The Analysis of Efficiency of Space-Diversity Reception

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Abstract. Space-diversity reception on two or three antennas is considered. Coherent and incoherent methods of signal addition in diversity branches are offered. Simulation results for DPSK and DQPSK signal reception in Rayleigh-Rice fading channel are represented.

Keywords: space-diversity reception, HF channel, Rayleigh fading, correlation, coherent and incoherent addition

INTRODUCTION

The space-diversity reception is an effective way to increase noise immunity in fading radio channels [1, 2, 4–10]. There are different types of diversity, but space diversity is the only method, which doesn't lead to division of transmitted power on diversity branches.

However, the analysis of efficiency of space-diversity reception shows that there are questions connected with degree of compliance between initial prerequisites and results of efficiency calculation for the real channel. First, the fading law changes over a wide range in real communication channel [3, 10, 11]. Second, the condition of statistical independence cannot be satisfied for this type of reception that affects the diversity reception. Besides, calculation of diversity reception efficiency is carried out for a case of optimum coherent addition of diversity branches. Practical realization of coherent addition is connected with difficulty of determine of diversity branch parameters that are coefficient of transfer, phase of a signal and spectral density of additive interference [1, 2]. Therefore efficiency analysis of processing methods of space-diversity reception, which ensure the desirable noise immunity, is the task of interest.

Incoherent addition of diversity branches is the simplest variant of realization. However efficiency estimation of this variant is connected with considerable mathematical difficulties due to fast fading and correlation of fading in branches. This is related to frequently used signals such as time-and-frequency signals and DPSK signals [5]. The only possibility to get objective estimate of real efficiency of space-diversity reception is to simulate the diversity branch reception with incoherent addition of branches [6, 7, 9].

Simulation

Random process distributed under the generalized Rayleigh-Rice law with the correlated quadrature components was chosen as a model of fading. Correlated quadrature components set transfer coefficients for time diversity branches with the average fading period which is significantly exceeded symbol duration. This model allows to vary fading intensity in necessary limits. Also it allows to create necessary correlation level of fading in diversity branches. Modeling conditions of reception were set by three parameters: mean square of transfer coefficient (mean value of SNR in diversity branch); fading parameter β^2, which defines fluctuation intensity (or dispersion) of transfer coefficient; correlation coefficient of fading in branches R, which defines paired correlation in diversity branches.

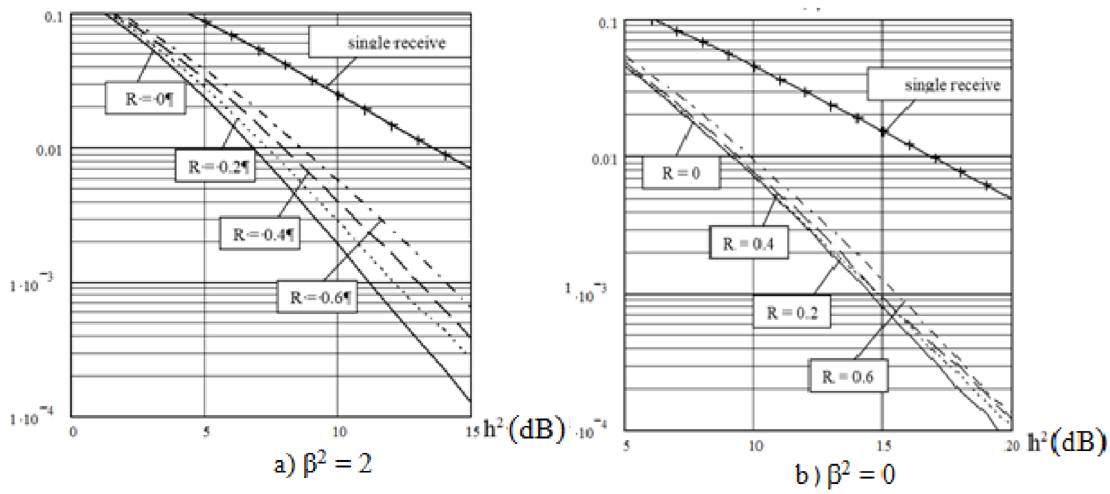


Figure 1. Bit error rate (BER) in case of incoherent DPSK signal reception using two diversity branches

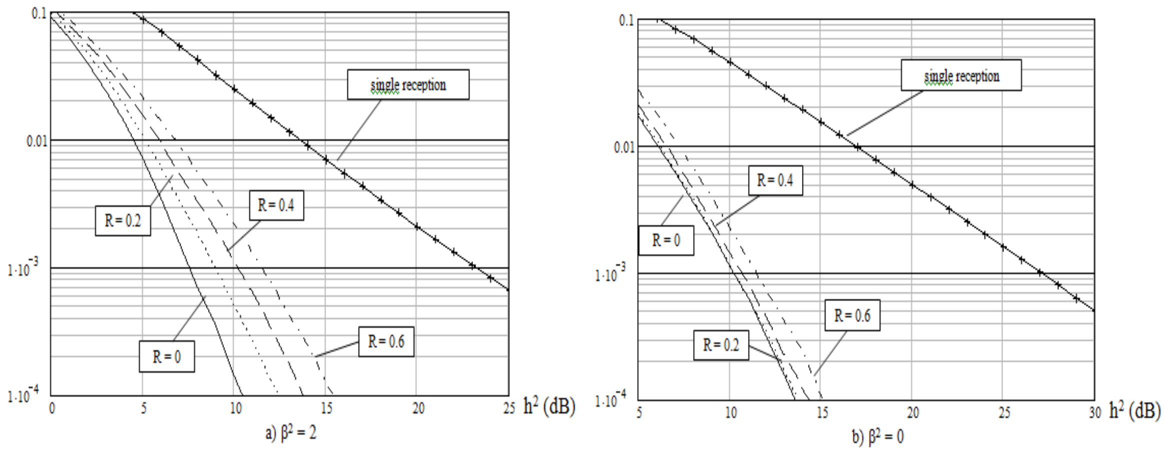


Figure 2. Bit error rate in case of incoherent DPSK signal reception using three diversity branches

Modeling results of incoherent addition in diversity branches of DPSK and DQPSK signals are presented in Figures 1–4 as a dependence of bit error rate versus mean SNR value. Simulation has been carried out for the most typical values of fading parameters for HF channel and for following values of fading correlation coefficients $R = 0$; 0.2; 0.4 and 0.6. The dependences of bit error rate of single, incoherent reception under the same conditions are presented for comparison. According to the results we can draw following conclusion: first, incoherent addition provides rather high efficiency in spite of its nonoptimality (equilibrium addition without taking current SNR into account was realized). Considerable gain in comparison with single incoherent reception is received. Secondly, gain is increased with increase of requirement for reception quality, number of diversity branches and fading intensity [6, 8, 9]. Thirdly, the growth of fading correlation in diversity branches leads to degradation of diversity reception. However diversity reception provides considerable gain even at R = 0.6. Extent of correlation influence in diversity branches is decreased with reduction of parameter β^2.

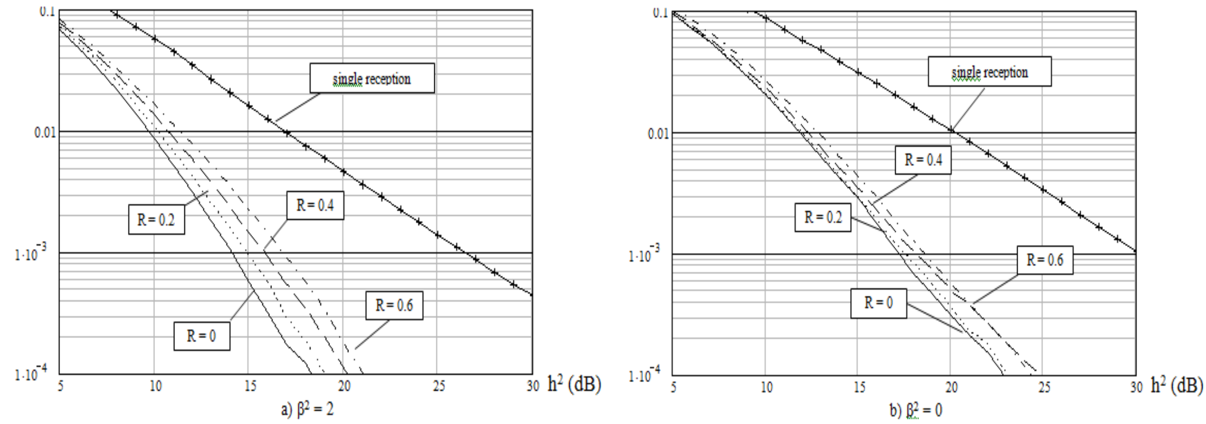


Figure 3. Bit error rate in case of incoherent DQPSK signal reception using two diversity branches

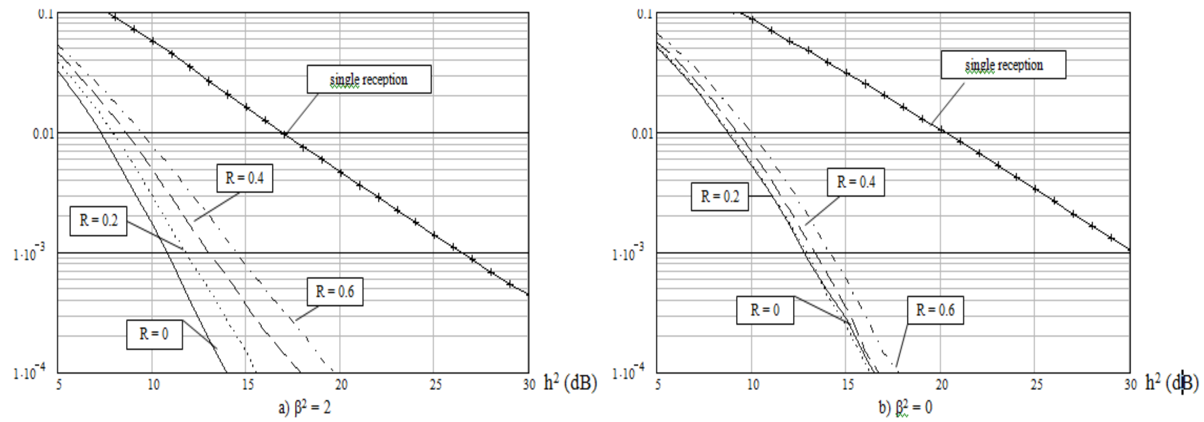


Figure 4. Bit error rate in case of incoherent DQPSK signal reception using three diversity branches

Gain values versus SNR at incoherent addition of diversity are presented in Table 1. Those values correspond to Figures 1–4 for three values of BER. Incoherent addition of two diversity branches provides gain of at least 9 dB in case of fading intensity $\beta^2 < 2$, correlation $R < 0.6$, BER = 10^{-3} . Incoherent addition of three diversity branches provides gain of at least 12 dB. At BER = 10^{-3} degradation of diversity reception due to correlation does not exceed 3.3 dB for $\beta^2 = 2$ and 1.2 dB for $\beta^2 = 0$ (Rayleigh fading).

If the base of space diversity is comparable to radio wave length, the mutual delay in diversity branches is much less than duration of package. Therefore, when addition is realized there is no need to solve a problem of mutual synchronization in branches. That fact simplifies process of addition and allows realizing the timing using total signal, providing thereby significant improvement of synchronization quality.

Since mutual delays of signals in diversity branches are negligible and phase difference is changed rather slowly, we can get high quality estimation of phase differences without tracking phases of signals in each diversity branch. High quality estimation of phase differences allows executing coherent addition of branches with the subsequent incoherent reception of information from a total signal. The estimation of a constant phase difference of two complex sequences (each sequence represents response to DPSK signal sample) can be calculated as following:

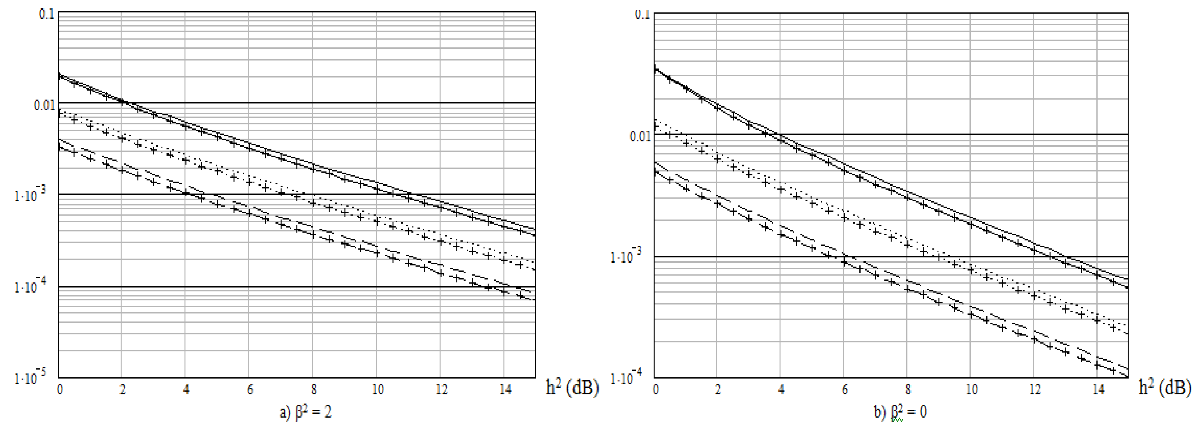
$$\Delta\varphi(X,Y)=\arg\left\{\sum_{i=1}^{n_0} x_i\hat{y}_i\right\}=\arg\left\{\begin{bmatrix} x_1 & x_2 & \cdots & x_{n_0}\end{bmatrix}\begin{bmatrix}\hat{y}_1\\ \hat{y}_2\\ \vdots \\ \hat{y}_{n_0}\end{bmatrix}\right\}. \quad (1)$$

Table 1. Gain in SNR in comparison with single reception

Modulation type	Number of branches	Fading β^2	Correlation R	Bit error rate		
				10^{-2}	10^{-3}	10^{-4}
DPSK	2	2	0	6.7	12.1	17.5
			0.6	5	9.1	14
		0	0	7.6	12.1	16.7
			0.6	6.9	11.6	16.5
	3	2	0	9.1	15.5	22.3
			0.6	6.6	12.1	18.3
		0	0	10.6	16.6	23
			0.6	9.6	15.5	21.5
DQPSK	2	2	0	7.1	12.4	18.1
			0.6	5.3	9.2	14
		0	0	8.2	12.8	17.5
			0.6	7.3	11.7	16.2
	3	2	0	9.5	15.7	22.5
			0.6	7.3	12.1	17.8
		0	0	11.2	17	23.1
			0.6	10.1	15.7	21.5

The simulation results of phase shift estimation in fading branches are presented in Figure 5. The figure depicts the dependence of error dispersion of mean SNR for two values of sequence length n_0. The analysis of results shows that estimation of error dispersion should be equal to 10^{-3} radian^2 to achieve high quality of coherent addition. Therefore, correct selection of parameter n_0 ensures necessary estimation quality in given SNR range, which correspond to current transfer quality index.

Transfer quality estimation of DPSK signal was taken to determine the importance of transfer coefficient calculation in case of coherent addition with equal weight. The dependence of BER from mean SNR for reception of DPSK signal and $n_0 = 512$ is presented in Figures 6 and 7. The reception is coherent (i.e. phase shift and transfer coefficient are known) and fading in branches is independent ($R = 0$). Comparison of simulation results and theory calculation shows that there is a negligible degradation if the weight is not taken into account. The degradation is maximum for Rayleigh fading, but it is less than 1.2 dB for BER = 10^{-2}–10^{-4}. The losses do not exceed 0.7 dB at $\beta^2 = 2$ and three branch reception. Comparison of dependences in Figures 1, 2, 6 and 7 shows that coherent addition with equal weight provides for miserable gain. It is about 0.8 dB better than incoherent addition gain. Correlation influence is similar for both coherent and incoherent addition. The influence is strong if transfer coefficient has regular component and one is weak Rayleigh fading channel ($\beta^2 = 0$).



Line type			Marker	
$n_0 = 128$	$n_0 = 256$	$n_0 = 512$	$R = 0$	$R = 0.6$
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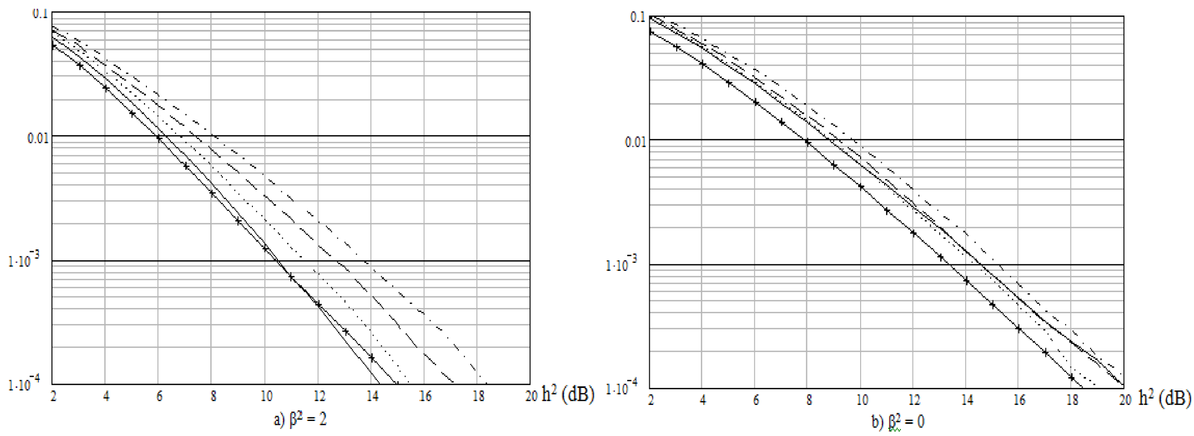
Figure 5. Dispersion of estimation error of mutual phase shift in diversity branches



Simulation of addition with equal weight				Optimal
$R = 0$	$R = 0.2$	$R = 0.4$	$R = 0.6$	
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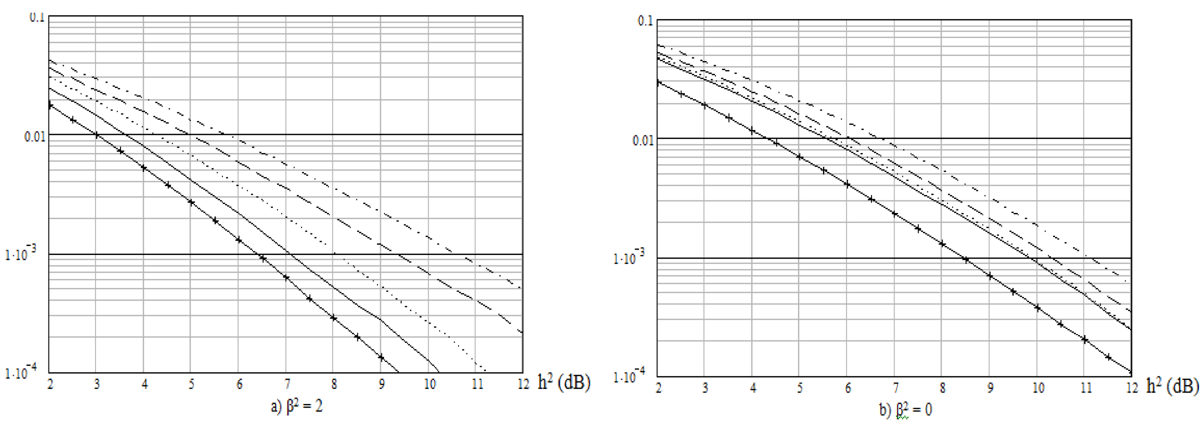
Figure 6. Bit error rate in case of coherent DQPSK signal reception using two diversity branches



Simulation of addition with equal weight				Optimal
$R = 0$	$R = 0.2$	$R = 0.4$	$R = 0.6$	
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Figure 7. Bit error rate in case of coherent DQPSK signal reception using three diversity branches

CONCLUSION

According to the results of research we draw the following main conclusions:

1. Space-diversity reception allows to increase reception quality significantly. Efficiency of space-diversity reception directly depends on requirement to reception efficiency. So, SNR gain that correspond to BER = 10^{-3} is about 10 dB for two branch reception. SNR gain that correspond to BER = 10^{-4} is not less than 14 dB.

2. Fading correlation in diversity branches reduces efficiency of space-diversity reception. However this influence is negligible at Rayleigh fading channel. Fading correlation reduces efficiency of space-diversity reception considerably if transfer coefficient component is regular and huge. So, the losses caused by correlation influence on efficiency of space-diversity reception are about 3–4 dB at $R = 0.6$ and $\beta^2 = 0$ and satisfactory SNR (it is typical for HF channel). Therefore it is necessary to collect the information about real fading correlation level at reception on spaced antennas and find the ways to ensure not significant values of correlation.

3. Efficiency of incoherent addition of DPSK signals slightly concedes to coherent addition efficiency. Since realization of incoherent addition is easier than coherent addition, it allows to include more diversity branches. Besides, incoherent addition can be executed before timing is established. And efficiency of timing can be increased since we process overall signal. Therefore incoherent addition is more preferable in terms of efficiency/costs ratio.

4. Incoherent addition is less sensitive than coherent to differences in frequency shift in branches. In this case phase incursion has a weak influence to reception quality. And it is enough to synchronize only clock frequencies of synchronization. As a result relatively high space diversity can be used to get negligible fading correlation. If difference of phase incursion is significant, synchronization with the leading generator should be foreseen. Phase incursion is caused by reference generator instability in line channel and by duration of package.

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