Influence of the FEC Channel Coding on Error Rates and Picture Quality in DVB Baseband Transmission

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Abstract. *The paper deals with the component analysis of DTV (Digital Television) and DVB (Digital Video Broadcasting) baseband channel coding. Used FEC (Forward Error Correction) error-protection codes principles are shortly outlined and the simulation model applied in Matlab is presented. Results of achieved bit and symbol error rates and corresponding picture quality evaluation analysis are presented, including the evaluation of influence of the channel coding on transmitted RGB images and their noise rates related to MOS (Mean Opinion Score). Conclusion of the paper contains comparison of DVB channel codes efficiency.*

Keywords

Digital television, channel coding, forward error correction, error rates, picture quality, MOS.

1. Introduction

The principal of the transmission with channel error-protection coding is shown in Fig. 1. At the transmitter side the redundancy information is added to the source coded digital signal in the channel encoder. This enables the channel decoder in the receiver to correct certain number of errors. The addition of the redundancy information leads to an increase in the data volume to be transmitted. Transmitted digital signal is overlaid with errors within the transmission channel that are caused by the invalidation of one or more bits or symbols. The task of channel encoding in the receiver side is to find the position of the incorrect symbols and bits by the evaluation of the redundancy that is also possibly affected by the transmission errors. The added redundancy is then removed [1].

2. Forward Error Correction in DVB

For the transmission of DTV over satellite and via terrestrial transmission networks the RS code is used with the convolution code and the interleaving (see Fig. 2).

The RS code is symbol-oriented code well suited to the correction of symbol errors, but there is no significance which bit of a symbol is incorrect. An 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. Other possible block codes parameters are RS (255, 235) that can correct up to 10 symbol errors, RS (255, 223) up to 16 symbol errors and RS (255, 205) up to 25 symbol errors [2].

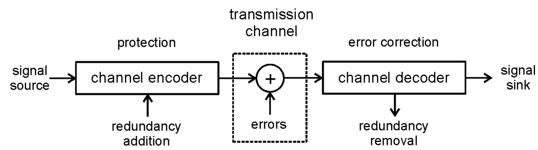


Fig. 1. Transmission with channel error-protection coding.

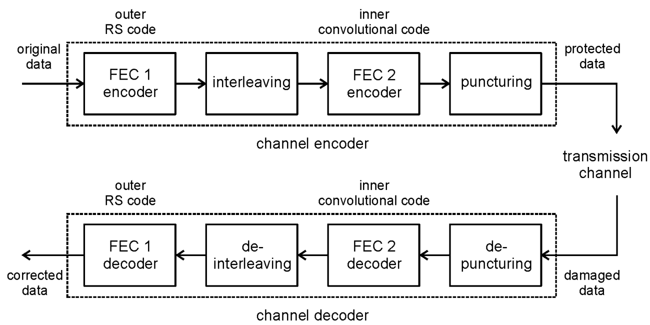


Fig. 2. Coding for forward error correction in DVB transmission.

After the outer code the interleaving with depth $I = 12$ is used. The convolution codes are the binary codes, the information is spread over several transmitting symbols. The code is therefore always bit-oriented. From the frame length of the outer code with $n = 204$ the base delay results as $M = n/I = 17$ [1]. To correct long burst errors in addition to bit errors and short burst errors the interleaving is inserted between the outer and the inner code.

Finally the convolution code is applied to the interleaved symbols. Its rate is $R = 1/2$, the constraint length is $K = 7$. Optionally the 2/3, 3/4, 5/6 and 7/8 rates are possible [3]. Coding for error correction by transmission over cable channel 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.

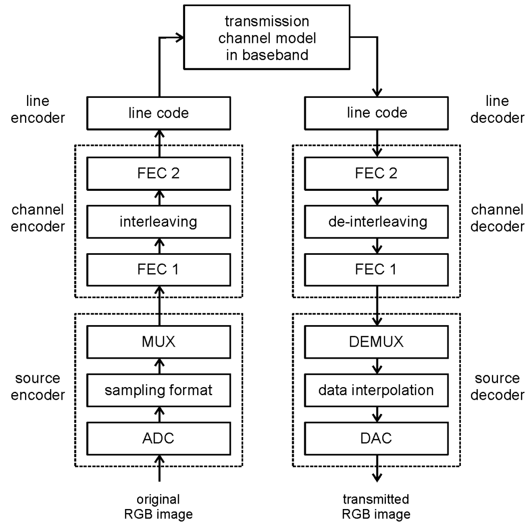


Fig. 3. Model for the DVB baseband transmission simulation.

3. Transmission Simulation Model

The transmission simulation model is shown in Fig. 3. The original image is represented with the one non-compressed *RGB* image. The standard image is in encoder sampled into raster 720 × 576 picture elements in according to DVB basic resolution. Then the *RGB* samples are converted and after analog-to-digital conversion (ADC) the digital image components YC_BC_R are obtained. The ADC allows quantization of 8 or 10 bits per each picture sample. The next step allows sampling format selection 4:4:4, 4:2:2, 4:2:0 or 4:2:0 SIF. It is provide by YC_BC_R picture matrixes decimation and down-sampling. The composition of serial or parallel digital data multiplex (MUX) is individual for each sampling format. The digital signal elements sequence is standardized by ITU R-601 recommendation and generates multiplex of image samples. The digital signal is ensured against transmission errors with forward error correction codes (FEC1 + FEC2) with inserted interleaving. The last block of the encoder is selection of line code for the transmission. Possible line codes are NRZ and RZ in unipolar or bipolar version [4].

Then the protected serial or parallel digital signal is transmitted through the model of the digital transmission channel in baseband. The developed model for digital baseband transmission channel simulation is the FIR filter with low-pass character and variable parameters and method of design [4] [7].

Design of the proposed digital transmission channel model deals with the input parameters of the channel in accordance with selected design method. The acceptable design methods for analysis 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.

Parameter	Setting
Sampling format	**4 : 2 : 0**
Transmission multiplex	**serial multiplex** **27 MHz sampling** **8 bits per sample**
Transmission channel model	**LP character,** $f_{LP} = 0.925\ f_s/2$ **Hamming window** $N = 30$
FEC1 – RS code	**none** **RS (255, 239)** **RS (255, 235)** **RS (255, 223)** **RS (255, 205)** **RS (204, 188)**
Interleaving depth	**4, 8, 12, 16, 20 symbols**
FEC2 – convolution code rate	**none** **1/2, 2/3, 3/4, 5/6, 7/8**
Noise character and level	**additive white noise** **30 % relative amplitude**
Reflected signal level / delay	**0 % / 0 samples**
Source coding	**NRZ unipolar**
Decision level	**0V**

Tab. 1. Setup of the component transmission analysis.

The conversions at the decoder side are vice-versa to described encoder side. Only the image data interpolation in dependence on used sampling format is added before digital-to-analog conversion (DAC) block as the last process of the component analysis.

4. Transmission Analysis Setup

The error-protection component analysis consists of the RS code, interleaving depth and convolutional code parameters variation. Complete setup of the component analysis parameters presents the Tab. 1.

The setup of the transmission analysis is set to the developed simulation model and error rates and objective picture quality are the results. The transmission model allows additive perturbation in the transmission channel model. These possible perturbations are additive noise and additive signal reflection.

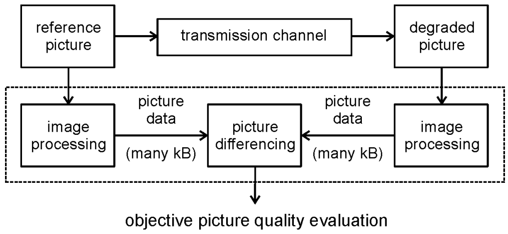


Fig. 4. Objective picture quality measurements.

5. Transmission Quality Evaluation

The main objective criteria in digital data transmission are *BER* (bit error rate) and *SER* (symbol error rate). These rates evaluation allows in component analysis comparison of input and output samples values and their bits and symbols. *BER* of transmission can be evaluated as

$$BER = \frac{wbn}{tbn} , \tag{1}$$

where *wbn* is number of wrong received bits and *tbn* is total number of all received bits. In case of transmission simulation all the encoded and decoded data are available.

The similar is the *SER* evaluation with equation

$$SER = \frac{wsn}{tsn} , \tag{2}$$

where *wsn* is number of wrong received symbols and *tsn* is total number of all received symbols.

The error rates can be properly evaluated as BER_1 before FEC2 decoding (rate without any error protection), BER_2 after the FEC2 decoding (digital transmission protected against bit errors), SER_1 before FEC1 decoding (symbol error rate without the symbol protection) and SER_2 after the FEC1 decoding (symbol error rate of full protected digital transmission) [7].

6. Picture Quality Evaluation

There are several dimensions of picture quality evaluation (PQE) generally splitted into the subjective and objective measurements. Subjective measurements are the result of human observers providing their opinion of the video quality and objective measurements are performed with the aid of instrumentation, calibrated scales and mathematical algorithms. Perception based on objective evaluation presents *PQS* (Picture Quality Scale) and perception based on subjective evaluation is quantified by *MOS* (Mean Opinion Score) [5]. Direct measurements are performed with the test pictures and scenes and they are used for both measurements - subjective and objective picture quality. The objective quality is well established and the methods are based on comparison of reference with degraded picture.

Picture	SAM	SFM
Christines	330.28	15.92
Fruits	289.97	29.05
Square	139.31	32.13
Posters	134.09	46.05
Garden	72.75	37.97
Generator	3820.90	66.03

Tab. 2. Objective SAM and SFM measures of reference pictures.

Picture differencing uses a matrix-based mathematical computation to process each picture or sequence of pictures (see Fig. 4). The pixel-by-pixel reference between filtered version of the reference and degraded pictures is used to determine the objective quality score. The picture differencing measures can contain evaluation of *MSE* (Mean Square Error), *NMSE* (Normalized *MSE*), *SNR* (Signal to Noise Ratio), *PSNR* (Peak *SNR* etc. [6]

The *MSE*, *NMSE*, *SNR* and *PSNR* are usually used in objective PQE according to ITU-R recommendation. Definition equations for these evaluation measures are in eq. (3) to (6)

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \left[f(i,j) - f'(i,j) \right]^2 , \tag{3}$$

$$NMSE = \frac{MSE}{\sigma^2} = \frac{1}{MN\sigma^2} \sum_{i=1}^{M} \sum_{j=1}^{N} \left[f(i,j) - f'(i,j) \right]^2 , \tag{4}$$

$$SNR = 10 \log \frac{\sigma^2}{MSE} = -10 \log NMSE , \tag{5}$$

$$PSNR = 10 \log \frac{\left(2^n - 1\right)^2}{MSE} , \tag{6}$$

where $M \times N$ are dimensions of reference and degraded picture, $f(i, j)$ and $f'(i, j)$ are their pixel values and σ is standard defined dispersion of reference image.

To bring the objective picture quality test value closer to the subjectively perceived picture quality, other quantities in the test picture must also be taken into consideration. These are spatial measures, the *SFM* (Spatial Frequency Measure) indicates the overall activity level in a picture, defined by row and column frequencies and in spectral domain the *SAM* (Spectral Activity Measure) that is defined as a measure of picture predictability. The evaluation deals with the DFT coefficients of picture and *SAM* has the dynamic range of [1, infinity) [6].

The objective PQE needs test pictures with different features: structured real pictures with details and textures, pictures with large color areas combined with artificial parts (e.g. picture graphics and television logos), picture with variable spatial and frequency activity etc. Test reference pictures used in this analysis and simulation are shown in Fig. 5 and their mentioned *SAM* and *SFM* measures are in Tab. 2.

7. Results of Transmission Analysis

The aim of the analysis was to determine the influence of channel encoder parameters on achieved error rates and objective PQE metrics. Evaluated data were *BER* after the convolutional decoding and *SER* after the Viterbi decoding of the RS code. These rates were evaluated in [%], where error rate 0 % corresponds to absolutely errorless transmission and vice versa 100 % corresponds to absolutely erroneous transmission and lost of the data and corresponding picture. Subsequent objective PQE was based on the *MSE*, *NMSE* error metrics and *PSR* and *PSNR* [dB] noise rates evaluation mainly [7].


a)


b)


c)


d)


e)

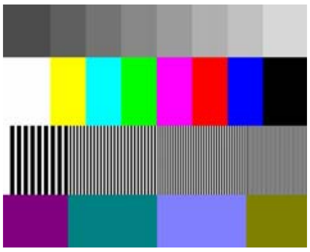
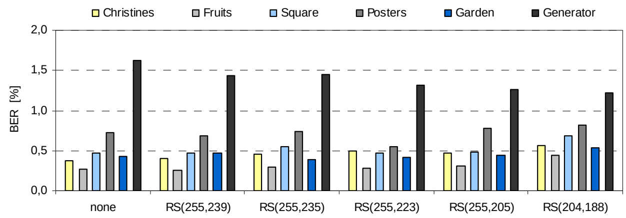

f)

Fig. 5. Test reference pictures used for error rates and picture quality evaluation a) "Christines", b) "Fruits", c) "Square", d) "Posters", e) "Garden", f) "Generator".

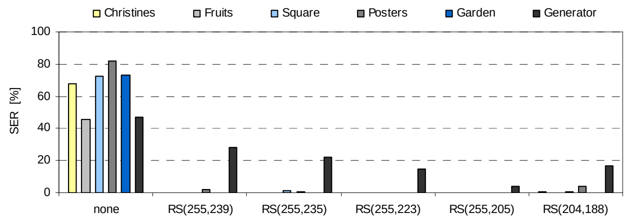
7.1 RS Code – Symbol Oriented Protection

The first analysis evaluated the RS code and its parameters influence on transmitted signal and decoded pictures. The results of introduced metrics are shown in Fig. 6 a) to d). *BER* after the convolutional decoding gains the interval of approx. (0.2 – 0.8) %, except the problematic artificial picture "Generator" with *BER* approx. (1.2 – 1.6) %. Lowest average *BER* has the picture „Fruits" (0.3229 %).

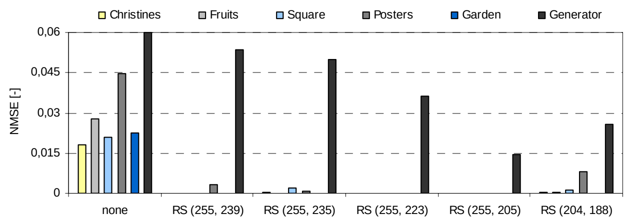
The *SER* evaluation gains interval (0 - 4) % and it is easy to see that RS protection against symbol error works well and mostly independent on chosen parameters. The problem was with the test picture "Generator" transmission only. Evaluated *SER* without protection gained (45 – 81) % interval. *NMSE* evaluation reaches the highest values for the transmission without any protection and for the test picture "Generator" for which the protection failed. The best results of *PSNR* achieved the transmission protected by RS (255, 205) with the average *PSNR* = 47.565 dB that means excellent picture quality in *MOS* scale. The worst case is the transmission without any protection with the average *PSNR* = 28.382 dB that means poor quality in *MOS* scale. Some illustrative pictures are in Fig. 7 a) to l).



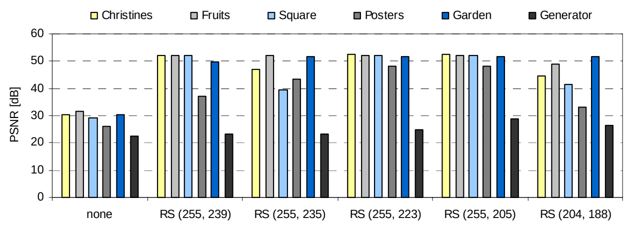
a) BER after convolutional decoding vs. used RS code



b) SER after Viterbi decoding vs. used RS code



c) NMSE error vs.used RS code



d) PSNR noise rate vs.used RS code

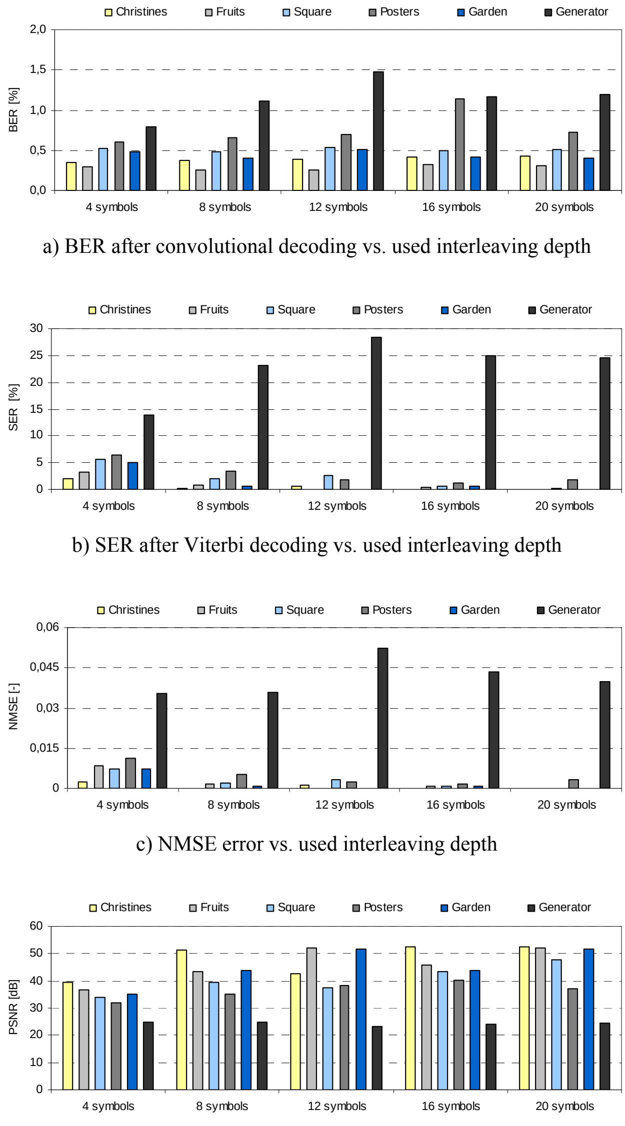
Fig. 6. Dependence of transmission and picture quality results on used RS code.

7.2 Interleaving – Burst Oriented Protection

The second analysis evaluated the interleaving depth influence on transmitted signal and decoded pictures. The results of introduced metrics are shown in Fig 8. a) to d). *BER* after the convolutional decoding gains the interval of approx. (0.3 – 0.7) %, except the artificial picture "Generator" again with *BER* approx. (0.8 – 1.5) %. The results are similar to results in previous analysis because of the same bit protection. *SER* evaluation gains the interval (0 – 6.5) %. The problem is again with the test picture "Generator" where the error protection failed due to RS code capacity overload. Evaluated *SER* without protection gains the interval (3 – 14) %.

a) *PSNR* = 30.515 dB
g) *PSNR* = 52.321 dB
b) *PSNR* = 31.633 dB
h) *PSNR* = 52.146 dB
c) *PSNR* = 29.403 dB
i) *PSNR* = 52.088 dB
d) *PSNR* = 25.932 dB
j) *PSNR* = 48.228 dB
e) *PSNR* = 30.205 dB
k) *PSNR* = 51.797 dB
f) *PSNR* = 22.607 dB
l) *PSNR* = 28.815 dB

Fig. 7. Comparison of the all degraded reference pictures from the Fig. 5 after the transmission with a) to f) none symbol protection, g) to l) used RS (255, 205) code.



a) BER after convolutional decoding vs. used interleaving depth

b) SER after Viterbi decoding vs. used interleaving depth

c) NMSE error vs. used interleaving depth

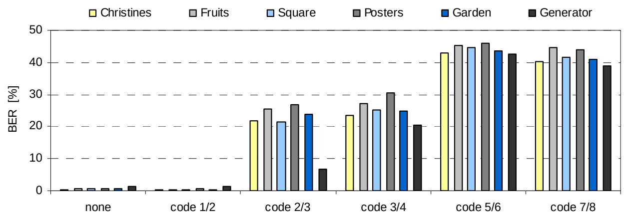
d) PSNR noise rate vs. used interleaving depth

Fig. 8. Dependence of transmission and picture quality results on used interleaving depth.

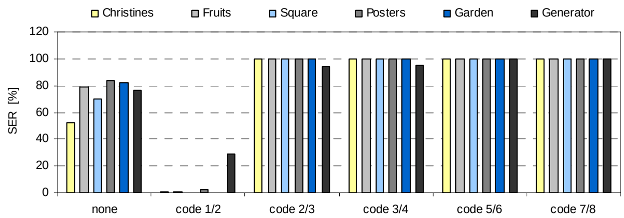
NMSE error evaluation reaches the highest values for the transmission with interleaving depth I = 4 to 8 and for the test picture “Generator”, for which the protection failed again. The best results of *PSNR* achieved the transmission protected with I = 20 symbols with the average *PSNR* = =44.464 dB that means nearly excellent picture quality in *MOS* scale. The worst case of transmission is the transmission with the interleaving depth I = 4 symbols with *PSNR* = =33.685 dB that means fair picture quality in *MOS* scale. The most convenient used interleaving depth is I = 16 to 20 symbols that secures lowest error rates and picture quality.

7.3 Convolutional Code – Bit Oriented Protection

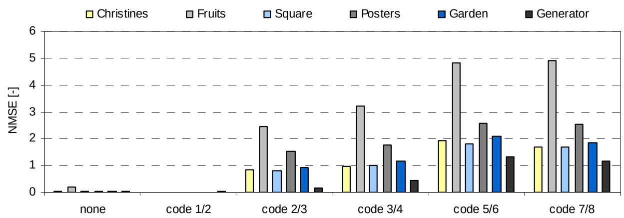
The third analysis evaluated the convolutional code and its rate parameters influence on transmitted signal and decoded pictures. The results of introduced metrics are shown in Fig. 9 a) to d). *BER* after the convolutional decoding increases with the increasing rate *R*. Important results in this case of transmission are analysis of RS decoding difficulty and according achieved *SER*. The results shows that only the convolutional code with rate $R = 1/2$ is convenient and the other rates produces highest *SER* than transmission without the error protection. *NMSE* evaluation increases with increasing rate *R*, but the ratio *PSNR* is very low for any convolutional code except the code with $R = 1/2$. The average *PSNR* for this case is equal to 40.895 dB that means good picture quality in *MOS* scale. Some illustrative pictures are in Fig. 10 a) to l).



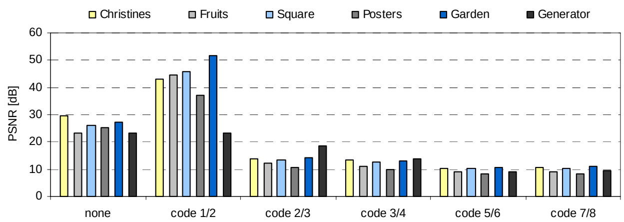
a) BER after convolutional decoding vs. used convolutional code



b) SER after Viterbi decoding vs. used convolutional code



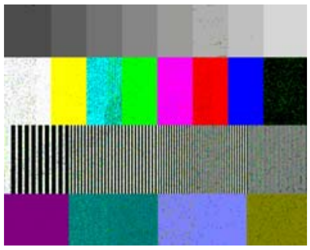
c) NMSE error vs. used convolutional code



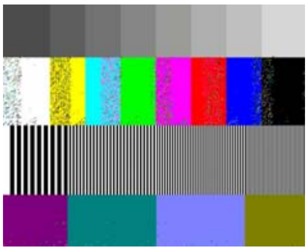
d) PSNR noise rate vs. used convolutional code

Fig. 9. Dependence of transmission and picture quality results on used convolutional code.

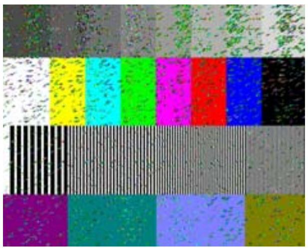

a) *PSNR* = 26.093 dB

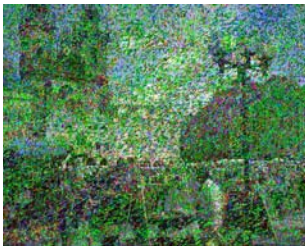

b) *PSNR* = 23.297 dB

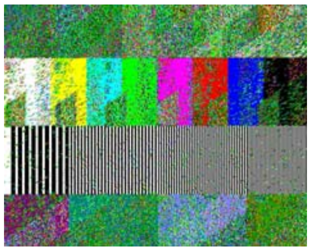

c) *PSNR* = 45.765 dB

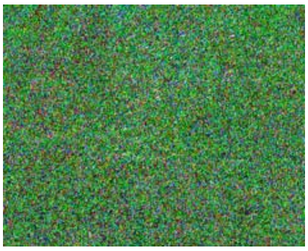

d) *PSNR* = 23.264 dB

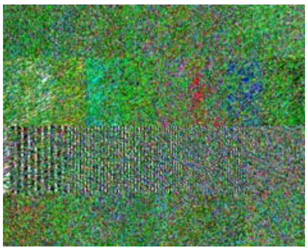

e) *PSNR* = 13.472 dB

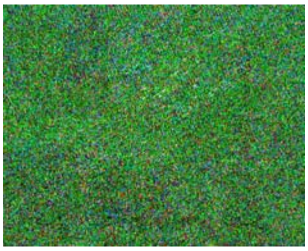

f) *PSNR* = 18.367 dB


g) *PSNR* = 12.634 dB


h) *PSNR* = 14.000 dB


i) *PSNR* = 10.073 dB


j) *PSNR* = 9.097 dB


k) *PSNR* = 10.393 dB

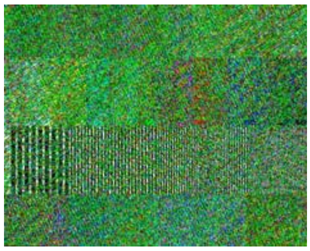

l) *PSNR* = 9.653 dB

Fig. 10. Comparison of the degraded reference pictures "Square" and "Generator" after the transmission using convolutional code with rate R equal to a) and b) none, c) and d) 1/2, e) and f) 2/3, g) and h) 3/4, i) and j) 5/6, k) and l) 7/8.

8. Conclusion

The paper contained component analysis and presentation of results of error-protected transmission in DTV and DVB provides by FEC channel coding. The simulation model with the possibility of source, channel and link encoder and decoder parameters setup was implemented in Matlab. The detailed analysis of the source, channel and link coding of the simulation model was done. Influence of the source encoder parameters on error rates is not too critical. The sampling format selection affects only the image resolution and only the parallel transmission multiplex causes increase of the *BER* and *SER*. Influence of RS coding and its application on error rates and picture quality is evident. It almost does not depend on RS parameters, but it is necessary to use it. Influence of used interleaving depth on results of error rates and picture quality is not too serious. The higher depth (more than 12 symbols) gives better results. Principal influence on error rates results has the convolutional code. Only the code with rate R = 1/2 gives excellent picture quality and other rates are worst than transmission without the convolutional protection. Only the RZ unipolar code is not convenient for the transmission because it produces enormous increase of *BER*. The best results give the RZ and NRZ bipolar codes. Effect of the noise perturbation in the model of the channel is visible in transmitted and decoded pictures when the relative amplitude of the perturbation is greater the 40% of the transmitted signal. Detailed results have been published in the PhD thesis of the author [7].

Acknowledgements

The paper was supported by the Research programme of Brno University of Technology, *Electronic Communication Systems and New Generation Technology*, MSM 0021630513, and the grant project of the Czech Science Foundation GACR 102/05/2054 *Qualitative Aspects of Audiovisual Information Processing in Multimedia Systems.*

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