QAM modes
4.2	5.2	
4.3	5.3, 5.3.1	ATSC system description contains references to optional 8PSK and 16 QAM modes
4.4.1	5.4.1	
4.4.2	5.4.2	
4.4.3	5.4.3	
4.5	5.4.4, 5.4.5	
5	6.1	
Annex A	Annex A	ATSC document includes α=0.25
Annex B	not included	
Annex C	Annex B	ATSC document includes additional modes, lacks figures given in DVB spec.
Annex D	Annex B	ATSC document includes additional modes
Annex E	not included	

Table D.2. Corresponding Section Numbers in prEN 301 210 (QPSK, 8PSK, and 16QAM)

DVB Section No.	ATSC Section No.	Comments
4.1	5.1	
4.2	5.2	
4.3	5.3, 5.3.1	
4.4.1	5.4.1	
4.4.2	5.4.2	
4.4.3	5.4.3	
4.5.1	5.4.4	
4.5.2	5.4.5	
4.6.1	5.5.1 (8PSK) 5.6.1 (16QAM)	
4.6.2	5.5.2 (8PSK) 5.6.2 (16QAM)	
4.6.3	5.5.3 (8PSK) 5.6.3 (16QAM)	
4.7.1	5.5.4 (8PSK) 5.6.4 (16QAM)	
4.7.1.1	5.5.4.1	
4.7.1.2	5.5.4.2	
4.7.1.3	5.6.4.1	
4.7.2	5.5.5 (8PSK) 5.6.5 (16QAM)	
5	6.1 (QPSK) 6.2 (8PSK) 6.3 (16QAM)	
Annex A	Annex A	
Annex B	not included	
Annex C	3.1	
Annex D	not included	
Annex E	Annex B	ATSC document includes additional modes
Annex F	not included	