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Investigation on DVB-S2 Channel Characteristics

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Abstract – **This article represents the results of a simulation study of the characteristics of a satellite television channel shaped under the DVB-S2 standard. The formulas for determining BER of a radio channel when using QPSK, 8QPSK and 16APSK modulation are produced. The algorithms determining the probability of error after LDPC and BCH decoders are represented. Based on the analysis of the characteristics of the DVB-S2 channel, its noise immunity is evaluated, as well as the permissible transmission rate of video information and the power efficiency of the system**.

Keywords – **DVB-S2, CNR, BER, PAPR, Channel Capacity**

I. INTRODUCTION

The DVB-S2 standard is an improved version of the widely popular DVB-S standard. It counts on the use of improved methods of signal and channel coding as well as of additional modulations [1]. Using LDPC and BCH codes allows an increase of the transmission bit rate by nearly 30% compared to that in DVB-S at equal probability of error [2].

Unlike the DVB-S standard, which is primarily used for broadcasting of the TV programs' signal, the DVB-S2 standard provides for different possibilities for additional applications. For example, these are the HD resolution TV programs, the interactive services for users (Internet access) and various professional applications (Digital TV contribution and News Gathering, Internet connection etc.).

The adaptive coding and modulation (ACM) is also an innovation in the DVB-S2 standard that allows optimization of the parameters of the codes used and the modulation when transmitting IP-based services according to the parameters of the communication channel between the satellite and the user.

The continuous increase in the number of television programs broadcast by satellite, as well as of consumers using additional services, generates the need to increase the capacity of the communication channel. With DVB-S2 this problem is solved by using higher order modulations and more efficient channel codes. Details of the modulation types and channel codes adopted in DVB-S2 and their parameters are given in [1].

In satellite communications, one of the major problems is the large distance between the transmitter and receiver, which leads to great signal attenuation (200 dB). The noise and the interference in the satellite radio line are also a problem. In other words, the carrier to noise ratio (CNR) at the satellite receiver input is low, which is a reason for increasing the bit error rate (BER). It is known that in order to achieve pre-set quality of the received digital TV programs, the required BER at the MPEG decoder input shall not exceed 10^{-11}. This requirement is achieved through the use of more noise-resistant modulation methods and more effective channel coding [3].

The power limitation of the supply sources of satellite repeaters is a serious problem for the satellite TV systems. For that reason, their power efficiency should be taken into consideration when selecting a modulation method. In this regard, the MPSK modulations are the most suitable, but with the increase of their order M the radio channel noise immunity decreases. Therefore, 16APSK modulation has been established in DVB-S2 systems for satellite digital TV program transmission that satisfies the requirements to noise immunity, high transmission bit rate and efficient use of the power of the supply source at once [4, 5].

The aim of this work is to investigate the influence of the channel codes' rate and the modulation type on the noise immunity of the DVB-S2 channel, the permissible bit rate of the transmitted video information and the efficiency of the transmitter's power used.

II. DVB-S2 CHANNEL SHAPING

Figure 1 shows the block diagram of DVB-S2 transmitter and receiver. In the Scrambler block, a pseudo-random sequence is appended to the information digital video stream (through a modulo 2 sum), and its generator polynomial is of the type $G = 1+x^{14}+x^{15}$. Thus, the separation of the clock signal in the receiver and the electromagnetic compatibility of the system are ensured.

The scrambled digital signal passes through concatenated channel coding in the BCH Coder and LDPC Coder blocks. The LDPC codes' rate varies from 1/4 to 9/10 and the BCH code rate varies depending on the LDPC code rate. Details of the parameters of the used codes are provided in [1]. In the Interleaver block, the coded signal is subjected to bit interleaving in order to increase its resistance against group errors.

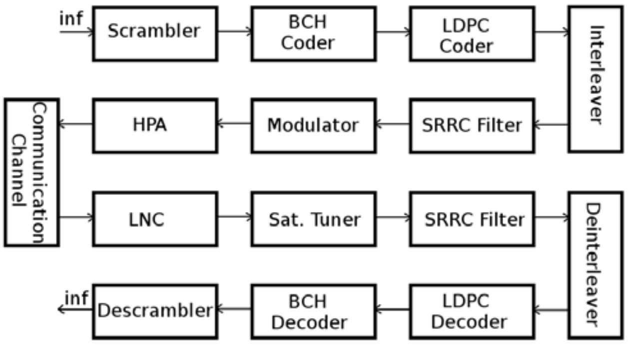

Fig. 1. DVB-S2 channel shaping

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After performing the channel coding, the signal is initially passed to $\sqrt{\cos^2}$ digital filter with roll-off factor $\alpha = 0.35/0.25/0.2$ to limit its spectrum, and then – to the modulator. Currently, QPSK, 8PSK and 16APSK modulations are the most widely used in the DVB-S2 systems. Figure 2 shows the diagrams of the signal vector for the three modulations.

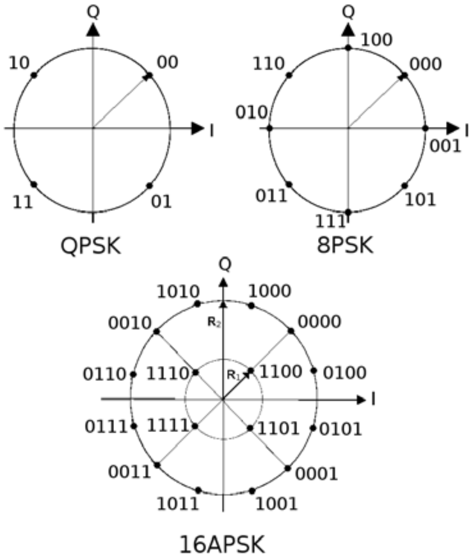

Fig. 2. Constellations used in DVB-S2

Typical for the 16APSK modulation is that the radius ratio of the outer and inner circles (γ_1) is changed depending on the rate of the channel code used [1]. The other parameters of the 16APSK constellation are constant and have the following values: number of signal points in the first circle ($n_1 = 4$), number of signal points in the second circle ($n_2 = 12$), initial phase shift of the first circle ($\varphi_1 = 45^\circ$), initial phase shift of the second circle ($\varphi_2 = 15^\circ$).

The processing of the received signal is performed in reverse order. The signal coming from the low noise converter (LNC) with first intermediate frequency (from 950 to 2050 MHz) is passed initially to a satellite tuner (Sat Tuner) where the following operations take place: selection of the desired channel and transfer of its spectrum to a second intermediate frequency (479.5 MHz), amplification of the signal by a second intermediate frequency and demodulation. Then the demodulated signal is passed sequentially to the reverse bit interleaving blocks (Deinterleaver), the LDPC and BCH decoders and the descrambler.

III. DVB-S2 RADIO CHANNEL NOISE IMMUNITY

The bit error probability at using MPSK modulation is determined by the expression [6]

$$P_b = \frac{1}{m}\operatorname{erfc}\left[\left(\sqrt{m\cdot\frac{E_b}{N_0}}\right)\sin\left(\frac{\pi}{M}\right)\right], \tag{1}$$

where $m = \log_2 M$ is the number of bits per symbol, $\operatorname{erfc}(x)$ – the complementary function of the error and E_b/N_0 – the energy-per-bit to noise power density ratio. The value of $\operatorname{erfc}(x)$ can be calculated by the formula

$$\operatorname{erfc}(x) \approx \frac{1}{x\sqrt{\pi}}\cdot\exp\left(-x^2\right). \tag{2}$$

At using 16APSK modulation, the bit error probability after the demodulator can be determined by the following dependence:

$$\begin{aligned} P_{b,16APSK} \approx{} & \frac{1}{16}\operatorname{erfc}\left(2\sqrt{\frac{1+\gamma_1^{\,2}+\sqrt{3}.\gamma_1}{1+3\gamma_1^{\,2}}}\sqrt{\frac{E_b}{N_0}}\right)+ \\ & +\frac{1}{4}\operatorname{erfc}\left(\frac{2(\gamma_1-1)}{\sqrt{1+3\gamma_1^{\,2}}}\sqrt{\frac{E_b}{N_0}}\right)+ \\ & +\frac{1}{16}\operatorname{erfc}\left(\frac{4}{\sqrt{2(1+3\gamma_1^{\,2})}}\sqrt{\frac{E_b}{N_0}}\right)+ \\ & +\frac{3}{16}\operatorname{erfc}\left(\frac{2\gamma_1\sqrt{2-\sqrt{3}}}{\sqrt{1+3\gamma_1^{\,2}}}\sqrt{\frac{E_b}{N_0}}\right). \end{aligned} \tag{3}$$

It was obtained by using the algorithm described in [7] and refers to 4-12-APSK constellation, which is adopted in the DVB-S2 standard.

The bit error probability P_{i+1} after i+1 iterations in the LDPC decoder is determined under the formula

$$P_{i+1} = P_b - \sum_{j=1}^{\omega_c}\lambda_j\left[\begin{array}{l} P_b\displaystyle\sum_{l=\alpha_j}^{j-1}\binom{j-1}{l}Q_i^{\,l}\left(1-Q_i\right)^{j-1-l} - \\ -(1-P_b)\displaystyle\sum_{l=\alpha_j}^{j-1}\left[\begin{array}{l}\dbinom{j-1}{l}\left(\dfrac{1-Q_i}{M-1}\right)^{l}\text{x} \\ \text{x}\left(1-\dfrac{1-Q_i}{M-1}\right)^{j-1-l}\end{array}\right]\end{array}\right], \tag{4}$$

where:

$$Q_i = \frac{1}{M}\left\{1+\left(M-1\right)\sum_{q=2}^{\omega_r}\left[\rho_q\left(1-\frac{MP_i}{M-1}\right)^{q-1}\right]\right\}. \tag{5}$$

The following symbols are used in these expressions: P_b is the bit error probability in the communication channel, j and q – the number of units in a column and in a row of the parity-check matrix respectively; λ_j – the relative number of columns containing j number of units; ω_c – the maximum number of units in a column; ρ_q – the relative number of rows, containing q number of units; ω_r – the maximum number of units in a row. The value of the parameter α_j is chosen as the smallest whole number $\alpha_j > (j-1)/2$, for which the following requirement is fulfilled:

$$\frac{1-P_b}{P_b} \le \frac{Q_i^{\alpha_j}\left(M-1\right)^{j-2}}{\left(1-Q_i\right)^{2\alpha_j+1-j}\left(M-2-Q_i\right)^{j-1-\alpha_j}}. \tag{6}$$

The dependence determining the bit error probability at AWGN channel and the regular LDPC code, provided in [8] and the method described in [9] are used as a base to work out expressions (4), (5) and (6).

The probability of bit error after the BCH decoder P_{BCH} is determined by the expression [10]

$$P_{BCH} = \frac{1}{Nl} \sum_{j=T+1}^{N} j \binom{N}{j} (P_{i+1} l)^j \, (1 - P_{i+1} l)^{N-j} \, , \qquad (7)$$

where N is the data packet length, T – the number of errors that can be corrected by the BCH code, l – the number of bits contained in one coded symbol, and P_{i+1} – the bit error probability after i+1 iterations in the LDPC decoder. Because binary BCH codes are used in the DVB-S2, so $l = 1$.

The relation between the carrier to noise ratio (CNR) and the parameter E_b/N_0 is as follows:

$$CNR = \frac{E_b}{N_0} + 10\,\lg(m) + 10.\lg\left(1 - \frac{\alpha}{4}\right) + + 10\,\lg(R_{LDPC}) + 10\,\lg(R_{BCH}) \, , \qquad (8)$$

where R_{BCH} and R_{LDPC} are BCH and LDPC code rates, and α is the roll-off factor of the $\sqrt{\cos^2}$ filter.

Figure 3, figure 4 and figure 5 show the dependences of the bit error ratio (BER) at the input of the MPEG2/4 decoder on the CNR at the input of the receiver for different modulations and LDPC code rates. They are achieved at $\alpha = 0.35$ and can be used to determine the required value of the CNR parameter (in dB) at which QEF reception is ensured, i.e. BER $\leq 10^{-11}$. The results of this research are represented in Table 1.

TABLE 1. CNR ENSURING THE QEF RECEPTION

R_{LDPC}	QPSK	8PSK	16APSK
3/5	2.04 dB	5.60 dB	–
2/3	2.98 dB	6.68 dB	9.37 dB
3/4	4.71 dB	8.27 dB	10.56 dB
4/5	5.77 dB	–	11.34 dB
5/6	6.55 dB	10.23 dB	11.97 dB
8/9	7.66 dB	11.56 dB	12.89 dB
9/10	7.93 dB	11.88 dB	13.20 dB

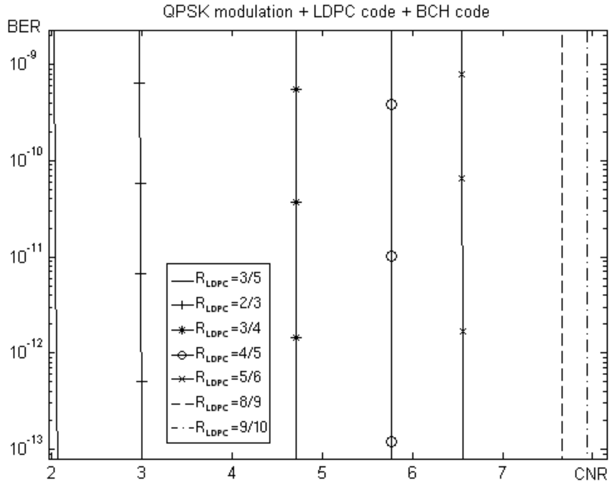

Fig. 3. Noise immunity of QPSK DVB-S2 channel

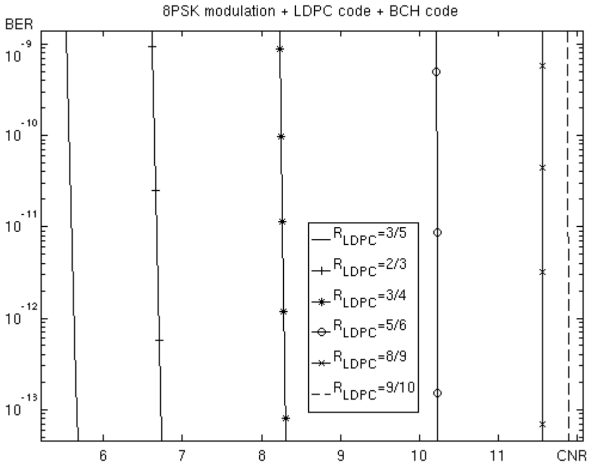

Fig. 4. Noise immunity of 8PSK DVB-S2 channel

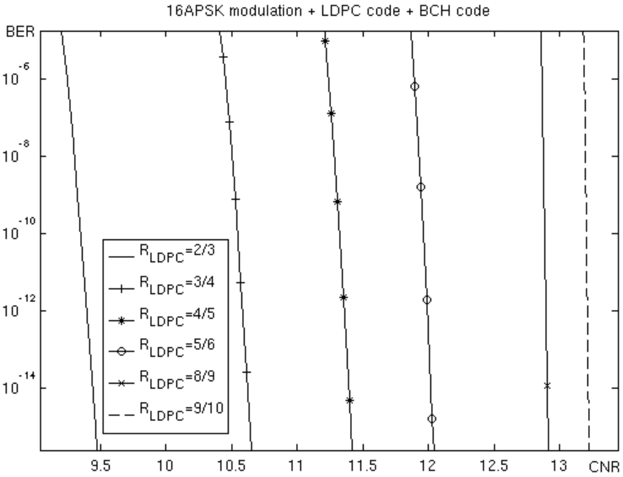

Fig. 5. Noise immunity of 16APSK DVB-S2 channel

Apparently, the noise immunity of DVB-S2 channel is reduced by increasing the code rate. This is due to the fact that at higher code rate the number of parity bits decreases and hence the efficiency of channel coding is reduced.

IV. TRANSMISSION BIT RATE AND POWER EFFICIENCY

The maximum transmission bit rate of the useful information (R_b) depends on the spectral efficiency of the modulation method applied ε and the effective bandwidth of the radio channel ($B_{ch,e}$) and is calculated under the formula

$$R_b = \varepsilon . B_{ch,e} \, . \qquad (9)$$

The spectral efficiency ε characterizes the transmission bit rate in a bandwidth of 1 Hz and is determined by the number of bits per symbol of the digital signal, i.e. $\varepsilon = m = \log_2(M)$. The parameter $B_{ch,e}$ depends on the channel bandwidth B_{ch}, the code rate of LDPC and BCH codes and the roll-off factor of the digital filter α, and is obtained using the expression

$$B_{ch,e} = B_{ch} \left(\frac{1}{1+\alpha} \right) R_{LDPC} R_{BCH} \, . \qquad (10)$$

Table 2 represents the values of the maximum transmission bit rate achieved (in Mbit/s) depending on the type of modulation and the rate of channel codes used. These results refer to a DVB-S2 channel with a bandwidth B_{ch} = 36 MHz.

TABLE 2. MAXIMUM TRANSMISSION BIT RATE

R_{LDPC}	QPSK	8PSK	16APSK
3/5	31.84 Mbit/s	47.76 Mbit/s	–
2/3	35.42 Mbit/s	53.14 Mbit/s	70.85 Mbit/s
3/4	39.84 Mbit/s	59.76 Mbit/s	79.68 Mbit/s
4/5	42.51 Mbit/s	–	85.02 Mbit/s
5/6	44.31 Mbit/s	66.47 Mbit/s	88.63 Mbit/s
8/9	47.30 Mbit/s	70.95 Mbit/s	94.60 Mbit/s
9/10	47.89 Mbit/s	71.84 Mbit/s	95.79 Mbit/s

The table shows that by increasing the LDPC code rate the transmission bit rate grows. At a higher channel code rate, however, the noise immunity of the radio channel is reduced.

In order to evaluate the efficiency of the power used the PAPR parameter (Peak to Average Power Ratio) is used. It is the ratio between the maximum and the average signal power for a period T and is obtained using the following expression [11]:

$$PAPR = \frac{\max_{t\in[0,T]} |s(t)|^2}{\frac{1}{T}\int_0^T |s(t)|^2\, dt} = \frac{M r_N^2}{\sum_{i=1}^{M} r_{p(i)}^2}, \qquad (11)$$

where r_N denotes the radius of the outermost circle, and $r_{p(i)}$ denotes the radius of the circle on which the i-th signal point is located.

Since at MPSK modulations all the signal points are located on the same circle, for them PAPR = 1. At 16APSK modulation the radius ratio of the inner and outer circle (γ_1) changes depending on the rate of the channel code used. This means that the power efficiency of the system will depend on the LDPC code rate, which is seen in Table 3.

TABLE 3. POWER EFFICIENCY OF 16APSK

R_{LDPC}	2/3	3/4	4/5	5/6	8/9	9/10
PAPR	1.289	1.281	1.277	1.275	1.271	1.269

The table shows that by increasing the rate of the channel codes used, the value of the parameter PAPR decreases. This means that the efficiency of the used transmitter's power grows.

V. CONCLUSION

The represented analytical and graphical dependences allow to determine the CNR ratio at the satellite TV receiver input that is needed to provide QEF reception, depending on the type of modulation and the rate of the channel code used. Thus, it is possible to provide an adaptive modification of the modulation and of the channel code rate depending on the current ratio CNR, thereby maintaining the quality of received information at deterioration of the parameters of the communication channel. Furthermore, the results of the surveys carried out provide the opportunity for parallel assessment of DVB-S2 channels' noise immunity and both the transmission bit rate and the factor of use of the transmitter's power at any time.

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