Increasing the Reliability of Video Information Transmitted over Satellite Radio Channel

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Abstract **– The work deals with the results of a research work on the effectiveness of different methods to improve noise immunity of the satellite radio channel when digital TV signals are transmitted. An algorithm to determine the achievable value of the CNR parameter at the satellite receiver input is suggested that takes into consideration both the attenuation of signals, noise and interference in the radio channel and the parameters of the equipment applied.**

Keywords **– DVB-S receiver, CNR, noise figure of the LNB, antenna gain, E_b/N_0 , BER, RS- and convolutional coding .**

I. Introduction

The work of the systems of satellite television is based on the active retranslation of signals from satellites, which are launched into geostationary orbit. For transmission of signals to the satellite the frequency band from 14 to 18 GHz is used, while 10,7-12,75 GHz frequency band is used for transmission from satellites to the Earth. The width of the satellite radio channel is most often from 26 MHz to 36 MHz, whereas the polarization of signals in adjacent channels is orthogonal. At present, the majority of satellite TV programs are digital and for shaping of their signals the DVB-S standard has been established.

One of the main problems in satellite TV systems is the high attenuation of signals in a radio channel Satellite - Earth (more then 200 dB) and comparatively high level of noise that adds to the useful signal. This leads to worsening of the Carrier to Noise Ratio (CNR) at the satellite receiver input, and from there to worsening of the quality of received picture and sound. The quality of received signals is measured by the parameter Bit Error Ratio (BER), and in order to achieve a studio quality of image and sound, BER need to be more than 10^{-7} [1-5].

For that reason the MPEG-2 transport stream, which is to be sent to the satellite as QPSK-modulated signal, must firstly be provided with error protection before being fed into the actual modulator. In DVB-S, two error protection mechanisms are used, namely a Reed-Solomon block code which is coupled with convolutional (trellis) coding [6-8].

In the RS-coder the MPEG-2 transport stream packets with a length of 188 bytes are expanded by 16 bytes. The RS (204,188) coding allows correction of up to 8 errors at the receiving end. After performing the convolutional coding, the digital data stream is expanded by a factor which depends on the selected code rate (1/2, 3/4, 2/3, 5/6 and 7/8). If the code rate is 1/2, the data stream is expanded by a factor of 2. The error protection is now at a maximum and the net data rate has dropped to a minimum. A code rate of 7/8 provides only a minimum overhead but also only a minimum error protection. The available net rate is then at a maximum. The good compromise is usually a code rate of 3/4 [9-12].

The aim of this work is to examine the influence of the satellite radio path parameters and the parameters of the receiver equipment used on the reliability of received video information at signal shaping of satellite TV programs under the DVB-S standard.

II. Attenuation of Signals and Noise in Satellite radio Channel

The attenuation of satellite TV signals is due both to the huge distance between the satellite and the Earth (about 36 000 km) and to other factors. The more important of these factors are: absorption of electromagnetic energy in the atmosphere and in the hydro meteors (rain, snow etc.) and loses due to inaccurate orientation of the receive antenna (receiver directional error) and to the rotation of polarization plane of radio waves (polarization error).

For calculation of signal attenuation along the radio path Satellite - Earth the following expression is used:

$$L = L_0 + \Delta L = 20\lg d + 20\lg f + 92.4 + \Delta L , \quad (1)$$

where L_0 is the free space attenuation, d is the Satellite-Earth distance in km, f is the frequency of the received signal in GHz, and ΔL gives loses in atmosphere (0.3 dB) and hydro meteorites (for our climatic zone – under 1 dB), the receiver directional error (0.5 dB) and the polarization error (0.2 dB). At the maximum transmitter-receiver distance (for the Polar Regions) $L_0 \approx 206$ dB, i.e. it grows with about 1 dB compared to the attenuation on the Equator.

The level of the received satellite signals C could be determined (in dBW) under the formula:

$$C = EIRP - L + G , \quad (2)$$

where EIRP is the satellite equivalent isotropic radiated power in dBW and G is the antenna gain in dB. For the satellite television systems the values of EIRP parameter are within the limits from 45 to 65 dbW.

The noise in a satellite radio channel is caused by external sources, for example the outer space (the Sun, the Moon, planets and stars), the atmosphere, the Earth etc. and from the

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receiver itself (internal noise). For determination of the noise power at the receiver input the following expression is used:

$$N = 10\lg k + 10\lg B + 10\lg\left(T_0\right) + NF . \qquad (3)$$

where k = 1.38.10^{-23} W/Hz.K is the Boltzmann' constant, B is the channel bandwidth in Hz, T_0 is the temperature in ^{0}K (usually it is accepted that T_0 = 293 K), NF is the noise figure of the receiver in dB.

III. INFLUENCE OF THE PARAMETERS OF THE RECEIVING EQUIPMENT ON CNR

Taking into account expressions (2) and (3), the following formula is obtained for calculation of carrier to noise ratio at the receiver input in dB:

$$CNR = EIRP - L + G - 10\lg B - NF + 144 , \qquad (4)$$

where B is substituted in MHz.

In order to compensate the huge attenuation of signals by the Satellite - Earth radio path, it is necessary to use antennas with comparatively large size (most often parabolic ones with about 40 dB gain factor) and receivers where double down-conversion of signals is applied. At the first down-conversion, witch is made in the low noise block (LNB), the received signals are shifted to the band of the first intermediate frequency (IF) f_{i1} = (950 … 2050) MHz, and are amplified with about 55-60 dB. The second down-conversion provides shifting of the selected program's signal to the second IF f_{i2} = 479,8 MHz, at which over 100 dB gain can be achieved.

The receiver's self-noise can be reduced through realization of its input stages (LNB) with low-noise elements (Ga-As and HEMT transistors). The noise figure of the modern LNBs varies within the limits from 1.0 to 0.6 dB. Penetrating of external noise in the receiver is determined mainly by the receive antenna radiation pattern. To obtain low levels of these noises it is necessary for the receive antenna to have a high directivity factor, i.e. very small beamwidth and low levels of side lobes in its receive antenna radiation pattern.

Generally parabolic antennas are used to receive satellite TV programs. Their gain factor *G* (in dB) is related to the diameter of the reflector *D* (in m), the frequency of received signal *f* (in GHz) and the aperture efficiency η through the following dependence:

$$\begin{aligned} G &= 10\lg\left[\left(2\pi/\lambda^2\right)\cdot\eta\cdot\left(\pi D^2/4\right)\right] = \\ &= 20\lg D + 20\lg f + 20.4 + 10\lg\eta . \end{aligned} \qquad (5)$$

The values of the parameter η for a circular parabolic antenna typically runs about 0.55, while values of 0.7 and higher are available for high performance antenna systems.

After taking into consideration the parameters of currently manufactured satellite antennas and low noise blocks and they are substituted in expression (4), the real idea about the possible limits of CNR parameter variations can be obtained. With the values of this parameter calculated in such a way, the bit rate ratio on the output of DVB-S tuner is about 10^{-2}. A significant reduction of BER is achieved after the channel decoding in the DVB-S receiver.

IV. DETERMINING THE PARAMETER E_B/N_0 AT THE OUTPUT OF SATELLITE RECEIVER

Figure 1 presents the block scheme of a DVB-S receiver, named also DVB-S set-top box (without MPEG-2 decoder). In the satellite front-end the signal undergoes a second down-conversion to a second satellite IF. This down-conversion is performed with the aid of an IQ mixer which is fed by an oscillator controlled by the carrier recovery circuit. The I and Q signals are then A/D converted and supplied to a matched filter in which the same root cosine square filtering process as at the transmitting end takes place with a roll-off factor of 0.35. The baseband square root raised cosine filter has a theoretical function defined by the following expression:

$$H(f)=\begin{cases}1, & f<f_N(1-\alpha)\\ \left\{\frac{1}{2}+\frac{1}{2}\cdot\sin\left(\frac{\pi}{2f_N}\right)\cdot\left[\frac{f_N-f}{\alpha}\right]\right\}^{1/2}, & f_N(1-\alpha)<f<f_N(1+\alpha)\\ 0, & f>f_N(1+\alpha),\end{cases} \qquad (6)$$

where $f_N = 1/(2T_S)$ is the Nyquist frequency, T_S is the symbol duration and α is the roll-off factor.

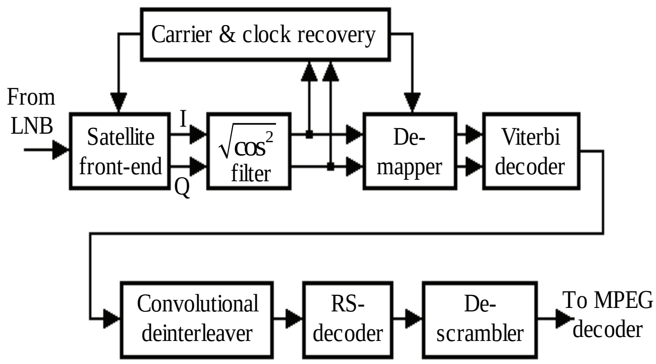

Fig. 1. DVB-S set-top box

The demapper again generates a data stream from which the first errors are removed in the Viterbi decoder. Then, the data stream is passed to convolutional de-interleaving block where any burst errors, i.e. multiple errors in a packet, are broken up into individual errors. The bit errors still present are then corrected in the Reed Solomon decoder. If the error protected TS packet with the length of 204 bytes contains more than 8 errors, the error protection will fail. TS packets flagged as errored must not be used by the MPEG-2 decoder and error concealment must be applied. After the Reed Solomon decoding, the energy dispersal is removed and the MPEG-2 transport stream is supplied to an MPEG-2 decoder.

For determination of signal to noise ratio (SNR) after the matched filter in dB the following expression is used:

$$SNR = CNR + 10\lg\left(1 - \alpha/4\right), \qquad (7)$$

where α is the roll-off factor of the root cosine square filter (in DVB-S standard, α = 0.35).

The parameter SNR is related to the energy per information bit E_b referred to the normalized noise power N_0 thought the following dependence:

$$SNR = E_b/N_0 + 10\lg m, \qquad (8)$$

where m = $\log_2 M$ is the number of bits-per-symbol and M is the number of constellation points (in this case m = 2).

After the channel decoding, the value of the parameter E_b/N_0 grows proportionally to the rate of the RS-code and the one of the selected convolutional code. The RS-code rate is R_{RS} = 204/188 = 0.922, while the convolutional code rate R_C can take one of the following five possible values: 1/2, 3/4, 2/3, 5/6 and 7/8. Considering the growth of the energy per information bit and expressions (6) and (7) are determined, the following formula is obtained for calculation of the parameter E_b/N_0 at the output of satellite receiver (in dB):

$$E_b/N_0 = CNR - 10\lg m + 10\lg\left(1 - \alpha/4\right) - 10\lg R_{RS} - 10\lg R_C. \qquad (9)$$

From expression (8) it follows that as a result of the Reed-Solomon and convolutional coding an increase of E_b/N_0 from 0.93 dB (at R_C = 7/8) up to 3.36 dB (at R_C = 1/2) can be achieved, which is a prerequisite for substantial decrease of BER of the received digital information.

V. Requirements to CNR Ensuring the Achievement of Pre-set BER

The dependence of the bit error ratio (BER) from the parameter E_b/N_0 is used most often for evaluation of the reliability of the received digital information. When QPSK method is used for transmission of the signals on the radio channel, it can be described with the expression:

$$BER = Q\left[\sqrt{2 \cdot 10^{0.1(E_b/N_0)}}\right], \qquad (10)$$

where Q(*x*) is the Gauss error integral, and the value of E_b/N_0 is substituted in dB. The following approximate formula is worked out for determining of Q(*x*):

$$Q(x) \approx \left(x\sqrt{2\pi}\right)^{-1} \cdot \exp\left(-0.5 \cdot x^2\right). \qquad (11)$$

Expression (10) is used for evaluation of the reliability of received video information when channel coding is not applied in the satellite receiver. The decrease of the probability of error as a result of Reed-Solomon and convolutional coding can be determined when the argument of the function Q(*x*) is substituted by *x**. The new value of the argument is calculated with the formula:

$$x^* = \left[\frac{2 \cdot 10^{0.1(E_b/N_0)}}{R_{RS} \cdot R_C}\right]^{1/2}, \qquad (12)$$

where E_b/N_0 is in dB.

After (11) is substituted in expression (10), the following dependence is obtained for determining the Gauss error integral which takes into consideration the profit ΔQ(*x*) of using the Reed-Solomon and convolutional coding:

$$Q(x^*) = Q(x) \cdot \exp\left\{-0.5x^2\left[\left(R_{RS} \cdot R_C\right)^{-1} - 1\right]\right\} \times \left(R_{RS} \cdot R_C\right)^{1/2} = Q(x) \cdot \Delta Q(x). \qquad (13)$$

Figure 2 shows the dependences of BER from E_b/N_0 obtained at convolutional code rate of 1/2, 2/3, 3/4, 5/6, 7/8 and 1. From them, it is easy to determine the necessary values of the parameter E_b/N_0 at which the bit error ratio does not exceed 10^{-7}. The dependence referring to R_C = 1 takes into consideration the effect of application of RS coding only in the receiver. Having in mind that in absence of a channel coding the pre-set maximum value of BER (10^{-7}) is ensured at E_b/N_0 = 11.3 dB, a conclusion can be made that the DVB-S receiver requires with about 1 to 3.4 dB less values of the parameter E_b/N_0.

In the course of designing the satellite radio channel, the parameter CNR is used, which is related to E_b/N_0 through dependence (8). By taking into account the regulated in the DVB-S standard values of the roll off factor α of the digital filter (α = 0.35) used and the rate of RS (204,188) code, the following formula for calculation of CNR is worked out:

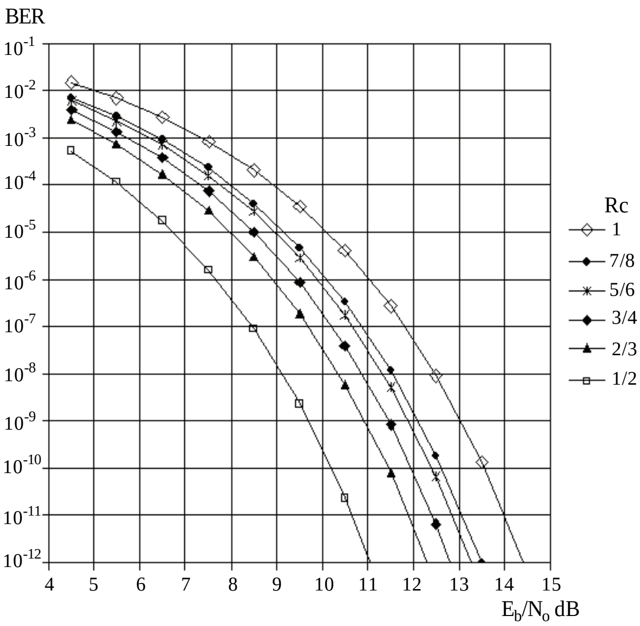

Fig. 2. BER in DVB-S as a function of E_b/N_0

$$CNR = E_b/N_0 + 2.26 + 10\lg R_C. \qquad (13)$$

After taking into consideration the values of parameter E_b/N_0, which are required for achieving $BER = 10^{-7}$ at R_C = 1/2, 3/4, 2/3, 5/6 and 7/8, it is found out that the actual CNR values can be expected between 7 … 12 dB. For example, if it is accepted that $R_C = 3/4$ (in this case $BER = 10^{-7}$ is achieved at $E_b/N_0 = 9.7$ dB), the carrier to noise ratio at the satellite receiver input needs to be 10.7 dB.

By known values of CNR, satellite equivalent isotropic radiated power (EIRP), attenuation of the received signal (L) and channel bandwidth (B) it is easy to determine the diameter of the receive antenna and to select appropriate low noise block for the specific case, whereas using for that purpose expressions (4) and (5). For example, at EIRP = 52 dBW, L = 207 dB (this value is obtained taking into consideration the geographic location of Bulgaria), B = 27 MHz and selection of LNB with noise factor 1 dB, the gain of the receive antenna must be 37 dB. With the individual satellite receiving, where usually offset antennas are used, such antenna gain can be achieved with antenna diameter of 60 cm.

VI. CONCLUSION

The results presented in this work are used to develop algorithms for design of digital satellite TV channels of individual and of CATV systems. They allow taking into consideration the parameters of the satellite radio path and at the same time of the manufactured equipment, and they are the base for further investigations related to improvement of the quality of received digital satellite TV programs.

ACKNOWLEDGEMENT

The research described it this paper is supported by the Bulgarian National Science Fund under the contract No ДДВУ 02/74/2010.

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