CTuI2

Postdetection filtering in heterodyne differential receivers

I. Roudas, Y. Jaouen, P. Gallion, *Department of Communications, Ecole Nationale Superieure des Telecommunications, 46, rue Barrault, 75634 Paris, Cedex 13, France*

Continuous-phase frequency-shift keying (CPFSK) is an attractive modulation format for coherent optical communication systems.[1] CPFSK can be demodulated by means of differential detection (Fig. 1). This type of receiver combines improved sensitivity and circuit simplicity, but it is sensitive to laser phase noise. However, its performance can be optimized by proper choice of receiver filters. In a previous paper we presented a method for optimizing the bandpass filter of the receiver.[2] In this paper, the effect of the postdetection (low-pass) filtering is, for the first time to our knowledge, accurately analyzed.

The low-pass filter is modeled as a finite-time integrator, i.e., a filter whose impulse response is a rectangular pulse of duration τ_1. Because we are interested only in the influence of the low-pass filter, the bandpass filter is considered large. We make the common assumption that the phase noise is a Wiener process[3] and can be written as

$$\phi(t) = \int_0^t \dot{\phi}(t')\mathrm{d}t',$$

where $\dot{\phi}(t)$ is a zero-mean Gaussian random variable with double-sided power spectral density $D = 2\pi\Delta\nu$ and $\Delta\nu$ is the spectral linewidth at the intermediate frequency.

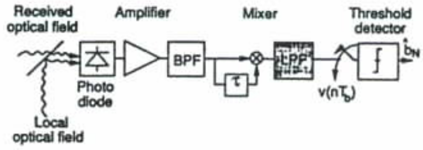
Using fundamental properties of the Gaussian variables and the Wiener process (Ref. 4, pp. 49–50), we have been able to derive recursive relations for the moments $\mu_k = E[v^k(nT_b)]$ of the demodulator output. A symbolic calculations mathematical package was used to compute analytically the moments up to the tenth order. The first three moments are given in Table 1.

Since the number of moments that can be practically calculated with this procedure is limited because of the excessive computer time required, we use the maximum-entropy criterion[5] to approximate the probability-distribution function (pdf) of the output.

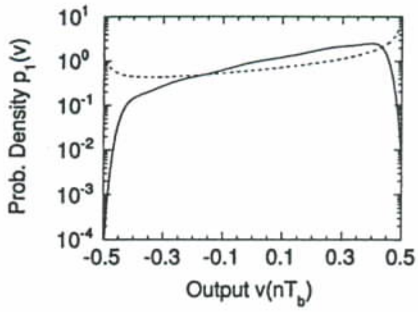
In the following we assume that the values of the delay time τ and the duration τ_1 of the impulse response are chosen as $\tau_1 = \tau$ and $D\tau = 2$. Figure 2 shows the probability density $p_1(v)$ before (dashed curve) and after (solid curve) the postdetection filter when a 1 is transmitted. The output $v(nT_b)$ is normalized in the range [–0.5, 0.5]. The former pdf was plotted by using the analytical expression (18) of Ref. 6. The latter pdf was plotted by using the method presented above. We observe that filtering alters the shape and diminishes the queues of the pdf, as expected.

The error floor can be evaluated by the numerical integration

$$P_{\text{floor}} = \int_{-0.5}^{0} p(v)\mathrm{d}v\,.$$



CTuI2 **Fig. 1.** Block diagram of the heterodyne differential receiver (Abbreviations used: BPF = bandpass filter, LPF = Post-detection (lowpass) filter, T = delay).



CTuI2 **Fig. 2.** Output probability density before (full line) and after (dashed line) post-detection filtering (Conditions: $\tau_1 = \tau$, $D\tau = 1$).

CTuI2 **Table 1.** The first three theoretical moments.

Moment	Theoretical expression
μ_1	$\frac{1}{2}e^{-\frac{D\tau}{2}}$
μ_2	$\frac{1}{4D\tau_1}\left(1-e^{-2D\tau}\right)-\frac{1}{4D^2\tau_1^2}\left(1-e^{-D\tau_1}\right)\left[1-e^{-D(2\tau-\tau_1)}\right]$
μ_3	$\frac{1}{32}e^{-\frac{D\tau}{2}}+\frac{3}{64D^3\tau_1{}^3}\left(1-e^{2D\tau_1}+D\tau_1+De^{2D\tau_1}\tau_1\right)e^{-\frac{9D\tau}{2}}+$ $\frac{3}{8\tau_1{}^3}\left(\frac{1}{8D^3}-\frac{1}{8D^3}e^{-2D\tau_1}-\frac{\tau_1}{4D^2}+\frac{\tau_1{}^2}{4D}\right)e^{-\frac{D\tau}{2}}$

The validity of the approach was checked by using MonteCarlo simulation. Results for different combinations of D, τ, and τ_1 show that postdetection filtering can reduce the phase-noise variance by up to 69% of its initial value and can lead to a significant reduction of the error-floor. This confirms the validity of a previous approximate analyses.[3,7]

In conclusion, the present model provides a method for accurate error-floor evaluation. In the future, it can be extended to include intersymbol interference and output-sample correlation.

1. P. W. Hooijmans, *Coherent Optical System Design* (Wiley, New York, 1994).
2. I. Roudas, Y. Jaouen, P. Gallion, in *Conference on Lasers and Electro-Optics*, 1994 Technical Digest Series, Vol. 8 (Optical Society of America, Washington, D.C., 1994), paper CThI33.
3. L. G. Kazovsky, IEEE Opt. Commun. 7, 66 (1986).
4. E. Wong, *Stochastic Processes in Information and Dynamical Systems*, (McGraw-Hill, New York, 1971).
5. M. Kavehrad, M. Joseph, IEEE Trans. Commun. **COM-34**, 1183 (1986).
6. G. Nicholson, Opt. Quantum Electron. 17, 399 (1985).
7. G. Jacobsen, J. Lightwave Technol. **11**, 1622 (1993).