RECOMMENDATION ITU-R BO.1408-1

Transmission system for advanced multimedia services provided by integrated services digital broadcasting in a broadcasting-satellite channel

(Question ITU-R 3/6)

(1999-2002)

The ITU Radiocommunication Assembly,

considering

a) that various kinds of information such as video, including high-definition television (HDTV) as well as limited-definition television (LDTV), audio, text, graphics, and data are provided to the public via the broadcasting channels;

b) that information and services can be integrated efficiently and flexibly by using digital techniques;

c) that integrated services digital broadcasting (ISDB) techniques can be used to implement services exploiting the full advantages of digital broadcasting;

d) that the MPEG transport stream (MPEG-TS) is widely applied as a container of digitally coded information;

e) that a great benefit is obtained if the integration of data/services can be achieved on a TS basis, which requires the transmission system to deal with multiple MPEG-TSs;

f) that the recent progress in digital technology allows a highly bandwidth efficient modulation scheme such as 8-PSK in addition to the convolutionally-encoded QPSK and BPSK;

g) that the required service quality and service availability differ according to applications;

h) that rain attenuation, which differs by climatic zones, needs to be taken into account in satellite broadcasting systems;

j) that a common ISDB transmission system that provides a high flexibility of use as well as high spectrum efficiency while covering all the requirements for application, quality and rain attenuation is desirable, rather than introducing multiple systems specifically developed for particular applications;

k) that Recommendation ITU-R BO.1516 recommends common functional requirements for the integrated receiver-decoder (IRD) of digital multi-programme broadcasting by satellite,

noting

a) that advanced multimedia systems for ISDB type services are characterised by highest flexibility with respect to:

– handling several MPEG-TSs;
– allowing time multiplex of appropriate modulation schemes suitable for applications of various transmission robustness, e.g. 8-PSK, QPSK and BPSK;
– informing the demodulator about the transmission and multiplexing configuration by means of specially robust control signals;

– that the integrated circuits for satellite (ISDB-S) receivers could potentially be used for the system defined in Recommendation ITU-R BO.1516, because each of the components used in ISDB-S is also used in the systems defined in this Recommendation,

recommends

1 that the transmission system described in Annex 1 should be used for ISDB-S system applications.

ANNEX 1

General specifications for a generic satellite ISDB-S transmission system

Introduction

ISDB is a new type of broadcasting for multimedia services. It integrates, systematically, various kinds of digital content, each of which may include multi-programme video from LDTV to HDTV, multi-programme audio, graphics, texts, etc. Most digital content are nowadays encoded into the form of MPEG-TS and delivered worldwide. It is highly desired to integrate the digital content on an MPEG-TS basis.

Since the ISDB contains a variety of services, the system has to cover a wide range of requirements that may differ from one service to another. For example, a large transmission capacity is required for HDTV services, while a high service availability (or transmission reliability) is required for data services such as delivery of conditional access keys, downloading of software, etc. To integrate these signals of different service requirements, it is desired for the transmission systems to provide a series of modulation and/or error protection schemes which can be selected and combined flexibly in order to meet each requirement of the services integrated. This is especially true of the ISDB-S systems operating in the 11-12 GHz broadcasting-satellite service (BSS) band in countries that belong to the climate zones with high rain attenuation.

ISDB-S transmission systems are characterised by:

– MPEG interfacing: the input signals to the encoder and the output signals from the decoder conform to the MPEG-TS specifications;

– capability of signal integration on MPEG-TS basis: digital contents can be multiplexed without decoding/re-encoding of the input streams;

– flexible use of modulation schemes: digital content can be simultaneously transmitted with the appropriate modulation schemes for each integrated content in the ISDB stream;

– provision of a control signal that informs the receiver of the multiplexing and modulation configuration.

The generic system for ISDB-S is described below.

1 Block definition

A general configuration of the system is shown in Fig. 1. The system shall handle three kinds of signals in order to transmit multiple MPEG-TSs with various kinds of modulation schemes and in order to achieve stable and easy reception. The three signals shall be:

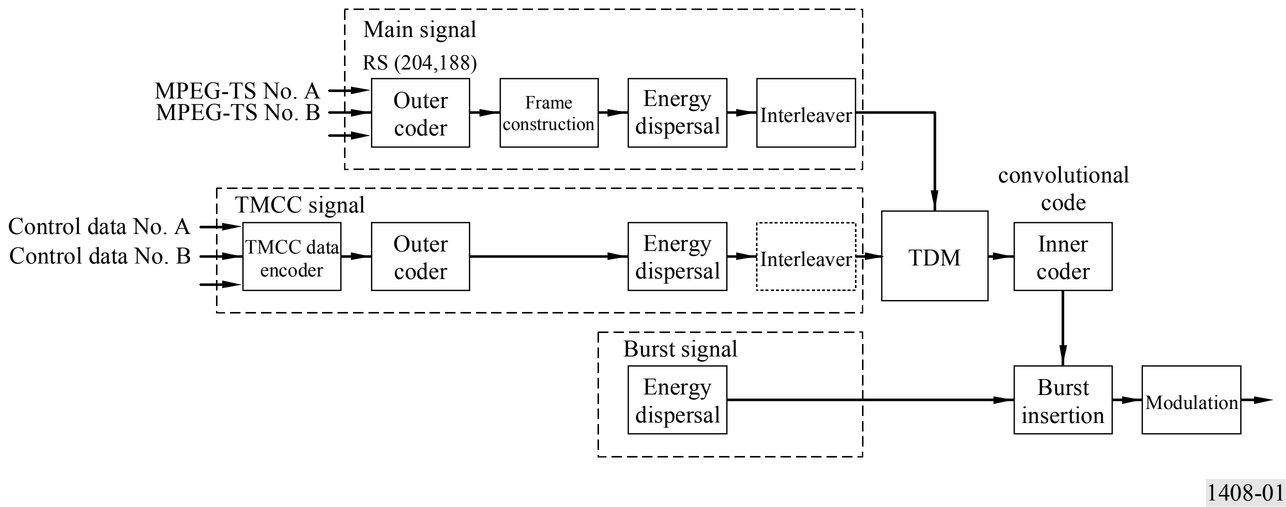
– main signal which consists of multiple MPEG-TSs and carries the programme content;

– transmission and multiplexing configuration control (TMCC) signal which informs the receiver of the modulation schemes applied, the identification of MPEG-TSs, etc.; and

– burst signal which ensures stable carrier recovery at the receiver under any reception condition (especially under low carrier-to-noise (*C*/*N*) ratio conditions).

FIGURE 1

General configuration of system



To handle multiple MPEG-TSs and to allow several modulation schemes to be used simultaneously, a frame structure is introduced to the main signal. The input MPEG-TSs shall be combined into a single stream, to which ordinary signal processes for satellite systems are applied (i.e., energy dispersal, interleaving and inner coding). The control data which designates the modulation schemes, etc. for each TS packet shall be encoded into the TMCC signal, to which a series of channel coding is applied. In most cases, some parts of the channel coding can be shared with the main signal. The burst signal shall be energy-dispersed to avoid line spectra in the transmission signal. This is done by modulating the burst with a random sequence. Therefore, the burst signal can carry information by modulating it with information data instead of modulating it with a random sequence. In this case, an additional channel coding may be necessary. These three signals shall be time-division multiplexed (time division multiplex (TDM)) and modulated by the designated modulation schemes.

2 Outer code for main signal

Reed-Solomon (RS) (204,188) shortened code, from the original RS (255,239) code, shall be applied to each input MPEG-TS packet (188 bytes) to generate the error protected packet (204 bytes). The RS coding shall also be applied to the first byte of the packet (MPEG sync word).

– Code generator polynomial: $g(x) = (x + \lambda^0)(x + \lambda^1)(x + \lambda^2)(x + \lambda^{15})$, where $\lambda = 02_h$

– Field generator polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$.

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

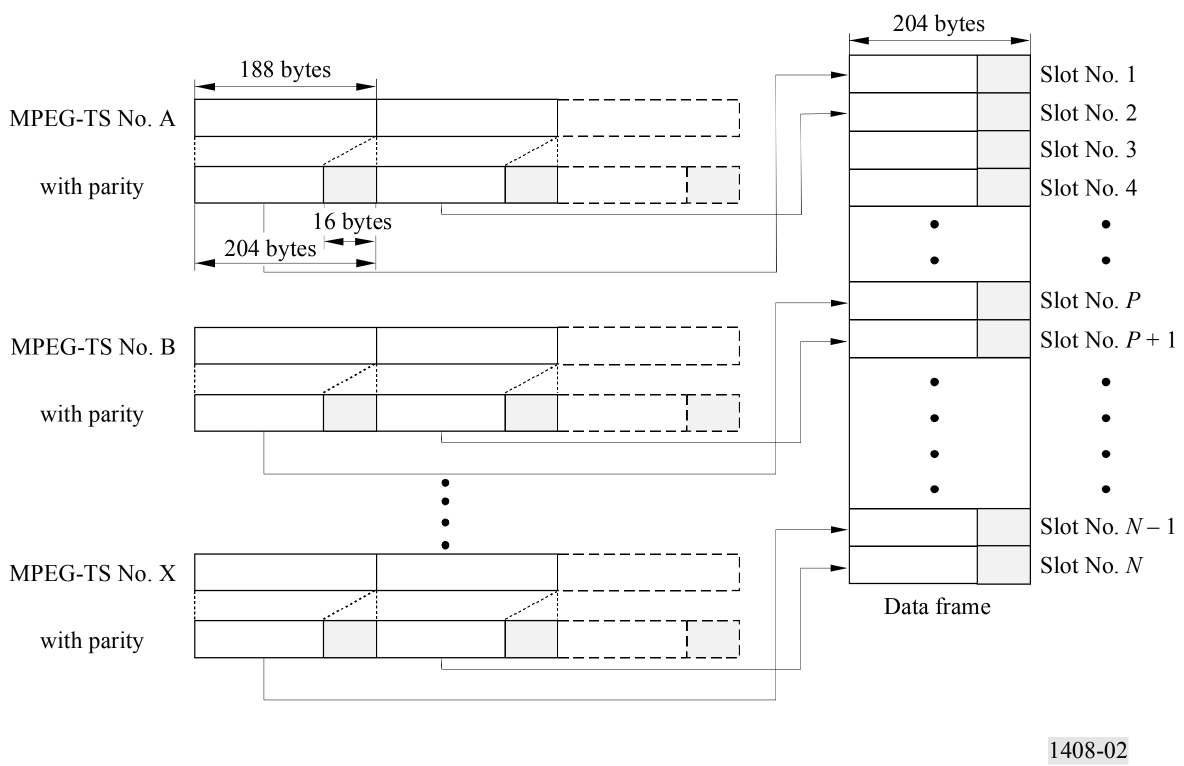
3 Transport combiner

3.1 Framing structure

To combine the TSs, the error-protected 204-byte packets shall be assigned to the "slots" in a "data frame", as shown in Fig. 2. The slot indicates the absolute position in the data frame and is used as the unit that designates the modulation scheme and MPEG-TS identification. The size of slot (the number of bytes in a slot) shall be 204 bytes to keep one-to-one correspondence between slots and error-protected packets. The data frame shall be composed of N slots.

FIGURE 2

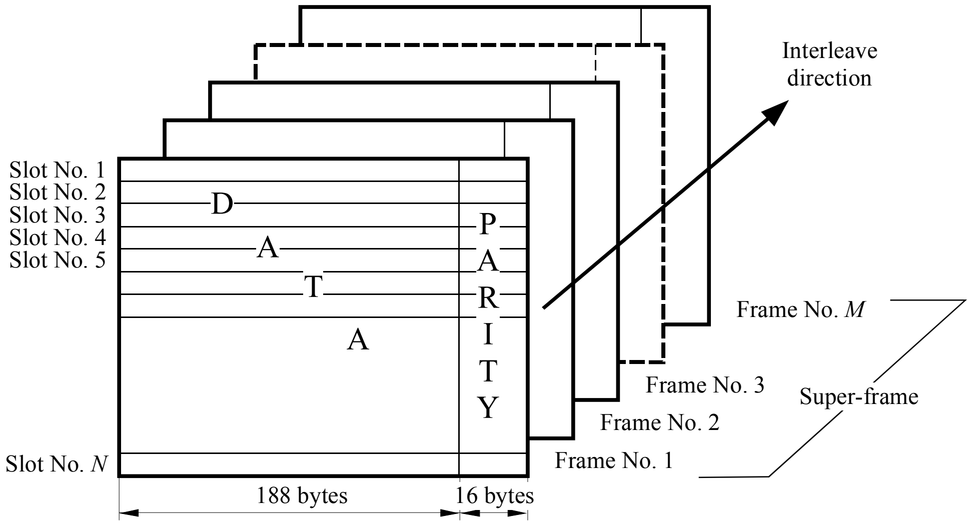
Frame structure



A super-frame is introduced to perform interleaving easily. Figure 3 shows the super-frame structure. The super-frame shall be composed of M frames, where M corresponds to the depth of interleaving.

FIGURE 3

Super-frame structure



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3.2 Slot assignment

As the spectrum efficiency or the transmissible bits per symbol varies with the combination of modulation and inner code rate, the number of packets being transmitted depends on the combination. Since the number of symbols to be modulated by a particular modulation scheme must be an integer value, the relationship between the number of packets transmitted and the number of symbols for the modulation is given by equation (1).

$$I_k = \frac{8\,B\,P_k}{E_k} \tag{1}$$

where:

- I_k, P_k: integers
- I_k: number of symbols transmitted with the k-th combination of the modulation scheme and inner code rate
- P_k: number of packets transmitted with the k-th combination of the modulation scheme and inner code rate
- E_k: spectrum efficiency of the k-th combination of the modulation scheme and inner code rate
- B: number of bytes per packet (= 204).

The number of symbols per data frame, I_D, is expressed by equation (2).

$$I_D = \sum_k I_k \tag{2}$$

The number of packets transmitted during a frame duration becomes maximum when all the packets are modulated by the modulation-code combination having the highest spectrum efficiency among the possible combinations in the system. Therefore, the number of slots provided by the system is given by substituting the I_D and E_{max} for equation (1).

$$N = \frac{I_D\,E_{max}}{8\,B} \tag{3}$$

where N denotes the number of slots that the system provides, and E_{max} denotes the highest spectrum efficiency of the modulation-coded combinations that the system provides.

When modulation-code combinations that do not have the highest spectrum efficiency are used, the number of packets being transmitted becomes lower than the number of the slots provided by the system. In this case, some of the slots shall be filled by dummy data to keep the frame size (the number of slots in a frame) constant. These slots are called "dummy slots". The number of dummy slots S_d in a frame is obtained by the following equation (4).

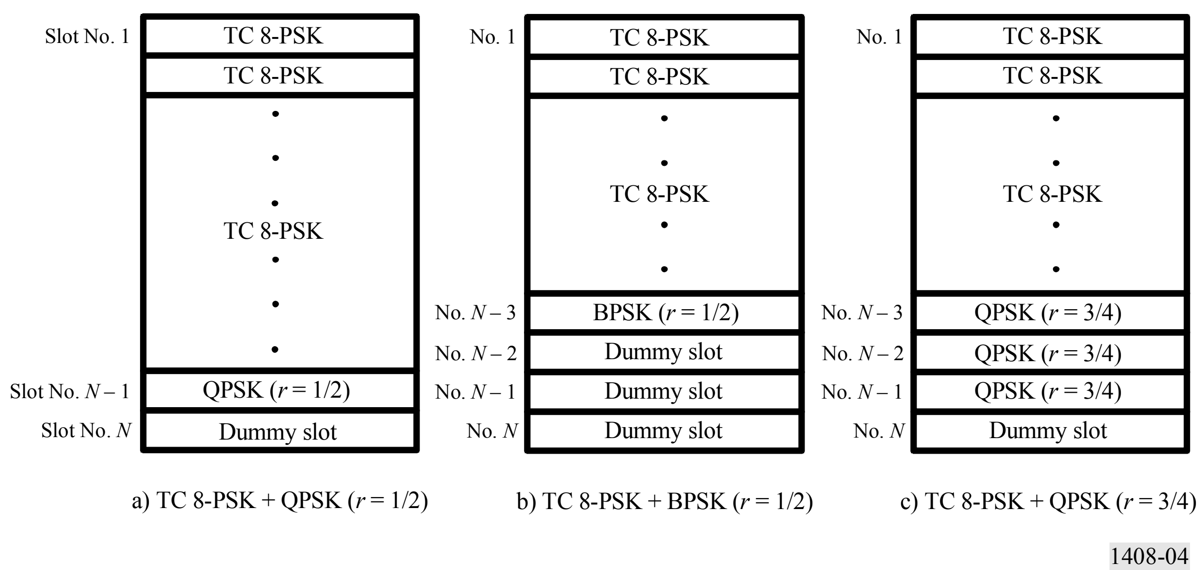
$$S_d = N - \sum_k P_k \tag{4}$$

In the case where multiple modulation schemes are used simultaneously, that is, part of the slots in a frame are modulated by a particular modulation-code combination while the rest of slots are modulated by the other combinations, the data shall be modulated from the highest spectrum efficient scheme to the lowest spectrum efficient scheme among the combinations being actually used. In other words, the packets transmitted with higher efficient combinations are assigned to the lower numbered slots in a frame. This modulation order gives the minimum value in the bit error ratio (BER) after decoding the convolutional code in a low C/N reception.

Figure 4 shows some examples of slot assignment when QPSK ($r = 1/2$, r denotes code rate), BPSK ($r = 1/2$), and QPSK ($r = 3/4$) are used, respectively with trellis coded (TC) 8-PSK ($r = 2/3$). In the examples, TC 8-PSK ($r = 2/3$) is assumed as the highest spectrum efficient combination of the system. Since the spectrum efficiency of QPSK ($r = 1/2$) is half that of the TC 8-PSK, one dummy slot is inserted (Fig. 4a)); since the spectrum efficiency of BPSK ($r = 1/2$) is a quarter that of the TC 8-PSK, three dummy slots are inserted (Fig. 4b)); and since the spectrum efficiency of QPSK ($r = 3/4$) is 3/4 that of the TC 8-PSK, one dummy slot is inserted for three active slots (Fig. 4c)).

FIGURE 4

Example of slot assignment

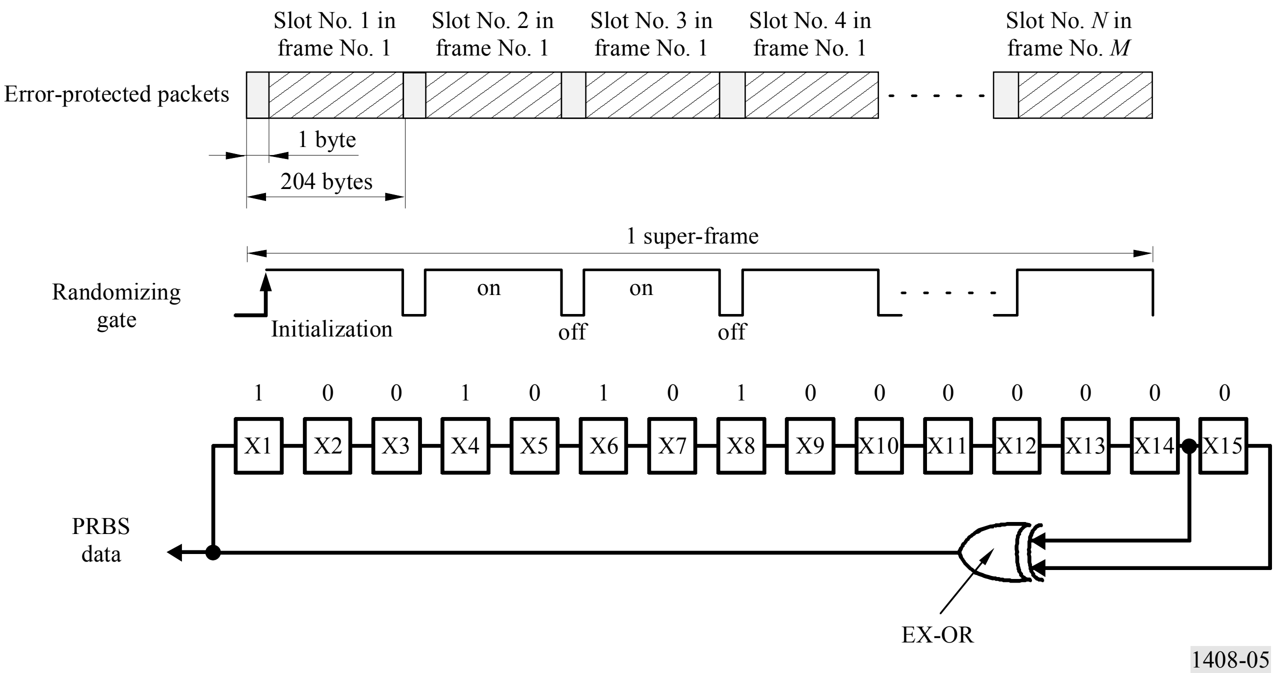


4 Randomization for energy dispersal for main signal

In order to comply with ITU Radio Regulations and to ensure adequate binary transitions, the data of the frame shall be randomized in accordance with the configuration depicted in Fig. 5.

FIGURE 5

Randomizer schematic diagram



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 Fig. 5, shall be initiated at the second byte of every super-frame. The first bit of the output of the PRBS generator shall be applied to the first bit (i.e., most significant bit (MSB)) of the second byte of slot No. 1 in frame No. 1. The PRBS shall be added to the data except to the first byte (MPEG sync byte) of every slot.

5 Interleaving for main signal

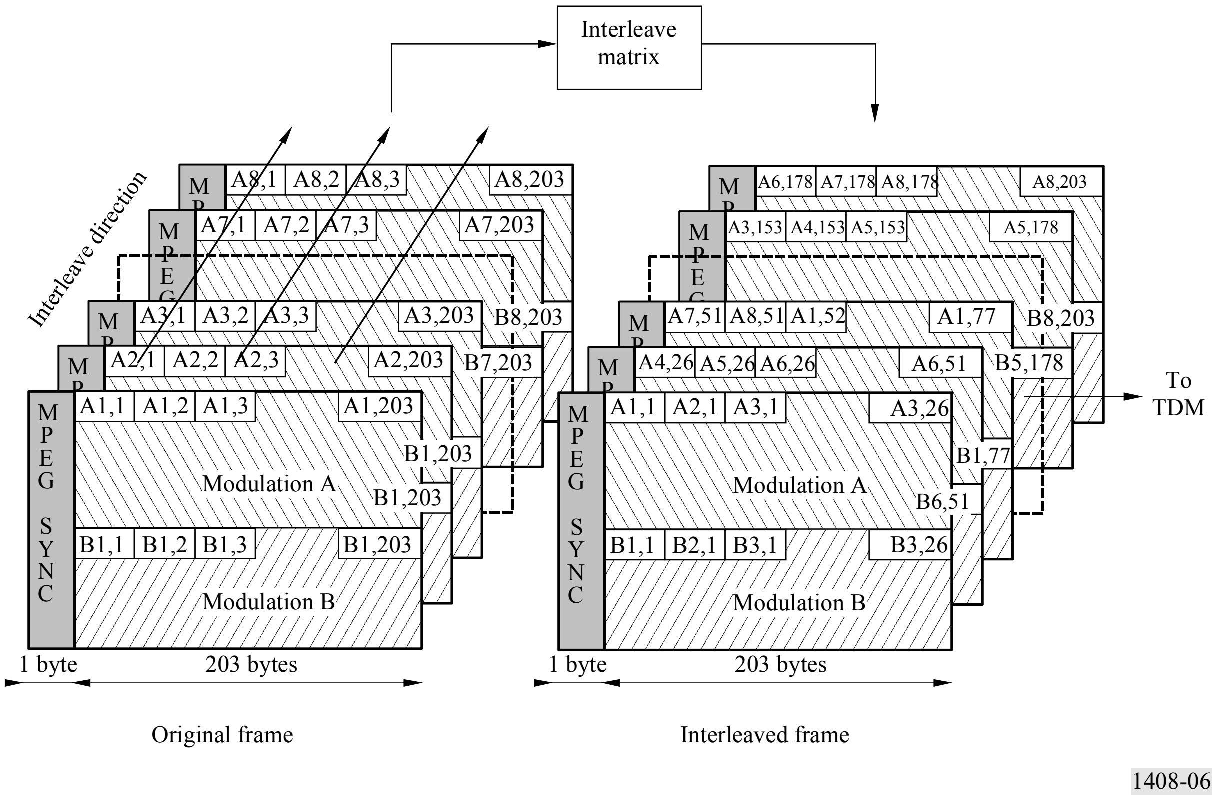
Inter-frame block interleaving with a depth of *M* shall be applied to the randomized data, as shown in Fig. 6. Slot assignment for every frame shall be identical throughout a super-frame, resulting in the data being interleaved only between those transmitted with the same modulation-code combination. Interleaving shall be applied except to the first byte (MPEG sync byte) of every slot.

Figure 6 illustrates an example of interleaving when the depth of interleaving is 8 (i.e., super-frame consists of 8 frames) and two kinds of modulation-code combinations are being used. The data in the original frame is read out in the inter-frame direction, i.e., in the order of A1,1; A2,1; A3,1; ..., where A*i*,*j* represents the byte data at *j*-th slot in *i*-th frame, to form the interleaved frame. The data in the interleaved frame is read out in the byte direction (horizontally) and fed to the TDM multiplexer.

It is not necessary to transmit the first byte of each packet (the MPEG sync word of 47_h) because the timing references (frame sync words) are sent by the TMCC signal. The omitted MPEG sync words have to be recovered at the receiver to perform outer decoding properly. Note that in this case, *B* in the equations (1) and (3) should take the value 203 in order for the equation to hold true.

FIGURE 6

Conceptual scheme of interleaving



6 TMCC signal

The TMCC signal shall carry the following information:

– modulation-code combination for each slot;

– MPEG-TS identification for each slot; and

– others (e.g., order of change, flag bit for emergency alert broadcasting).

TMCC information shall be transmitted in advance to the main signal because the main signal cannot be demodulated without the TMCC information. The minimum interval for TMCC information renewal shall be a duration of one super-frame. The receivers shall principally decode the TMCC information at every super-frame. The TMCC signal shall convey timing references in addition to the information above.

6.1 TMCC information encoding

The information carried by the TMCC signal shall be formatted as shown in Fig. 7. Details for each item are described below.

FIGURE 7

TMCC information format

Order of change	Modulation code combination for each slot	Relative TS ID for each slot	Corresponding table between relative TS ID and MPEG-TS_ID	Other information

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6.1.1 Order of change

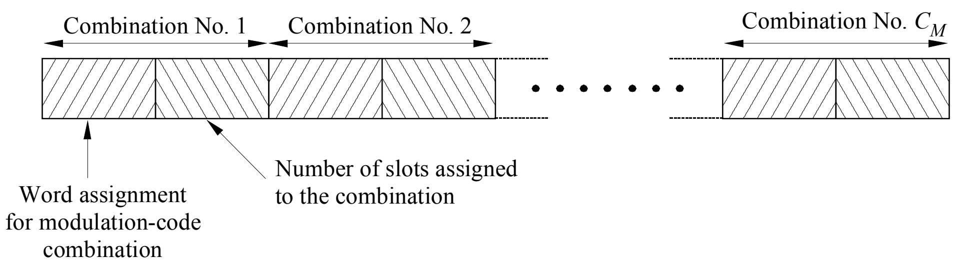
The order of change is a 5-bit number that indicates renewal of the TMCC information. It shall be incremented each time the TMCC is renewed. The receiver may detect just the bits and may decode the TMCC information only when the bits change. The use of order of change is optionally defined by the system.

6.1.2 Modulation-code combination information

This represents combinations of the modulation scheme and the convolutional code rate for each slot. To reduce the transmission bits for this information, the information shall be encoded into the format shown in Fig. 8. The maximum number of modulation-code combinations, C_M, that are used simultaneously shall be defined by the system taking into account the service requirements. The word assignment for the modulation-code combination shall be those defined in Table 1. When the number of modulation-code combinations being used is less than the maximum number specified by the system, the word "1111" shall be applied to the rest of the combinations and the number of slots assigned shall be set to zero.

FIGURE 8

Encoding format for modulation-code combination information



Note 1 - The order of the combinations shall be those defined in § 3.2 (slot assignment), i.e., from the highest efficient combination to the lowest efficient combination.

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6.1.3 TS identification

Instead of transmitting MPEG-TS_ID (16 bits) for each slot, a combination of relative TS IDs that identify only the TSs being transmitted and the corresponding table between these two kinds of IDs are employed. This results in reduced transmission bits. The relative TS IDs for each slot shall be transmitted sequentially from slot No. 1. The maximum number of TSs transmitted simultaneously, T_M, shall be defined by the system.

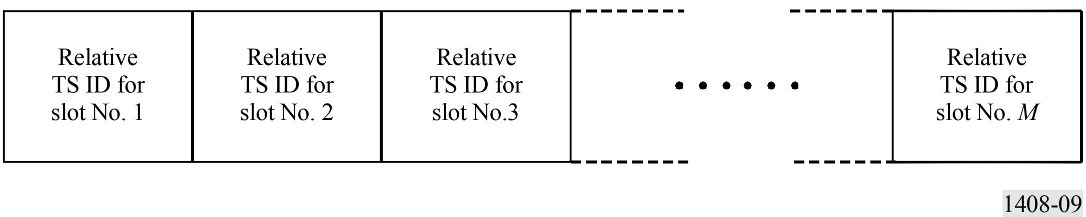
TABLE 1

Word assignment for modulation-code combination

Word	Modulation-code combination
0000	Reserved
0001	BPSK (r = 1/2)
0010	QPSK (r = 1/2)
0011	QPSK (r = 2/3)
0100	QPSK (r = 3/4)
0101	QPSK (r = 5/6)
0110	QPSK (r = 7/8)
0111	TC 8-PSK (r = 2/3)
1000-1110	Reserved
1111	Dummy

FIGURE 9

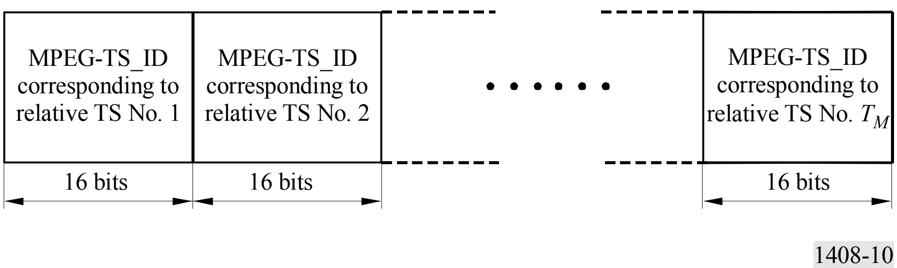
Data arrangement of relative TS ID information



The correspondence table shall be composed of an array of numbers that are 16-bit numbers to represent each MPEG-TS_ID. The numbers shall be arranged from the relative TS ID number 0 to T_M.

FIGURE 10

Data arrangement of correspondence table



6.1.4 Other information

The encoding format for the other information shall be defined appropriately by the system.

6.2 Outer coding for TMCC information

Since TMCC information is indispensable for the demodulation at receivers, the TMCC signal should be protected with a forward error correction (FEC) level higher than the FEC used for the main signal. For the same reason, it shall be transmitted with the modulation-code combination having the most robustness against transmission noise.

6.3 Timing references

Two kinds of timing references are used, i.e., the frame sync word that indicates the start of each frame and the frame identification words that identify the first frame (frame No. 1). These words shall be transmitted by each frame.

After dividing the outer coded TMCC data into *M* blocks (where *M* is the number of frames in a super-frame), the sync words shall be inserted in each block, as shown in Fig. 11. The sync word W1 shall be inserted at the beginning of each block. The word W2 shall be inserted at the end of the block that is transmitted in the first frame, while the word W3 shall be inserted at the end of the remaining blocks. The words W1, W2, and W3 shall consist of 2 bytes. W1 shall be $1B95_h$, W2 shall be $A340_h$, and W3 shall be $5CBF_h$ (W3 is obtained by inverting the bits of W2).

Note that the first 6 bits of the words will be changed by the payload information (contents of the main signal and/or TMCC signal) due to convolutional coding (constraint length of 7), which is applied to the TMCC signal at the succeeding process stage. In other words, the first 6 bits of the word are used as the termination bits of the convolutional code. Consequently, the unique bit pattern in the synchronizing word is 10 bits out of 16 bits of the original word.

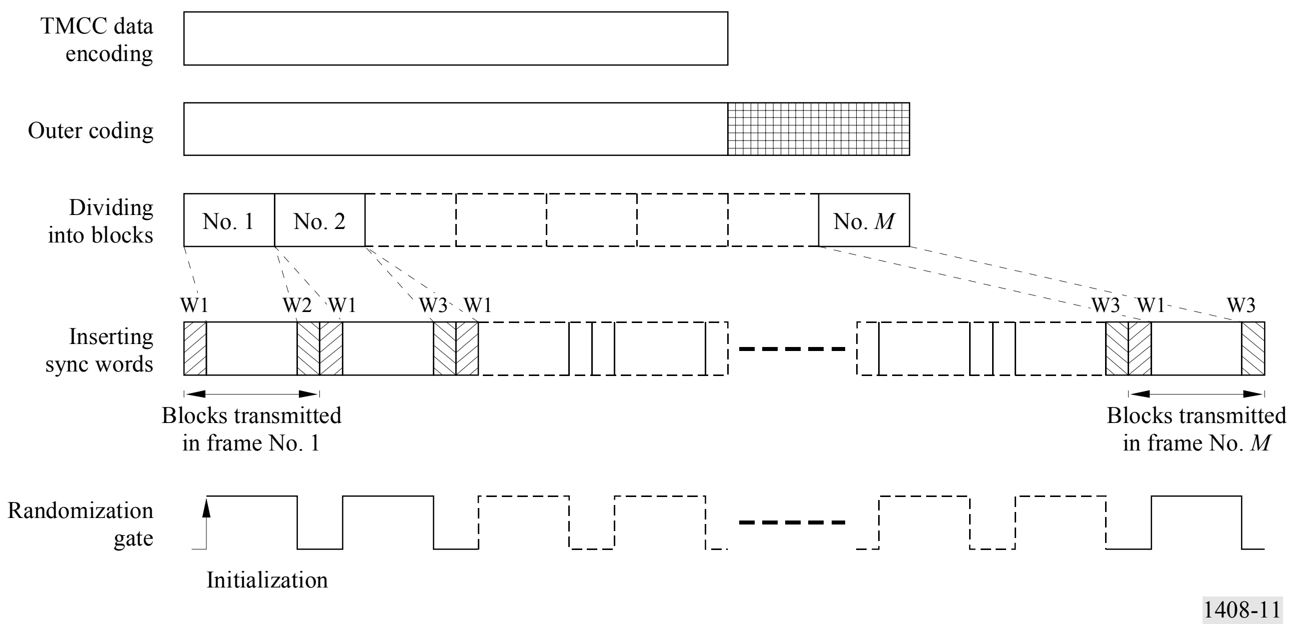
6.4 Channel coding for TMCC

The TMCC signal shall be randomized for energy dispersal. The polynomial for the PRBS generator shall be the same as that for the main signal. The pseudo-random sequence shall be initiated at the third byte (just after the sync word) of the first block. The first bit of the output of the generator shall be applied to the first bit (i.e., MSB) of the third byte of the first block. The pseudo-random sequence shall be added to the data, except the timing reference words.

Interleaving processes may not be needed for TMCC signals consisting of a small amount of bits because the effect of interleaving is limited. An appropriate interleaving process should be specified, if necessary.

FIGURE 11

Generation of TMCC signal



7 Burst signal

To keep a constant interval between the successive bursts throughout a frame (see Fig. 12), a burst signal shall be inserted in every 204 symbols of the convolutional coded main signal. Note that the burst shall be inserted in every 203 symbols when the MPEG sync words are not transmitted (see § 5). The duration of the burst shall be 4 symbols. The data for burst before modulation shall be randomized with an appropriate random sequence for energy dispersal. The modulation scheme for burst signal shall be the same as that applied to the TMCC signal (the most robust scheme against transmission noise).

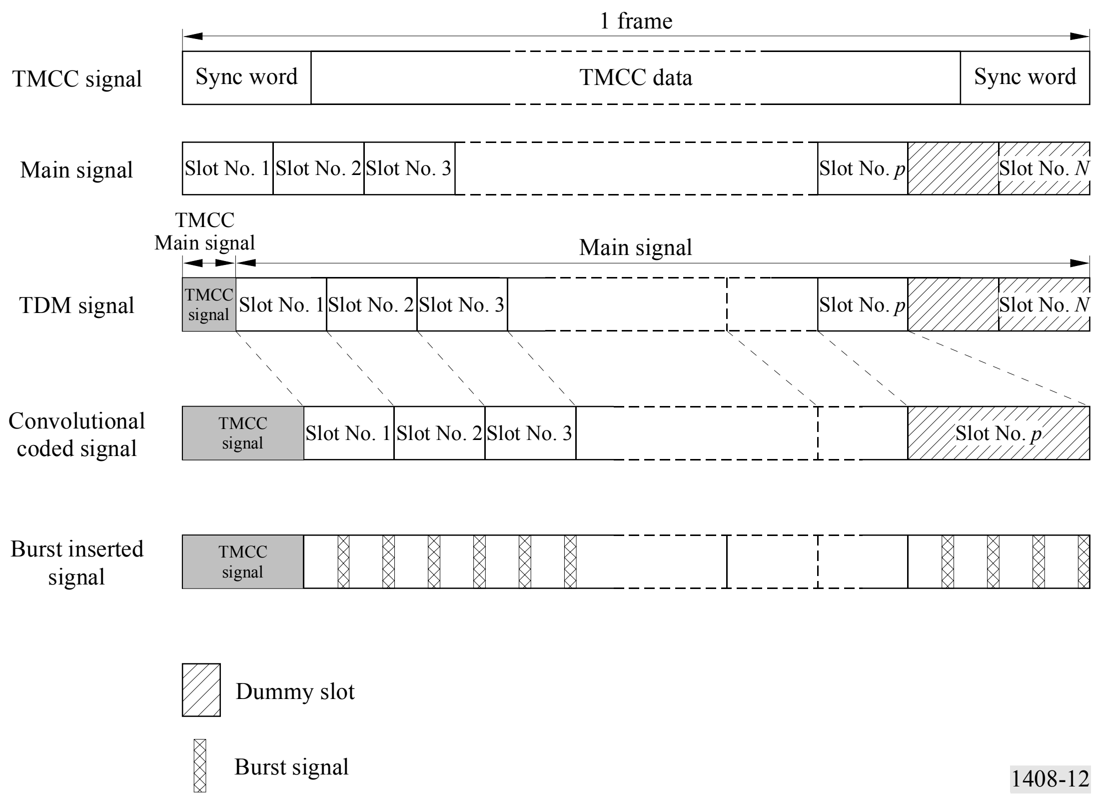
When carrier recovery in the receiver is carried out only from burst signals, the recovered carrier does not always lock to the right frequency. This problem (false lock of phase-locked loop (PLL)) can be solved by using the transmission signal during the TMCC duration in addition to the burst signal (when the PLL locks falsely, the number of cycles of the recovered carrier in a TMCC duration will be a different incorrect number, therefore, the PLL can be controlled by the difference in the number of cycles).

8 TDM

The main signal and the TMCC signal shall be time-division multiplexed at every frame. According to the modulation-code combinations designated for each slot, the time base of the multiplexed signal partially (slot basis) expands/compresses due to the convolutional coding process. By this operation, the dummy slots, if included in the main signal, shall be excluded from the transmission signal. Figure 12 illustrates conceptual integration processes of the main, TMCC, and burst signals for forming the transmission signal.

FIGURE 12

Integration of main, TMCC and burst signals



9 Inner coding, symbol mapping and modulation

The system shall allow for a variety of modulation schemes as well as a range of punctured convolutional codes based on a rate 1/2 convolutional code with a constraint length of 7. The generator polynomial shall be 171 octal and 133 octal (see Fig. 13). It may allow for the use of TC 8-PSK (TC 8-PSK), QPSK, and BPSK. When allowing these modulation schemes, the system shall allow for a code rate of 2/3 for TC 8-PSK, code rates of 1/2, 2/3, 3/4, 5/6, and 7/8 for QPSK and 1/2 for BPSK.

Figure 13 shows the convolutional encoder while Fig. 14 shows the code puncturing and symbol mapping circuitry. The punctured codes shall be those defined in Table 2. The symbol mapping shall be that specified in Fig. 15. With regard to BPSK, the two encoded bits (P0 and P1) shall be transmitted in the order of P1 and P0. The input bit B1 shall be used only in the case of TC 8-PSK, where B1 and B0 are two successive bits of a byte data (B1 represents the higher order bit).

For modulations and convolutional codes other than those described above, the appropriate specifications should be applied.

FIGURE 13

Convolutional encoder

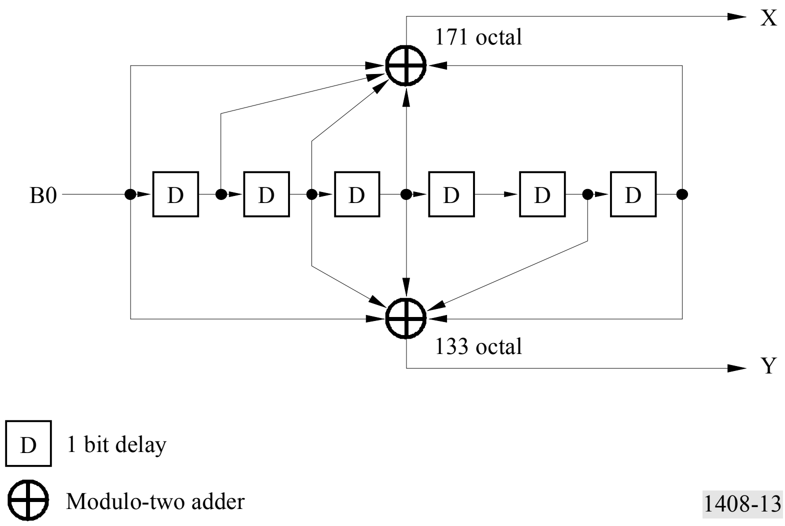


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FIGURE 14

Inner coding and symbol mapping circuitry

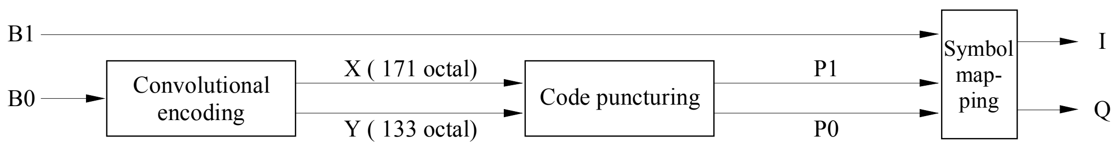

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TABLE 2

Punctured code definition

BPSK		QPSK										TC 8-PSK	
1/2		1/2		2/3		3/4		5/6		7/8		2/3	
P	d_{free}	*P*	d_{free}	*P*	d_{free}	*P*	d_{free}	*P*	d_{free}	*P*	d_{free}	*P*	d_{free}
$X = 1$ $Y = 1$ $P1 = X_1$ $P0 = Y_1$	10	$X = 1$ $Y = 1$ $P1 = X_1$ $P0 = Y_1$	10	$X = 10$ $Y = 11$ $P1 = X_1\ Y_2\ Y_3$ $P0 = Y_1\ X_3\ Y_4$	6	$X = 101$ $Y = 110$ $P1 = X_1\ Y_2$ $P0 = Y_1\ X_3$	5	$X = 10101$ $Y = 11010$ $P1 = X_1\ Y_2\ Y_4$ $P0 = Y_1\ X_3\ X_5$	4	$X = 1000101$ $Y = 1111010$ $P1 = X_1\ Y_2\ Y_4\ Y_6$ $P0 = Y_1\ Y_3\ X_5\ X_7$	3	$X = 1$ $Y = 1$ $P1 = X_1$ $P0 = Y_1$	10

1: bit transmitted bit

0: non transmitted bit

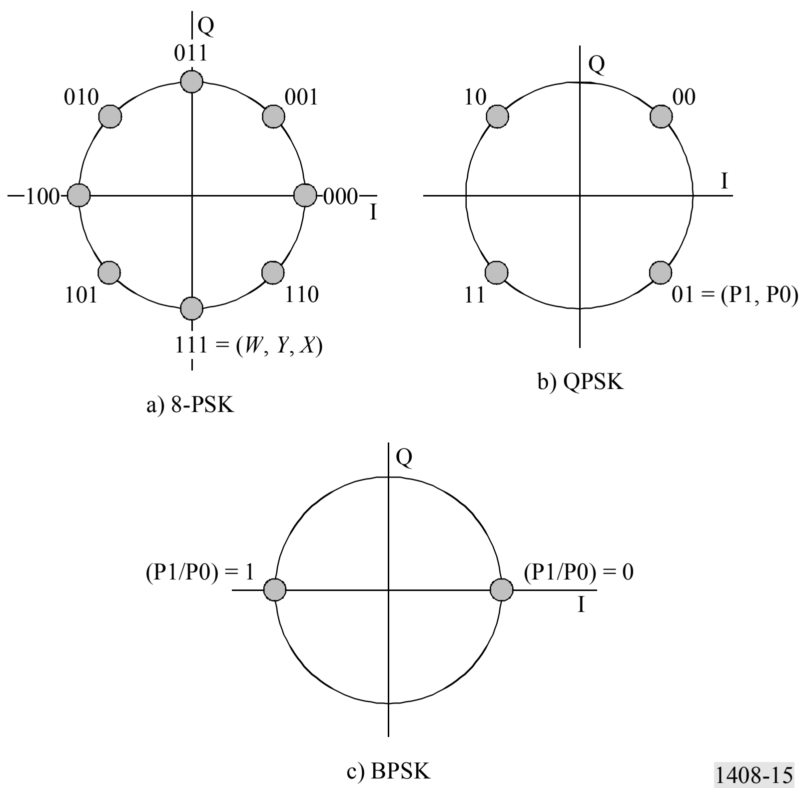
P: puncture

d_{libre}: convolutional code free distance

NOTE 1 – The punctured code is initialized at the start of the successive slots that are assigned to the corresponding code.

FIGURE 15

Symbol mapping



Prior to modulation, the I and Q signals shall be square-root raised cosine filtered for spectrum shaping. The roll-off factor shall be 0.35. The baseband square-root raised cosine filter shall have a theoretical function defined by the following expression:

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

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

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

where:

f_N: Nyquist frequency

α: roll-off factor = 0.35.

APPENDIX 1

TO ANNEX 1

Parameters for system using TC 8-PSK modulation

TABLE 3

System parameters

Item	Parameter	Notation	Value	Remarks
1	Number of slots per frame	N	48	
2	Number of frames per super-frame	M	8	
3	Number of bytes per slots during transmission	B	203	MPEG sync words not transmitted
4	Number of symbols per data frame	I_D	38 976	For main signal only
5	Number of symbols per frame		39 936	Including TMCC and burst
6	Number of modulation-code combinations		7	TC 8-PSK (r = 2/3) QPSK (r = 1/2) QPSK (r = 2/3) QPSK (r = 3/4) QPSK (r = 5/6) QPSK (r = 7/8) BPSK (r = 1/2)
7	Highest spectrum efficient modulation-code combination	E_{max}	2	(Bits/symbol)
8	Maximum number of modulation-code combinations used simultaneously	C_M	4	
9	Maximum number of TSs transmitted simultaneously	T_M	8	
10	Outer coding for TMCC			RS (64,48)
11	Interleaving for TMCC			Not applied
12	Other information by TMCC			Order of change 5 bits Flag for emergency alert 1 bit Uplink information 4 bits Reserved 62 bits
13	Total bits of TMCC information		384	

TABLE 4

Payload bit rates for various RF bandwidth

Band-width(1) (MHz)	Symbol rate (MBd)	MPEG-TS bit rates (Mbit/s)(2)						
		BPSK (r = 1/2)	QPSK					TC 8-PSK (r = 2/3)
			(r = 1/2)	(r = 2/3)	(r = 3/4)	(r = 5/6)	(r = 7/8)	
36	30.1	13.6	27.2	36.3	40.8	45.4	47.6	54.4
34.5	28.9	13.0	26.1	34.8	39.1	43.5	45.6	52.2
33	27.6	12.5	25.0	33.3	37.4	41.6	43.7	49.9
30	25.1	11.6	23.1	30.1	34.7	38.5	40.5	46.3
27	22.6	10.2	20.4	27.2	30.6	34.0	35.7	40.8
24	20.1	9.1	18.1	24.2	27.2	30.2	31.8	36.3

(1) The values express the occupied bandwidth (99% energy) when assuming typical non-linear characteristics of TWT and when assuming an RF filter bandwidth (–3 dB) that is 1.3 times the symbol rate.

(2) The values express the payload bit rates when the designated modulation-code combination is applied to all slots.