Exact Error Probability of DQPSK Signal with Nonlinear Phase Noise

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Differential quadrature phase-shift keying (DQPSK) [1-3] signal has received renewed attention recently for spectral-efficiency transmission systems. Nonlinear phase noise [4] is the major degradation for phase-modulated signals [4--9]. Correlated with received intensity [7-9], nonlinear phase noise can be compensated by the received intensity. The exact error probability of DQPSK signal is derived with and without linear compensation, taking into account the dependence between linear and nonlinear phase noise.

With Gray code, the bit-error probability is equal to

$$p_e = \frac{3}{8} - \frac{1}{\pi}\sum_{m=1}^{\infty}\frac{1}{m}\sin\left(\frac{m\pi}{4}\right)\left|\Psi_{\Phi_{cm}}(m)\right|^2, \tag{1}$$

where [7]

$$\Psi_{\Phi_{cm}}(m) = \frac{\sqrt{\pi}\lambda_{m,\alpha}^{3/2}}{2\lambda_m} e^{-\lambda_m + \frac{\lambda_{m,\alpha}}{2}} \Psi_\Phi\left[\frac{m<\Phi_{NL}>}{\rho_s + \frac{1}{2}}\right]\left[I_{\frac{m-1}{2}}\left(\frac{\lambda_{m,\alpha}}{2}\right) + I_{\frac{m+1}{2}}\left(\frac{\lambda_{m,\alpha}}{2}\right)\right], \quad m \geq 1, \tag{2}$$

with parameters of

$$\lambda_m = \frac{2\left[\frac{jm<\Phi_{NL}>}{\rho_s+\frac{1}{2}}\right]^{1/2}}{\sin\left\{2\left[\frac{jm<\Phi_{NL}>}{\rho_s+\frac{1}{2}}\right]^{1/2}\right\}}\rho_s, \quad \lambda_{m,\alpha} = \frac{\lambda_m}{1+\alpha\left[\frac{jm<\Phi_{NL}>}{\rho_s+\frac{1}{2}}\right]^{1/2}\tan\left\{2\left[\frac{jm<\Phi_{NL}>}{\rho_s+\frac{1}{2}}\right]^{1/2}\right\}}, \tag{3}$$

and $\Psi_\Phi(\nu) = \sec\sqrt{j\upsilon}\exp\left(\rho_s\sqrt{j\upsilon}\tan\sqrt{j\upsilon}\right)$ is the marginal characteristic function of nonlinear phase noise that depends solely on the signal-to-noise ratio (SNR) ρ_s [10], $\langle\Phi_{NL}\rangle$ is the mean nonlinear phase shift, and α is the linear compensation factor. The optimal compensation factor is $\alpha_{opt} = \frac{1}{2}\left(\rho_s + \frac{1}{3}\right)\left(\rho_s + \frac{1}{2}\right)^{-1}$. The usage of $\alpha = 0$ is the case without linear compensation.

Figure 1 plot the SNR penalty for a BER of 10^{-9} as a function of nonlinear phase noise. For a SNR penalty of less than 1 dB, the mean nonlinear phase shift must be less than 0.50 and 0.95 rad without and with linear compensation, respectively. The optimal operating point is for a mean nonlinear phase shift of $\langle\Phi_{NL}\rangle = 0.89$ and 1.72 rad without and with linear compensation, respectively, such that the increases of launched power does not degrade the system performance due to nonlinear phase noise.

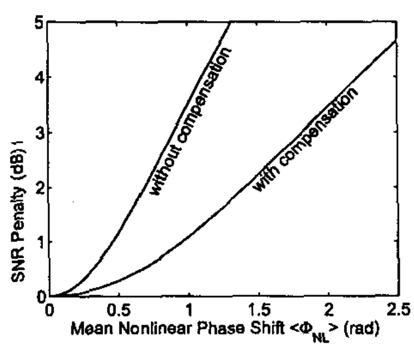

Fig. 1. The SNR penalty of DQPSK signal with and without linear compensation.

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