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The implementation of channel coding into the digital transmission chain consisting of VSG PXI-5670 - VSA PXI-5661

***Abstract**. This article is focused on techniques for error detection and correction, which occur during a transmission in modern digital communication channels. The real implementation of these channel coding techniques into the digital communication system is presented in this article. The system is based on the PXI modular platform consisting of RF VSG PXI-5670 and RF VSA NI PXI-5661. The proposed communication system structure is based on a software-defined radio conception. Author's goal was to describe and afterwards with real measuring, to revise properties of the measuring system based on this flexible approach. These systems seem to be very useful for testing of new generation transmission systems.*

***Streszczenie.** W artykule przedstawiono metody wykrywania i korekcji błędów przy transmisji danych. Zastosowano kodowanie kanałów wykorzystujące systemy RF VSG PXI-5670 i RF VSA NI PXI-5661. (**Zastosowanie kodowania kanałów w cyfrowej transmisji bazujące na RF VSG PXI-5670 i RF VSA NI PXI-5661**)*

Keywords: channel coding, error detection and correction, digital M-ary-QAM.
Słowa kluczowe: kodowanie kanałów, transmisja danych, wykrywanie błędów

Introduction

With current communication systems we can see large increase of requirements for maximal allowable bit error rate (BER) [1]. BER value varies in range from 10^{-2} to 10^{-12} Concrete value depends on the transmitted signal type (f.e. telephone call signal BER = 10^{-4}, HDTV BER = 10^{-10} for more details see [10]). However, these requirements cannot be met even with the use of most advanced modulation-demodulation methods [2]. In these cases, a situation can be improved by an appropriate protective signal coding carrying information in a transmitter channel encoder with convenient detection and if it is possible also with an automatic correction of incorrect received data in receiver channel decoder.

In many of their publications, the authors of this article are writing about the adaptive equalization, for example [8] (they also use adaptive techniques for ECG adaptation, see [23, 24])

The authors have also aimed to create a functional digital communication chain, in which parameters of encoder-decoder block channel could be flexible set, see Fig. 1 [9].

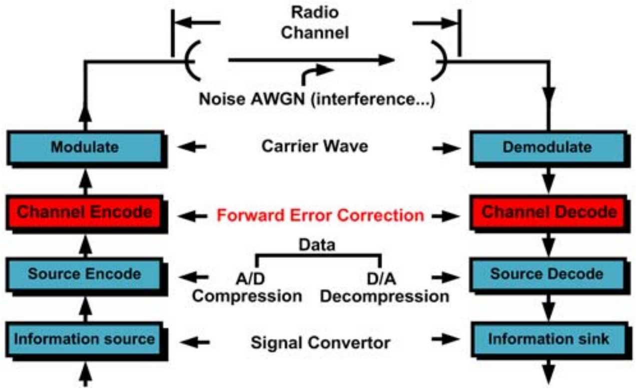

Fig.1. General Shannon's diagram of radio communication system

Idea of the authors was to present the system that would comfortably test new fundamentals in area of the channel coding field [11] without need of any constant hardware components upgrades or essential customer-vendor cooperation with purpose to modify the software.

Currently we have experience rapid development of the digital communication. The transmitted information capability and bit rate are still increasing, new communication systems are being developed and current systems are very fast running technically out of date. Many of the existing standards are pulled out in a sequence and replaced with the new ones. Looking on their count it becomes very clear that it is very difficult, if not impossible, to keep overview of all systems and standards and even more difficult to keep the testing technology in condition which allows us to be able to use them in all cases and in both- the development and also the application phase.

In this article, a reader will be able, according on a real mensuration, to know how to solve this very difficult task by using the PXI hardware platform on synthetic instrumentation basis [8], where a main part of whole system is it´s software part, what is the main reason of maximizing a system flexibility and also a possibility of its adaptation to the new requirements associated with the trend of new standards arrival.

For our own experiments the Rice´s channel [12] was used as a radio-channel model. The experimental measuring consists of two steps:

- BER rating without use of channel-coding
- BER rating with use of Golay codes

Radio channel

Communication (radio) channels can be simulated by several mathematical models. The most common models are:

- *AWGN channel* –ideal conditions for signal reception, signal is transmitted directly between receiver and transmitter without reflecting, more details in [13]
- **Rice´s channel**
- *Rayleigh´s channel* - a situation where direct signal is not dominant, more details in [14]

All the cases of the signal extension methods from above are shown in Fig. 2

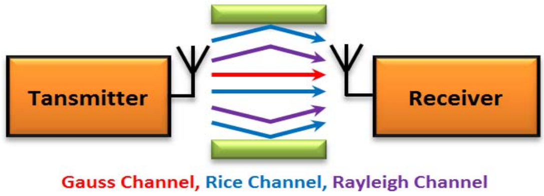

Fig.2. Signal propagation methods in various channel models

The authors have chosen for experiment the Rice´s channel. This channel is the most similar to an environment, where we were making real measurements (laboratory environment). The model takes into the account the multi-path signal propagation [17], which is mainly caused by the signal reflection. We can also see the fluctuation of signal intensity and it causes rise of the intersymbol interference called ISI [16].

Multi-path propagation in this channel causes the signal fluctuation, which results in rise of two signal leakage types:

- slow leakage - is caused by a shielding effect of hurdle
- fast leakage - is mainly caused by a multi-path wave propagation

Influence of the Rice´s channel on *x*(*t*) signal type can be mathematically described by the following equation [15]:

(1)
$$y(t)=\frac{\rho_0 x(t)+\sum_{i=1}^{N_e}\rho_i e^{-j2\pi\Theta_i}x(t-\tau_i)}{\sqrt{\sum_{i=0}^{N_e}\rho_i^2}}$$

where ρ_0 denotes the direct signal path attenuation, N_e denotes the number of reflections, ρ_i denotes attenuation of the reflected path, θi denotes phase shift caused by path *i* and τ denotes delay time.

Rice´s factor *K* indicates the ratio of the direct signal attenuation to the sum of all reflected signals and is described as follows [15]:

(2)
$$K=\frac{\rho_0^2}{\sum_{i=0}^{N_e}\rho_i^2}$$

Channel coding

The purpose of channel coding is to secure the signal against errors resulting from signal transmission in the communication channel. Fig. 3 shows the channel codes sorting [14].

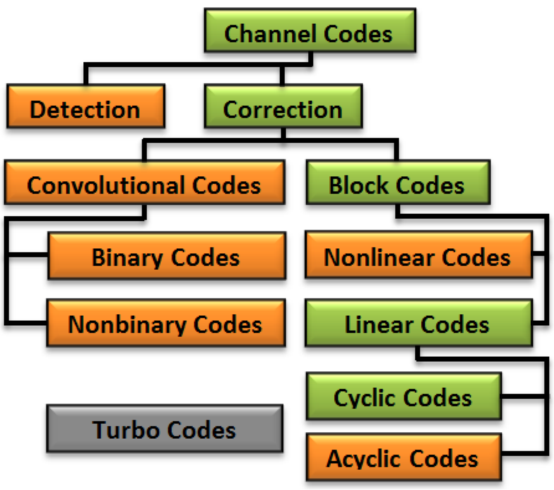

Fig.3. Basic sorting of channel codes

The essence of the signal security is moderate, deliberate and controlled redundancy increase (e.g. adding a particular number of control bits). This will reflect as a small increase of the signal bit rate and also necessary increase of the channel frequency bandwidth with a considerable reduction of BER.

The authors have used the Modulation Toolkit function library [19] for these real measurements, which is part of LabVIEW 2012 [7]. There were also implemented encoder – decoder blocks from this library into the transmission chain. MT Golay Encoder VI [19] and MT Golay Decoder VI were chosen [19] for measuring, see Fig. 4 and Fig. 5.

Modulation Toolkit includes a lot of other block codes, see Fig. 12. LabVIEW, of course, allows also custom programming of the block coding.

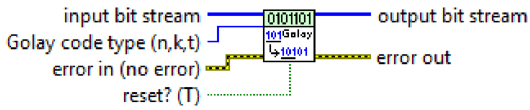

Fig.4. Used block MT Golay Encoder VI

Generates an Golay-encoded bit stream. The VI allows us to choose between the two triple-correcting Golay codes: the Golay (23,12,3) code and the extended Golay (24,12,3) code.

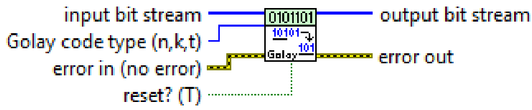

Fig.5. Used block MT Golay Encoder VI

Decodes an Golay-encoded bit stream. The decoder provides the two triple-correcting Golay codes: the Golay (23,12,3) code and the extended Golay (24,12,3) code. This VI uses the Arithmetic decoding algorithm for decoding the Golay (23,12,3) encoded bit stream and the Kasami error-trapping decoding algorithm for decoding the extended Golay (24,12,3) encoded bit stream [11].

M-ary QAM

M-ary QAM is a two-dimensional generalization of M-ary pulse amplitude modulation, and its formulation involves two orthogonal passband basis functions [1]:

(3)
$$\phi_I(t)=\sqrt{\frac{2}{T}}\cos(2\pi f_c t),\quad 0\le t\le T$$

(4)
$$\phi_Q(t)=\sqrt{\frac{2}{T}}\sin(2\pi f_c t),\quad 0\le t\le T$$

where f_c denotes the carrier frequency, and *T* denotes the symbol duration.

The transmitted M-ary QAM signal for the *k*-th symbol can therefore be expressed as:

(5)
$$s_k(t)=\sqrt{\frac{2E_0}{T}}I_K\cos(2\pi f_c t)-\sqrt{\frac{2E_0}{T}}Q_K\sin(2\pi f_c t),$$
$$0\le t\le T; k=1,\ldots,M$$

with constellation points coordinates given by Eq. (6). The coordinates of the *k*-th signal constellation point for square M-ary QAM signal constellation are given by:

(6) $$\{I_k, Q_k\} = \begin{bmatrix} (-\sqrt{M}+1, \sqrt{M}-1) & (-\sqrt{M}+3, \sqrt{M}-1) & \cdots & (\sqrt{M}-1, \sqrt{M}-1) \\ (-\sqrt{M}+1, \sqrt{M}-3) & (-\sqrt{M}+3, \sqrt{M}-3) & \cdots & (\sqrt{M}-1, \sqrt{M}-3) \\ \cdots & \cdots & \cdots & \cdots \\ (-\sqrt{M}+1, -\sqrt{M}+1) & (-\sqrt{M}+3, \sqrt{M}-1) & \cdots & (\sqrt{M}-1, \sqrt{M}+1) \end{bmatrix}$$

Used measuring equipment

The authors assembled a functional digital communication system consisting of the RF vector signal generator VSG PXI-5670 [3] and the RF vector signal analyzer VSA PXI-5661 [4], according to Fig. 1. It was therefore used a modern concept of PXI modular system [5] with plug-in measuring cards [20]. The proposed system concept is based on a software- defined radio SDR [6]. Key functional element of transmission systems like this is software that can be flexibly changed according to user needs. G programming language was used in the development application LabVIEW 2011 [7]. The proposed structure of the measuring equipment is shown in Fig. 6.

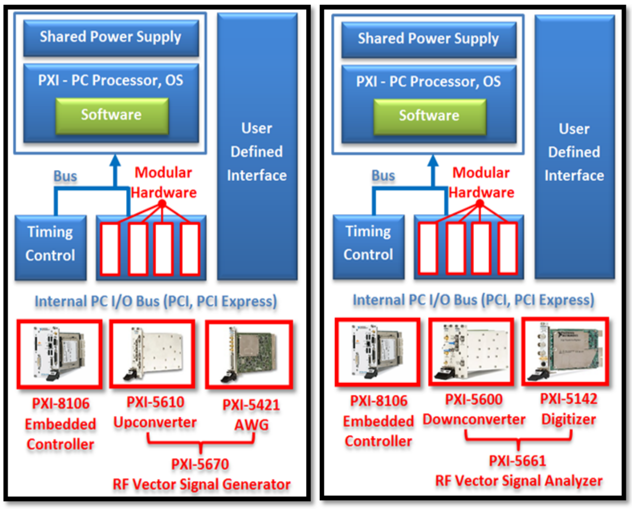

Fig.6. Structure of used measuring equipment

Individual transmission chain blocks were assembled with help from library functions NI LabVIEW - Toolkits for Commmunication [19] Modulation Toolkit [20], Spectral Measurements Toolkit [7], Advanced Signal Analysis Toolkit [7], Digital Filter Design Toolkit [7]). Simplified assembly of receiver and transmitter blocks is shown in Fig. 7 [5].

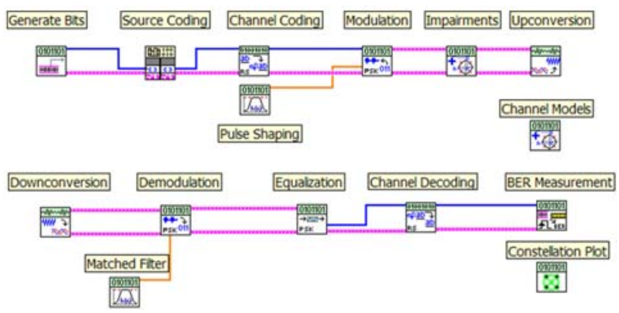

Fig.7. Assembly of individual blocks of transmission chain in LabVIEW 2011 program structure

As it is evident from Fig. 6 the authors have used for measurement two modular systems PXI. This means two separated PXI chassis [13], both equipped by Embedded Controller of type NI PXI-8106 [19]. First chassis fulfilled the function of RF vector signal generator NI VSG PXI-5670. This VSG consisted of two plug-in measuring cards (see Fig. 8) Unconverter of type NI PXI-5610 [20] and AWG - Arbitrary Waveform Generator, of type NI PXI-5421 [21]. The second chassis fulfilled the function of RF vector signal analyzer NI VSG PXI-5670. This VSA was composed (see Fig. 9) of two plug-in measuring cards Downconverter of type NI PXI-5600 [22] and Digitizer of type NI PXI-5142 [23]. The Fig. 8 shows both used PXI systems.

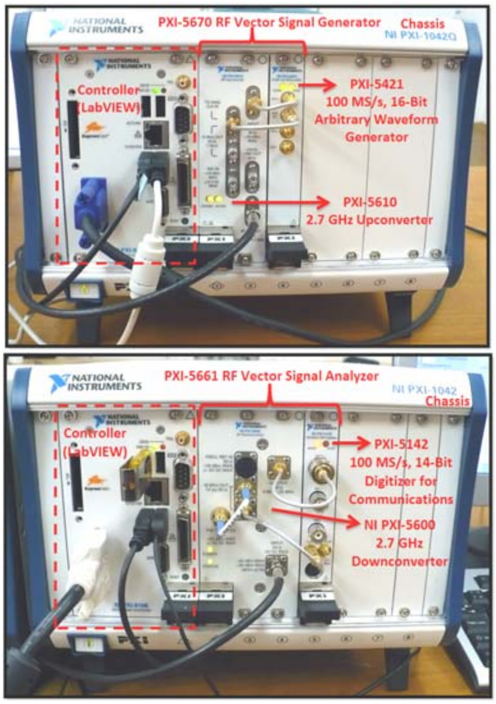

Fig.8. Used PXI systems RF VSG NI PXI-5670 and RF VSA NI PXI-5661

In Fig. 9 connection of measuring cards (modules) for realization of VSG and VSA is shown.

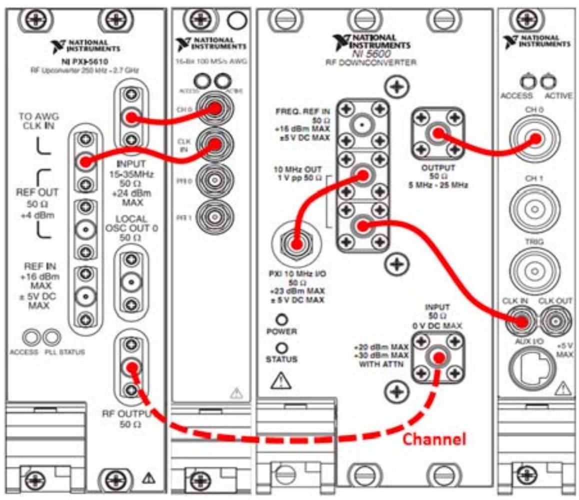

Fig.9. Connection of PXI measuring system

Experimental results

As a transmission channel model was used the Rice´s channel [9], which we have mentioned above. Used channel´s block is shown on Fig. 10. This block allowed us to setup K-factor [9], diversity order [9].

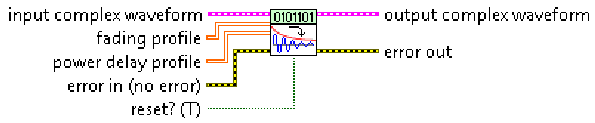

Fig. 10. Used MT Apply Fading Profile VI block

This article demonstrates a simple implementation of the Rician fading profile and programming techniques for applying the fading profile to a QAM signal. You can use this article as a starting point to build and apply the real-world Rician fading profiles.

Experimental measurements have consisted of two steps. First, data transfer without application of channel coding and then block of channel coding has been assembled to the transmission chain (see Fig. 4 and 5). The authors of this article has chosen for their experiments two triple-correcting Golay codes [9]: the Golay (23,12,3) code and the extended Golay (24,12,3) code.

To verify functionality of this designed system, according to used hardware (VSG and VSG), coaxial cable was used as a transmission channel (see Fig.11). So the authors were working with the real RF signal within these executed experiments.

Signal (PN sequence) modulated with M-QAM modulations was generated in transmitter on a carrier frequency 1.96 GHz, performance level of signal was 10 dBm with 3.84 MHz bandwidth, Roll of factor and filter root raised cosine 0.33, bit rate 2.625 MS/s. On transmitter´s side was evaluated a quality of signal received, this was done by BER measurement. On Fig. 12 and 13 are results BER vs. E_b/N_O for 16-QAM a 64-QAM.

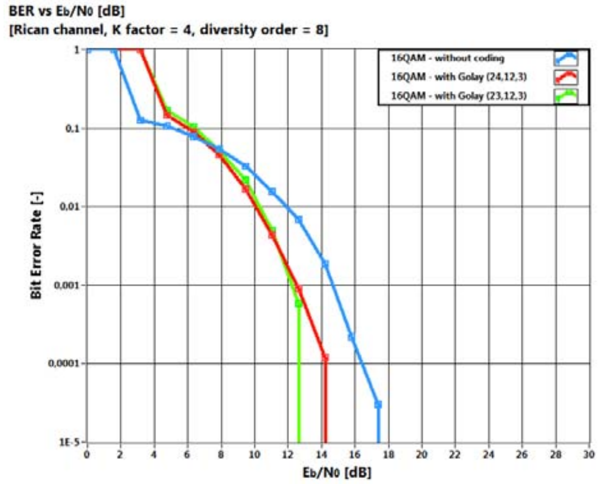

Fig12. BER vs. Eb/NO pro 16-QAM

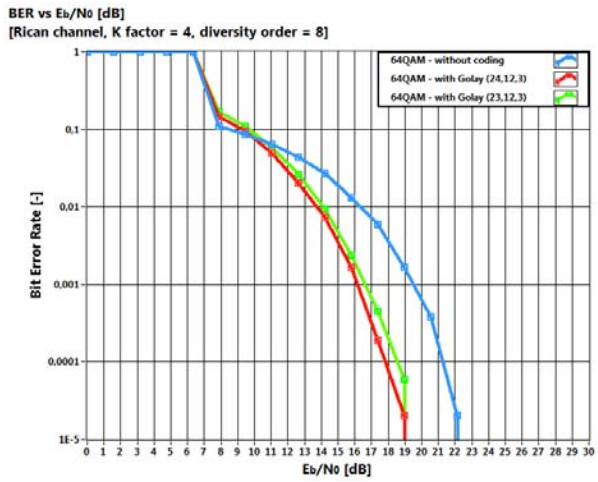

Fig.13. BER vs. Eb/NO pro 64-QAM

Implementation of channel coding has resulted in a massive reduce of errors in BER signal (see Fig. 12 and Fig. 13)

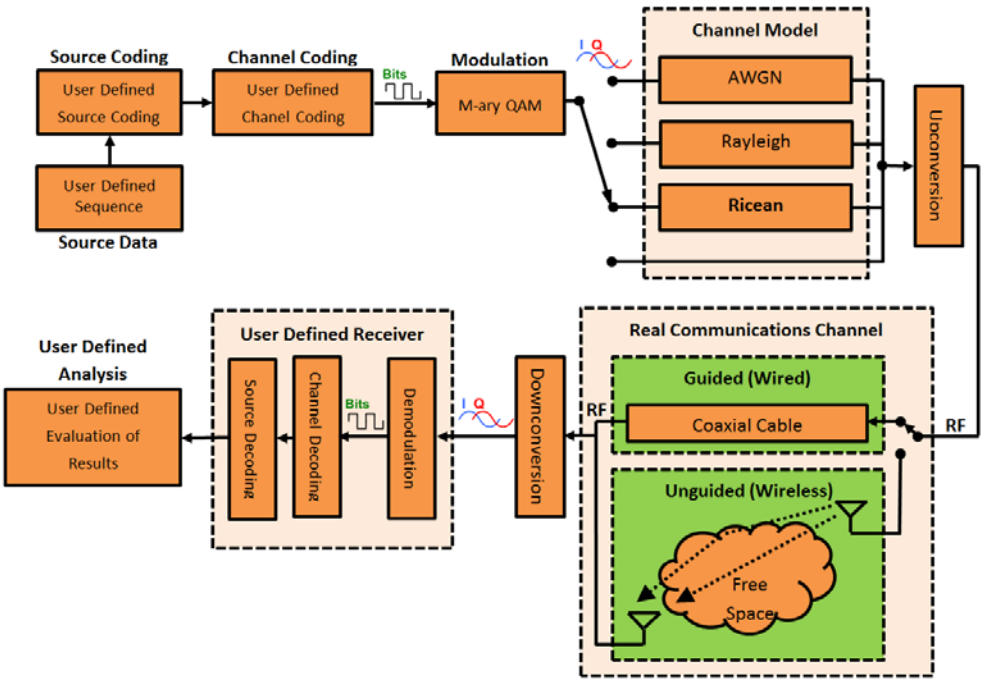

Fig.11. Simplified scheme of executed experiments

Conclusion

Authors, using real measuring techniques, explored the possibilities of channel coding techniques testing of systems using PXI hardware platform on the synthetic instrumentation basis, see Fig. 6.

Use of these modern tools appears to be very suitable for testing of new principles in the channel coding ambit without any need for a constant upgrading of hardware components and also without any customer-vendor cooperation in terms of software modifications. The authors used LabVIEW 2012. This software offers us various libraries which are suitable for channel coding-decoding, see Fig. 14.

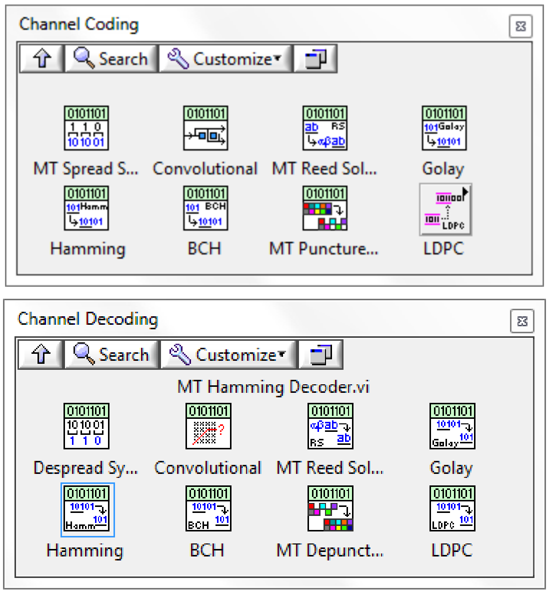

Fig.14. Options of Toolkits for Communication Lab-Channel Coding and Lab-Channel Decoding

The functionality of examined technologies was verified by the real measurements. For the experiments, the authors used the M-QAM modulation that was implemented right into the assembled transmission chain. Channel coding-decoding blocks were added into the transmission chain (Fig. 6). The two triple-correcting Golay codes: the Golay (23,12,3) code and the extended Golay (24,12,3) code were used for the experiment. The real measurements have achieved the results which have satisfied us. The main contribution from this article lies in the real verify of the proposed system functionality.

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