Design and Implementation of software-defined pi/4-DQPSK modem with receive antenna diversity

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Abstract. **Software-defined radio (SDR) is leading concept nowadays, for development of multifunctional radio systems. Article addresses design and implementation on SDR platform of digital modulator/demodulator (modem) with pi/4 differential quadrature phase shift keying modulation (pi/4-DQPSK) and antenna diversity in the receiver side. A model of the system was created in GNU Radio Framework. Experimental results of bit error rate (BER) in presence of additive white Gaussian noise (AWGN) is obtained through simulation and compared with no diversity system. Superiority of diversity scheme, based on criteria BER, is confirmed by numerical results. An experimental, model-based RF DQPSK modem was implemented with Universal Software Radio Peripheral (USRP) frontend. This step from development process confirms advantages of SDR concept, verifies model implementation trough ability to exchange digital information from the transceiver to the receiver in indoor environment and capability of constructive elements to support cocherense. For future implementation of full functional radio communication system, the need of additional blocks for synchronization is identified.**

Keywords: DQPSK modem, antenna diversity, GNU Radio Framework, software-defined radio system.

I. INTRODUCTION

The ever-growing demand for data communication creates constant search of new solutions in the area of digital communication systems. One of the main tasks of radio communication engineering is the creation of a system for reliable transmission of information. While the functional blocks of a typical radio communication system do not change dynamically in time, thanks to the development of new technologies and building elements implementing these functions, the design and characteristics of the products are constantly being improved. For a generalized distinction of functional and constructive changes in next generation systems, such definitions as digital, broadband, ultra-broadband, etc. are often placed in front of them. Improvements in the area of

computing devices and possibility of their embedding led to the creation of new concepts and architectures in radio communication systems. Such definitions as software-defined radio, cognitive radio, etc. have appeared. The concept of "software-defined radio system" is introduced in 80's of XX century and since then is object of substantial research [1],[2],[3]. Nowadays this paradigm is still vital and conceived as a main solution in practical implementation of digital communication systems.

Differential phase shift keying modulation schemes are preferred one for mobile communication systems, for theirs ability to work in non-coherent receivers. DQPSK modulation scheme is used in private mobile communication systems as TETRA [4], which is one of the system of choice for command and control support system for security and defence.

Different multiple antenna techniques have been developed to fight deleterious effect of multipath distortion and to increase data throughput or decrease bit error rate and after all the whole performance of the system [5]. Receive antenna diversity scheme is subclass of multiple antenna system and utilizes a single transmit antenna and multiple receive antennas. The diversity combining effect allows mitigation of numerous negative effects of the channel.

Design and implementation of pi/4-DQPSK software-defined modem with no diversity are reported [6],[7].The present study focuses on the model-based design and implementation of pi/4-DQPSK SDR modem with receive antenna diversity.

II. MATERIALS AND METHODS

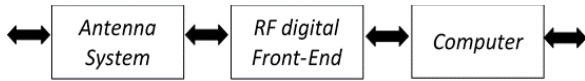The generalized constructive system definition of software-defined radio system is shown in Fig. 1.

Fig. 1. SDR block scheme.

The architecture of typical SDR consists of antenna system, radiofrequency (RF) front-end and general-purpose computing device (computer) [7]. RF front-end performs bandpass modulation/demodulation, digital-analog conversions and basic digital processing, as digital up/down conversion (DUC/DDC) decimation/ interpolation. Most popular bandpass modulation scheme used in available on the market RF front-ends is quadrature amplitude modulation (QAM). Main digital processing is performed typically on general purpose computer. Some of the popular applications, running on the computer and supporting SDR technology are GNU Radio, Matlab, LabVIEW, SystemVue, etc. GNU Radio is free and open-source framework, that allows usage of ready developed blocks for SDR and tools for writing new ones. Antenna system typically do not use diversity schemes. Recently there is tendency of introducing on the market of RF frontends, supporting multiple channels.

Pi/4 DQPSK modulation scheme uses differential encoding of QPSK symbols. Block schemes of the modem is shown in Fig.2.
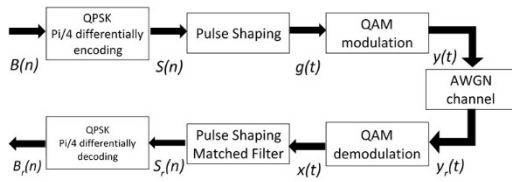

Fig. 2. Functional block scheme of pi/4-DQPSK modem.

Signal processing of QAM modulation/demodulation are following:

$$g(t) = I(t) + Q(t) \tag{1}$$

After multiplication with signal of local oscillator and taking real part, the output signal can be expressed as [5, 6]:

$$y(t) = Re\{v(t)\} = Re\{g(t)e^{j2\pi f_c t}\} =$$
$$= Re\{[I(t) + jQ(t)]e^{j2\pi f_c t}\} =$$
$$= I(t)\cos 2\pi f_c t - Q(t)\sin 2\pi f_c t \tag{2}$$

Assuming perfect radio transmission channel, signal after mixing with local oscillator of the receiver and lowpass filtering it, is:

$$x(t) = y(t)e^{-j2\pi f_c t} =$$
$$= [I(t)\cos 2\pi f_c t - Q(t)\sin 2\pi f_c t]e^{j2\pi f_c t} =$$
$$= \frac{1}{2}[I(t) + Q(t)] \tag{3}$$

In order to constrain the bandwidth of the transmitted signal *y(t)*, the baseband signal *g(t)* is filtered by appropriate filter. Typically, in practical implementation, such filter is of type root-raised cosine (RRC) [4] and play two additional roles of mitigation of inter-symbol interference (ISI) and a matched filter. The transfer function *H(f)* of the filter can be expressed as [4]:

$$H(f) = 1 \quad for \quad |f| \leq (1-\alpha)/2T$$

$$H(f) = \sqrt{0.5\left(1 - sin\left(\frac{\pi(2|f|T - 1)}{2\alpha}\right)\right)}$$
$$for \quad \frac{(1-\alpha)}{2T} \leq |f| \leq \frac{(1+\alpha)}{2T}$$
$$H(f) = 0 \quad for \quad |f| \geq (1+\alpha)/2T, \tag{4}$$

where α is the roll-off factor. For TETRA network it's value is chosen to be 0,35 [4].

The modulation symbol *S(n)* at the input of the shaping RRC filter in transmitter results from a differential encoding. It is formed by applying phase transition *Δφ(n)* to the previous modulation symbol $S(n-1)$:

$$S(n) = S(n-1)e^{-j\Delta\varphi(n)}$$
$$S(0) = 1 \tag{5}$$

The phase transition *Δφ(n)* depends on input dubits according Table 1.

TABLE 1 PHASE TRANSITIONS MAP

Dubits	Δφ(n)
1 1	-3π/4
0 1	3π/4
0 0	π/4
1 0	-π/4

Receive antenna diversity apply diversity combining only at receiver side of the communication system. General idea can be described using scheme in Fig.3.
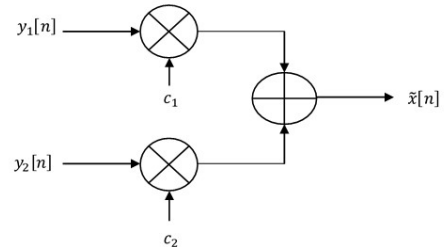

Fig. 3. Receiver divercity combiner.

Let $y_1[n]$ and $y_2[n]$ are two observations of transmitted symbol $x[n]$, each affected by different amount AWGN – $v_1[n]$ and $v_2[n]$:

$$y_1[n] = x[n] + v_1[n]$$
$$y_2[n] = x[n] + v_2[n] \tag{6}$$

The goal of the combiner is choose most appropriate coefficients c_1 and c_2, such that maximize signal-to-noise ratio (SNR) at the output. Applying scheme in Fig.3. SNR at output of diversity combiner will be [5]:

$$SNR_{final} = \frac{(c_1+c_2)^2\sigma_x^2}{c_1^2\sigma_{v1}^2+c_2^2\sigma_{v2}^2} \tag{7}$$

Simplest contemporary scheme of choosing c_1 and c_2 is "equal gain combining". This scheme averages the

two estimates $y_1[n]$ and $y_2[n]$ by selecting $c_1 = c_2 = 0{,}5$. Then SNR_{final} becomes:

$$SNR_{final} = \frac{\sigma_x^2}{0.25\sigma_{v1}^2 + 0.25\sigma_{v2}^2} = \frac{4}{\frac{\sigma_{v1}^2}{\sigma_x^2} + \frac{\sigma_{v2}^2}{\sigma_x^2}} =$$

$$= \frac{4}{\frac{1}{SNR_1} + \frac{1}{SNR_2}} = 4\frac{SNR_1.SNR_2}{SNR_1 + SNR_2} \qquad (8)$$

Equal gain combining gives best results when two SNR's are similar to each other – $SNR_1 = SNR_2$=SNR. Then:

$$SNR_{final} = 4\frac{SNR^2}{2SNR} = 2SNR \qquad (9)$$

In such case, there will be two times improvement of SNR, compared to no diversity.

Combining schemes in Fig.2 and Fig.3. results in scheme of system of interest – pi/4-DQPSK SDR modem with receive antenna diversity. Functional block scheme in Fig.4. is based on scheme in Fig.2. with introduction of multiple receiver arms (here in scheme – two) and addition of functional block "Diversity combiner" (here – equal gain combining is used).
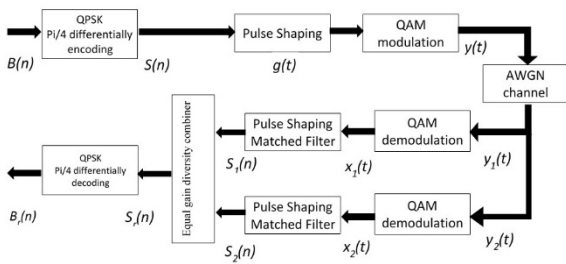

Fig. 4.   Functional block scheme of pi/4-DQPSK SDR modem with equal gain receive antenna diversity.

Based on previous described functional and mathematical models of pi/4-DQPSK SDR modem with equal gain receive antenna diversity, a computer model was built in GNU Radio framework. Application is based on previous work on modem with no diversity, described in [7]. Amendment was made in receiver side, where two channel receiver and diversity combiner was introduced. Single channel receiver is kept in overall model for performance comparison. In Fig.5. is shown part of the model that performs equal combining of two receiver channels. The outputs of pulse shaped filters, which acts as matched filters at the receiver, are equally combined and send to the pi/4-DQPSK detector.
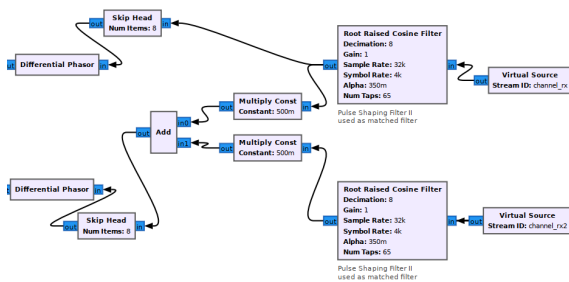

Fig. 5.   Computer model of pi/4-DQPSK SDR modem with equal gain receive antenna diversity – combiner part at the receiver only.

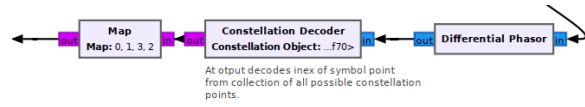Part of the model, that performs pi/4-DQPSK detection is shown in Fig.6.

Fig. 6.   Computer model of pi/4-DQPSK SDR modem with equal gain receive antenna diversity – detector part at the receiver only.

The detector part of the model of system with combining remains unchanged, compared to such with no combining.

Part of the model is dedidacated to visualisation and performance evaluation and comparison. In Fig.7. is shown block that visualize signal in time domain at different points of transceiver.
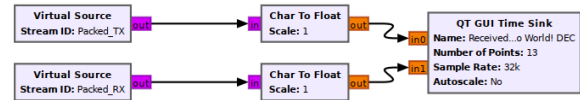

Fig. 7.   Part of computer model of pi/4-DQPSK SDR modem with equal gain receive antenna diversity – visualisation of signal at transmitter and receiver.

In Fig.8. is shown part of computer model that performs evaluation of performance of transceiver. As criteria of performance is chosen bit-error rate (BER). There is two measurements paths – one for receiver without combining and another with combining, which allows comparison and estimation of improvements.
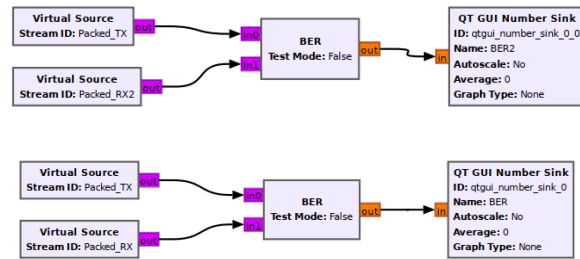

Fig. 8.   Part of computer model of pi/4-DQPSK SDR modem with equal gain receive antenna diversity – BER estimates.

III.   RESULTS AND DISCUSSION

Simulation with developed computer model was made for evaluation of overall ability for data exchange and comparison of performance of modem in the presence of additive white Gaussian noise. Control ASCII symbols "Hello World!" are sent multiple times and examined for correct receiving.

Time diagrams in Fig.9 show full identity of transmitted and received signal and symbols when no AWGN is introduced.

Time diagrams in Fig.10. shows difference between transmitted and received signals and resulted errors in detected symbols in presence of AWGN.

Long run of simulation allows measurement of bit error rate. Results for several values of noise level and two type of receivers – without and with diversity usage, are shown

in Table 2. Results for receiver with diversity shows improvement of BER compared with no diversity case.
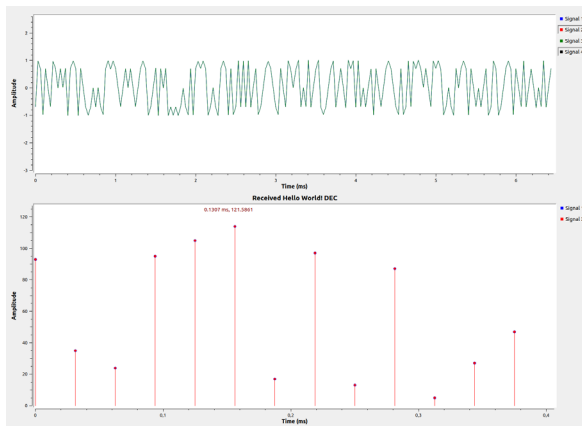

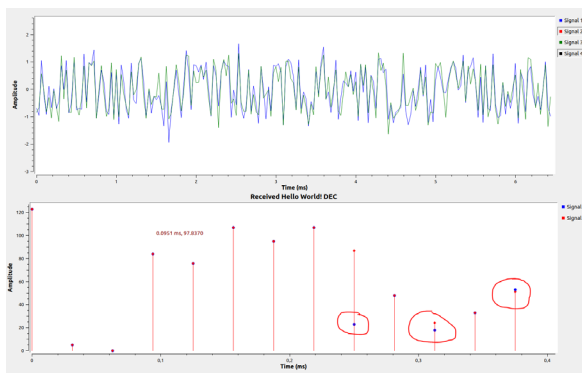Fig. 9. Time diagrams from simulation of pi/4-DQPSK SDR modem without AWGN.

Fig. 10. Time diagrams from simulation of pi/4-DQPSK SDR with AWGN.

TABLE 2. OBSERVED BER AS A FUNCTION OF E_B/E_N

Noise Level [absolute value]	BER (exp. part) no diversity	BER (exp. part) equal gain diversity
0,5	-5,0	-9,1
0,6	-3,7	-6,6
0,7	-2,9	-5
0,8	-2,4	-4,1

An real implementation of software-defined pi/4-DQPSK modem with receive antenna diversity was created. The realization is shown in Fig.11. Main parts of modem are: RF frontends, common clock generator, general-purpose computer, GNU Radio Framework and custom build Flowgraph. Common clock generator guarantees coherence synchronization of local oscillators of transmitter and receiver. As receiver RF frontend is used USRP B210. This device is two channel and special measures are taken by developer for coherence support [8]. The GNU Radio flowgraph that runs on the general-purpose computer is based on computer model described in part II of this paper. Amendments in Flowgraph was made in introducing particular blocks *USRP sink* and *USRP Source*, responsible for interface with RF Frontends.

Test of implementation in indoor environment shows reconstruction of transmitted text in the receiver and improvement of performance of receiver with diversity compared to no-diversity case, which validates the design.
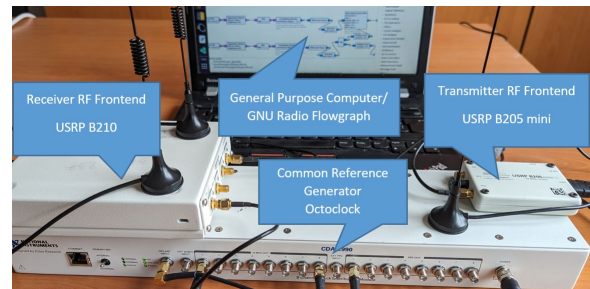

Fig. 11. Implementation of pi/4-DQPSK SDR modem with equal gain receive antenna diversity.

IV. CONCLUSIONS

In this study, design and implementation of pi/4-DQPSK modem with diversity at receiver side were made. The process was based on software-defined radio system concept. Computer model in GNU Radio framework of the system were developed. Performed simulation verified ability to transfer information from source to destination. Comparative study of BER for diversity scheme against no-diversity acknowledge the better performance of former at the price of little additional complexity of the RF receiver front-end and the flowgraph running on a general-purpose computer. The real implementation of the modem validates usage of SDR concept. The easy process of transition from model to implementation confirms advantages of software-defined radio systems. Based on constructed modem, a full SDR packet transceiver with receiver diversity can be build.

V. ACKNOWLEDGMENTS

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