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Digital Image Transmission Simulation Using the DVB Forward Error Correction Codes

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The contribution deals with the simulation of the digital video signal transmission through the baseband transmission channel model. The simulation model that covers selected phenomena of DVB (Digital Video Broadcasting) system signal processing is presented. The digital video signal is represented with the digital data of one non-compressed video frame that is channel encoded and protected against errors with the forward error correction (FEC) codes. The transmission channel model has influence on transmitted digital data and its distortion and the pertubative signals affect on the data decoding. The developed interactive simulation software (Matlab application) features are outlined too and the conclusion presents efficiency of the used FEC codes.

Key words: digital image, source and channel encoding, transmission channel model

1 INTRODUCTION

Digital television (DTV) or Digital Video Broadcasting (DVB) refers to the source coding of audio, data and video signals, the channel coding and the methods for the transport of the DVB signals via all kinds of transmission media. The DVB standards are determined for satellite DVB-S, cable DVB-C and terrestrial DVB-T broadcasting. There are common principles and characteristics of source and channel encoding in baseband for mentioned transmission media (source encoding MPEG-2, channel encoding FECs by block Reed-Solomon code and convolution code with interleaving). The systems are different by used modulation methods (QPSK for DVB-S, 16-256 QAM for DVB-C and COFDM for DVB-T) caused by different bandwidth, limits of radiated power, levels of distortion and perturbation in transmission media etc. [1].

The contribution presents partial solution of the grant project »*Simulation and analysis of the digital signal transmission and transmission distortions in DTV and DVB area*« no. B2813302 of the Grant Agency of the Academy of Sciences of the Czech Republic that was solved in 2003–2004 at Institute of Radio Electronics, Brno University of Technology and the author is supervisor of the project.

2 TRANSMISSION SIMULATION MODEL

The transmission simulation model deals with the selected baseband DVB processing phenomena (see Figure 1). The input signal corresponds to analog *RGB* image (one non-interlaced and non-compressed frame of the standard television signal) that is converted into digital YC_BC_R image samples and multiplexed into serial data. The conversion and multiplexing is according to CCIR ITU R-601 recommendation. This way created one-dimen-

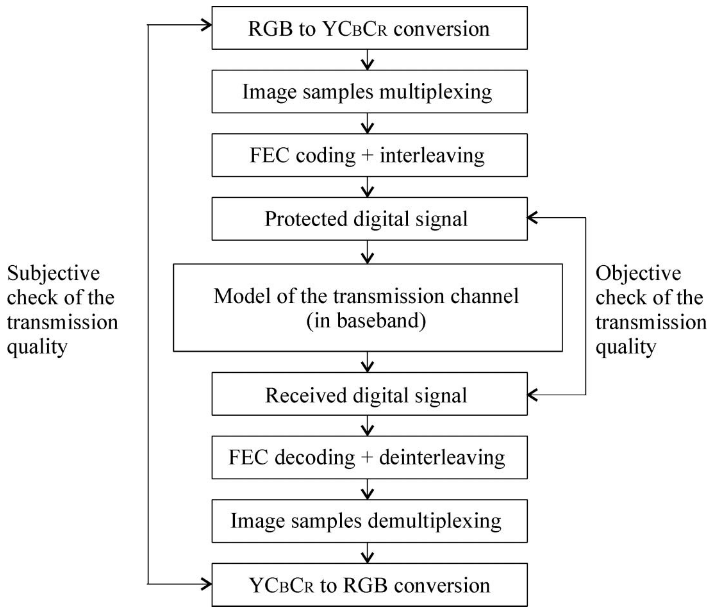

Fig. 1 The simulation and analysis transmission simulation model

sional digital signal is optionally channel encoded with FEC (Forward Error Correction) codes and symbols are interleaved. The protected digital signal is then transmitted with the model of the digital transmission channel. The model has variable parameters and can affect signal with the linear distortions and pertubative and reflected signals. After the transmission the signal is received, FEC decoded, deinterleaved, demultiplexed and the *RGB* image samples are counted and *RGB* image is visualized. Then the objective (bit-error rate *BER* evaluation) or subjective (image comparison) check of the transmission quality can be evaluated (dashed lines in Figure 1) in according to set up parameters of each block. The simulation model was applied in Matlab and the developed simulation software is used for research and education of DVB signal baseband processing in laboratory education. The next paragraphs specify particular blocks and the way of the model signal processing. The conclusion presents efficiency of DVB protection codes.

3 DIGITAL IMAGE AND VIDEO SIGNAL

One frame of the PAL CCIR 625/50 television signal is the standard analog image with 576 visible lines and according 720 pixels per line. This image consists of three components RGB. The DVB non-compressed image corresponds to the CCIR ITU R-601 recommendation [1] and the transmission components are the luminance signal Y and chrominance signals C_B and C_R. Each signal component is sampled by the standardized sampling frequency and quantized by 8 bits per sample. Table I presents possible sampling formats and subsequent frame resolution. The 4 : 4 : 4 sampling format is used for master record, the 4 : 2 : 2 and 4 : 2 : 0 sampling formats are used for standard television broadcasting (quality accords to PAL CCIR 625/50).

Table I **Sampling formats and image resolution**

Format	Resolution Y		Resolution C_BC_R	
	horizontal [pixels]	vertical [pixels]	horizontal [pixels]	vertical [pixels]
4 : 4 : 4	720	576	720	576
4 : 2 : 2	720	576	360	576
4 : 2 : 0	720	288	360	288

The data rate of the digital video signal components and its serial data multiplex depends on the sampling format. Table II shows the possible sampling frequencies f_s and according data rates H

Table II **Sampling frequencies and data rates**

Signal	4 : 4 : 4		4 : 2 : 2		4 : 2 : 0	
	f_s [MHz]	H [Mbps]	f_s [MHz]	H [Mbps]	f_s [MHz]	H [Mbps]
Y	13.5	108	13.5	108	13.5	108
C_B	13.5	108	6.75	54	6.75	27
C_R	13.5	108	6.75	54	6.75	27
MUX	40.5	324	27	216	27	162

for the sampling formats in baseband including the multiplexed serial data (*MUX*). The data rates are 0.768 times multiplied when only active part of the image is in-process [2].

4 ERROR PROTECTION CODES IN DVB

Two relevant methods of error protection in the transmission of digital television are forward error corrections by block Reed-Solomon code (FEC1) and convolution code (FEC2) with interleaving (see Figure 2). For the transmission of digital TV over satellite and via terrestrial transmission networks the RS (n, m) code – $n = m + k$ where m is the number of information symbols and k is the number of correction symbols – is concatenated with the convolution code by means of an interleaver. The RS code is based on the Galois field $GF(2^8)$, and therefore has a symbol size of 8 bits. The RS (255, 239) was chosen which processes a data block of 239 symbols and can correct up to 8 symbol errors by calculating 16 redundant correction symbols. As an MPEG-2 packet is 188 bytes long, the code was shortened, i.e. the first 51 information bytes were set to zero and not transmitted at all. In this way the RS (204, 188) is generated [1].

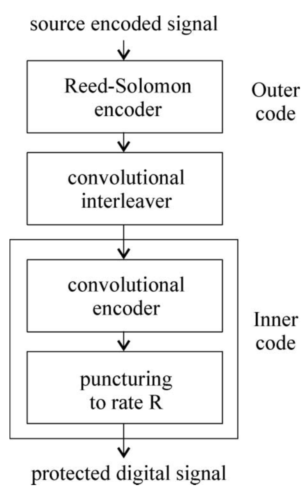

Fig. 2 Forward error correction codes in the transmission of the DVB

After the outer code a convolutional interleaver with depth $I = 12$ is used. From the frame length of the outer code with $n = 204$ the base delay results as $M = n/I = 17$. Finally a convolution code is applied to the interleaved symbols. Its rate $R = m/n$ – where m is the number of input bits and n is the number of output bits – is equal to 1/2, the constraint length is $K = 7$. Optionally the 2/3, 3/4, 5/6 and 7/8 rates are possible. Coding for error correction by transmission over cable is similar, only the convolution code is not required as the signal-to-noise performance in the cable channel is very much better than in the satellite channel.

5 TRANSMISSION CHANNEL MODEL

The philosophy of the digital transmission channel simulation appears from the similarity with the characteristics and the process of design and realization of the non-recursive digital filters FIR. These filters have finite impulse response, numerical stable algorithms of design and relatively easy hardware implementation on Digital Signal Processor (DSP) platform. Another advantage of these filters is the linear phase characteristic in mentioned frequency band that is important especially for digital components signal transmission in digital television.

The *conventional model* [3] for digital transmission channel simulation for baseband digital video signal transmission is the FIR filter with low-pass character and variable parameters and method of design. Design of the proposed digital transmission channel model deals with the input parameters of the channel in according to chosen method of design. The acceptable design methods for simulation in Matlab are the weighting of the impulse response method, sampling of the frequency characteristic method and design by approximation of frequency characteristic with LS algorithm. These methods give stable results and ensure successful implementation [4].

The *developed model* [5] can change the character of the filter (LP, HP, BP, BS, multiband), possibility of design method selection and it has variable parameters (filter order, cut-off frequencies, attenuations and allowed ripples of transmission module in passband and stopband, eventually interactive design by using the tolerant field of the digital transmission channel model). The pertubative signals influence on the transmitted digital signal is substituted with one source of pertubation signal. This source is optionally added to useful signal – additive pertubation and may be modeled for e.g. as the white noise with normal distribution. The next possibility of pertubative signal is the reflected signal and its influence on the transmitted digital signal.

6 SIMULATION SOFTWARE FEATURES

The developed Matlab GUI application [6] for the simulation and modeling uses functions of the Signal Processing, Image Processing and Communication Toolboxes of Matlab and allows:

⇒ *input image* selection from file – BMP, PCX, JPG, PNG, TIF, FIG;

⇒ digital video signal *sampling format* selection corresponds to ITU R-601 recommendation – 4 : 4 : 4, 4 : 2 : 2, 4 : 2 : 0;

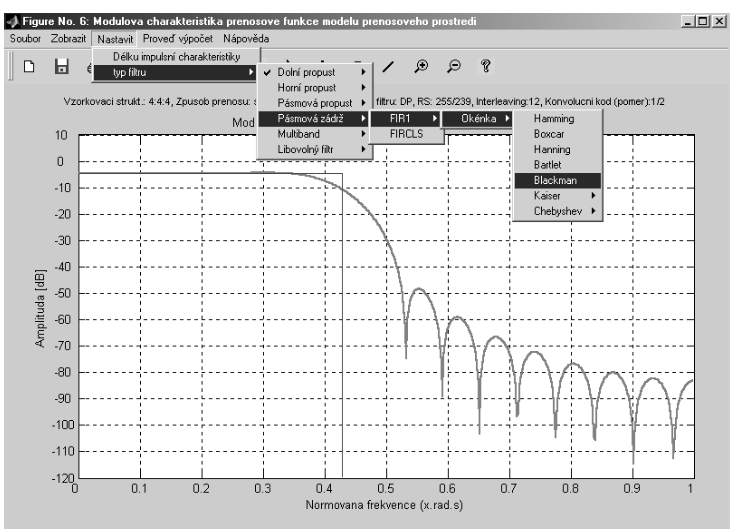

Fig. 3 The transmission channel model parameters editor – interactive design (example of low-pass transmission channel FIR design using tolerant field)

Fig. 4 Subjective check of transmission quality – comparison of input RGB and B&W images with transmitted images that are overlaid by the transmission errors (only exampple without specification)

- ⇒ *transmission quality* selection corresponds to ITU R-601 recommendation – 8 or 10 bits per component samples;
- ⇒ *transmission multiplex* type selection corresponds to DVB standard – serial or parallel multiplex;
- ⇒ FEC1 parameters setting of *RS code*, *n* and *m* parameters in according to DVB standard – RS (255, 239), RS (255, 235), RS (255, 223), RS (255, 205);
- ⇒ *intereleaver* depth *I* settings – up to 20;
- ⇒ FEC2 parameters setting of *convolution code*, rater $R = m/n$ selection in according to DVB standard – 1/2, 2/3, 3/4, 5/6, 7/8;
- ⇒ design and visualization of the baseband *transmission channel model parameters*, including interactive graphics methods of design and saving the model parameters – low-pass, high-pass, pass-band, stop-band and multiband filter type;
- ⇒ additive *noise pertubation* model and *reflected transmission signal* model that are used in the transmission channel model;
- ⇒ *decision level* setting in according to used source coding – NRZ unipolar/bipolar, RZ unipolar/bipolar;
- ⇒ *channel* and *source decoding*, *restoration* of the image from transmitted component signals and objective and subjective evaluation of the transmission influence on transmitted image;
- ⇒ *objective evaluation* of transmission quality – block and bit error rates of protected/non-protected digital signals;
- ⇒ *subjective evaluation* of transmission quality – the input/output image in spatial domain comparison including *Zoom function* for detail display;
- ⇒ *interactive help* – HTML text (in czech).

7 RESULTS

Independently of whether the encoding and decoding is in frequency or time domain, the efficiency of the RS code is the same. The residual bit-error rate (*BER*) of various RS codes based on *GF* (2^8) is shown in Figure 5. Although the RS codes are symbol-oriented codes, the analysis of the efficiency takes bit errors into account. The efficiency of the code increases with an increase in the number of test symbols. At an input bit-error rate of $2 \cdot 10^{-3}$ the residual bit error rate of the RS (255, 205) code is approx $1 \cdot 10^{-10}$ – the coding gain is thus more than 10 to the power of 7 – whereas in the case of the RS (255, 239) code at the same input bit-error rate the output bit-error rate is $9 \cdot 10^{-4}$ – the coding gain is only slightly greater than 0.5. For all DVB transmis-

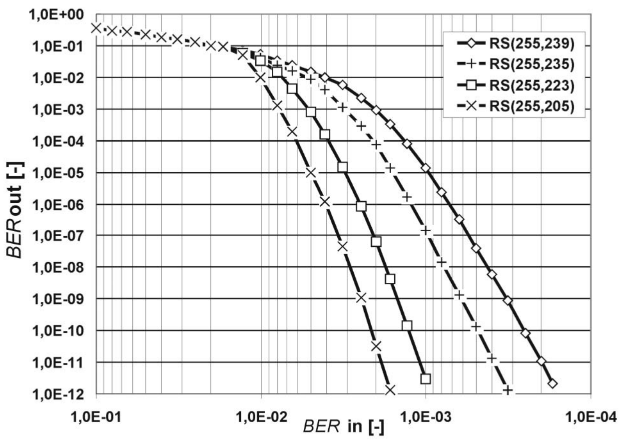

Fig. 5 Residual bit-error rate value of various RS (255, 255–2t) codes

sion standards a modified (shortened) RS (255, 239) code is used which makes it possible residual bit-error rate of approx $1 \cdot 10^{-11}$ at an input bit-error rate of $2 \cdot 10^{-4}$ while correcting up to 8 symbol errors per block.

The residual bit-error rate of convolutional codes of rate R is a function of E_b/N_0 (energy transmitted per bit divided by the noise-power density of the white Gaussian noise) and the parameter K describes the length of the code. The performance of the error correction increases with increased K. For the DVB standard a convolutional code of rate $R = 1/2$ with a constraint length $K = 7$ is used. With $E_b/N_0 = 3.2$ dB it is possible to achieve a bit-error rate of less than $2 \cdot 10^{-4}$ at the output of the decoder, this ratio corresponds to the maximum of the bit-error rate at the input of the RS decoder, so finally a bit-error rate at the output of the RS decoder of less than $1 \cdot 10^{-11}$ is obtained.

8 CONCLUSION

Described philosophy, model for simulation and analysis and software implementation is the partial solution of the mentioned grant project and gives some general results for baseband digital transmission channel simulation and analysis of digital television transmission. The developed Matlab GUI application for the simulation and analysis uses functions of the Signal Processing, Image Processing and Communication Toolboxes of Matlab. It can be used for the illustrative modeling and experimental education of the digital television technique area. This work presents the open modular application that can be ensemble with the other transmission phenomena of the DVB standard signal processing (digital modulation techniques, transmission in RF band etc.)

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REFERENCES

[1] U. Riemers, **Digital Video Broadcasting**. The International Standard for Digital Television. Springer-Verlag Berlin Heildeberger New York, 2001.

[2] G. W. Collins, **Fundamentals of Digital Television Transmission**. A Wiley-Interscience Publication, John Wiley & Sons, Inc., 2001.

[3] T. Kratochvíl, V. Říčný, **Characteristics of an Ideal Low-Pass Discrete Digital Filter Used for Transmission of the Video Signal in TV Technique**. In proceedings ERK 2000, pp. 25–28, Portorose, (Slovenia), September 2000.

[4] T. Kratochvíl, **Simulation of the Digital Real Transmission Channel Characteristics**. Research report of development project of the Ministry of Education of the Czech Republic no. 156/2001, Brno (Czech Republic), January 2001.

[5] T. Kratochvíl, V. Říčný, **The Digital Image Transmission Simulation**. In proceedings VIPromCom 2002, pp. 401–406, Zadar (Croatia), June 2002.

[6] T. Kratochvíl, J. Hrdina, **Utilization of Matlab for Education of the Digital Image Transmission**. In Proceedings Matlab 2002, Vol. 1, pp. 261–264, Prague (Czech Republic), November 2002.

Simulacija prijenosa digitalne slike uporabom DVB kodova za unaprijedno ispravljanje pogreške. Doprinos rada je u simulaciji prijenosa digitalnog videosignala putem modela kanala za prijenos u osnovnom pojasu. Prikazan je simulacijski model koji uključuje odabrane postupke obrade signala u sustavu za radiodifuziju digitalnog videosignala (DVB, *Digital Video Broadcasting*). Digitalni videosignal je predstavljen u obliku digitalnih podataka nekomprimirane slike, koja je kanalno kodirana i zaštićena od pogrešaka uporabom kodova za unaprijedno ispravljanje pogreške (FEC, *Forward Error Correction*). Model prijenosnog kanala ima utjecaj na prijenos digitalnih podataka, tako da izobličenje i smetajući signali u kanalu djeluju na dekodiranje podataka. Također su opisane značajke razvijene interaktivne programske podrške za simulaciju (Matlab aplikacija) i zaključci koji prikazuju djelotvornost korištenih FEC kodova.

Ključne riječi: digitalna slika, izvorno i kanalno kodiranje, model prijenosnog kanala

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