OPTIMUM IF FILTER BANDWIDTH FOR COHERENT OPTICAL HETERODYNE CPFSK DIFFERENTIAL RECEIVERS

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Topic related to :
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1 Introduction

An attractive modulation format for coherent optical communication systems is the continuous-phase frequency shift keying (CPFSK) [1]. CPFSK can be demodulated by means of differential detection (fig. 1) [1]. This type of receiver combines improved sensitivity and circuit simplicity. However, its performance depends mainly on the choice of the bandpass filter.

In this paper, the bandpass filter is modelled as a finite-time integrator, i. e. a filter whose equivalent low-pass impulse response is a rectangular pulse of duration τ_1. Its noise equivalent bandwidth B_{IF} $(= 1/\tau_1)$ is optimized to minimize error probability for given received power and phase noise level.

2 Error probability evaluation

Error probability evaluation must take into account the influence of the IF bandwidth on the signal (intersymbol interference) and noise (phase noise variance reduction and shot noise correlation). A closed-form expression for the error probability cannot be found so a semi-analytical technique is used [2]. This method consists in simulating the signal in the absence of noise in order to compute the signal distortion induced by the IF filter. The filtered phase noise variance and the shot noise correlation are calculated analytically. All the above values are used to calculate numerically the conditional error probability $P_{e|k}$ for each output sample k

$$P_{e|k} = \int_{-\infty}^{\infty} P_{e|k,\Delta\theta} p(\Delta\theta) d(\Delta\theta) \tag{1}$$

where $P_{e|k,\Delta\theta}$ is the conditional error probability given a phase error $\Delta\theta$ and $p(\Delta\theta)$ is the filtered phase noise probability density. An expression of $P_{e|k,\Delta\theta}$ can be found generalizing the formalism of [3], [4]. $p(\Delta\theta)$ is shown to be Gaussian with zero mean and variance given by [1].

The total error probability can then be estimated by averaging over all the output samples M

$$P_e = \frac{1}{M}\sum_{k=1}^{M} P_{e|k} \tag{2}$$

All the possible combinations of interfering bits must be considered. For bandwidths greater than the bit-rate, intersymbol interference is shown to be limited to two or three adjacent bits depending on the sampling instant. Thus a sequence length $M = 2^3$ is sufficient for all cases.

In the above analysis, shot noise limit conditions are assumed. The demodulator delay τ is chosen equal to $\tau = T_b/(2m)$ [1], where T_b is the bit period and m is the modulation index. The effects of the low-pass filtering are neglected.

3 Major results and discussion

Fig. 2 shows the optimum noise equivalent bandwidth B_{IF} (normalized to the bit-rate) and the corresponding minimum error probability $P_{e_{min}}$ for a given average number of photoelectrons per bit N_{ph} and different IF linewidth $\Delta\nu_{IF}$-delay τ products. The modulation index is $m = 0.5$. The value of $B_{IF}T_b$ is indicated near every point. For instance, for $N_{ph} = 17$ dB (50 photoelectrons per bit), the best performance is obtained with a filter bandwidth $B_{IF} = 1.4/T_b$ when $\Delta\nu_{IF}\tau = 0$

and $B_{IF} = 2/T_b$ when $\Delta\nu_{IF}\tau = 0.5\%$. The corresponding minimum error probabilities are $1.1\,10^{-9}$ and $6\,10^{-7}$ respectively. For comparison the error probability of the ideal asynchronous receiver is plotted (full line). Table 1 presents similar results for $m = 1$ in the absence of phase noise. For both indices, the penalty sensitivity at 10^{-9} is about 1 dB in comparison with the ideal asynchronous receiver in the absence of phase noise. The procedure can be applied to other modulation index values and filter shapes. Comparison with previously published results [1], [5] will be presented.

References

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FIGURES CAPTION

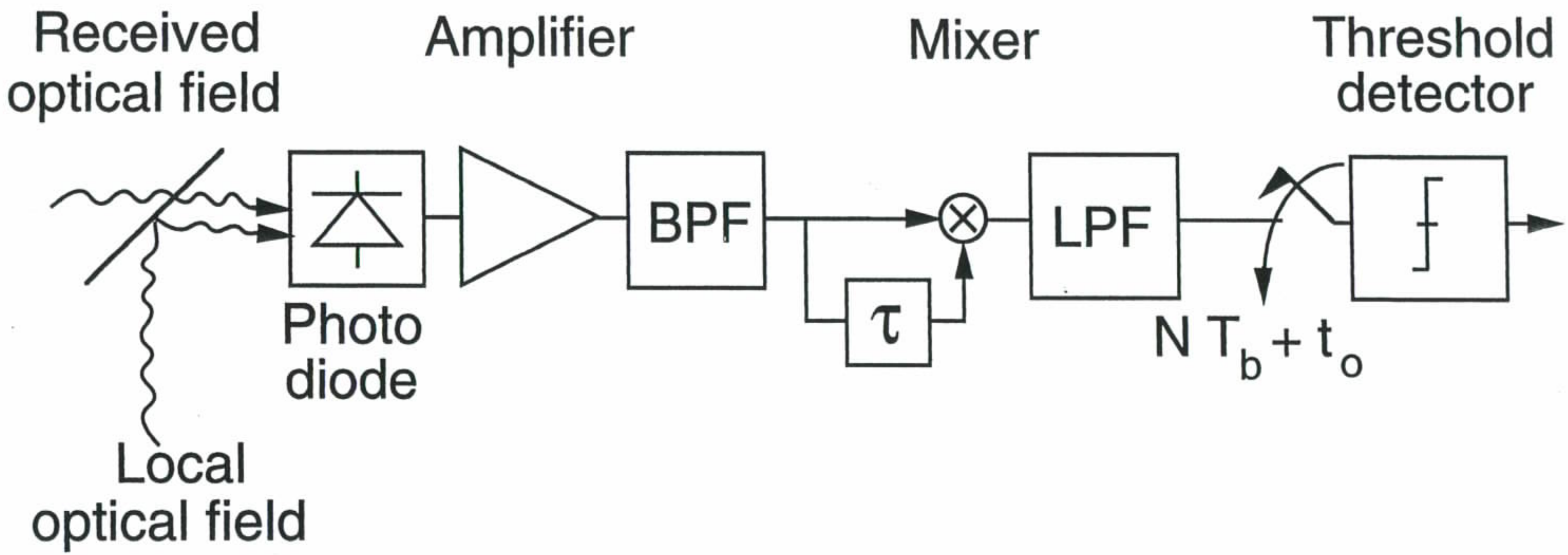
Fig. 1 Schematic representation of the heterodyne differential receiver (Abbreviations used: BPF=bandpass filter, LPF=low-pass filter, τ=delay).

Fig. 2 Optimum noise equivalent bandwidth B_{IF} (normalized to the bit-rate) and the corresponding minimum error probability $P_{e_{min}}$ for a given average number of photoelectrons per bit N_{ph} and different IF linewidth $\Delta\nu_{IF}$-delay τ products. Modulation index $m = 0.5$ (Symbols used : Full line : Asynchronous differential receiver, ■ : $\Delta\nu_{IF}\tau = 0$, □ : $\Delta\nu_{IF}\tau = 0.5\%$, ∘ : $\Delta\nu_{IF}\tau = 1\%$, • : $\Delta\nu_{IF}\tau = 2\%$. The optimum $B_{IF}T_b$ is indicated near every point).

TABLES CAPTION

Table 1. Optimum noise equivalent bandwidth B_{IF} (normalized to the bit-rate) and the corresponding minimum error probability $P_{e_{min}}$ for a given average number of photoelectrons per bit N_{ph} in the absence of phase noise. Modulation index $m = 1$.

N_{ph} (dB)	$B_{IF}T_b$	$P_{e_{min}}$
11	1.5	$2.02 \ 10^{-3}$
12	1.5	$5.37 \ 10^{-4}$
13	1.7	$1.01 \ 10^{-4}$
14	1.7	$1.26 \ 10^{-5}$
15	1.8	$8.94 \ 10^{-7}$
16	1.8	$3.23 \ 10^{-8}$
17	1.8	$1.03 \ 10^{-9}$
18	1.8	$2.75 \ 10^{-12}$



Received
optical field
Amplifier
Mixer
Threshold
detector
BPF
τ
LPF
Photo
diode
N T_b + t_o
Local
optical field

Fig. 1

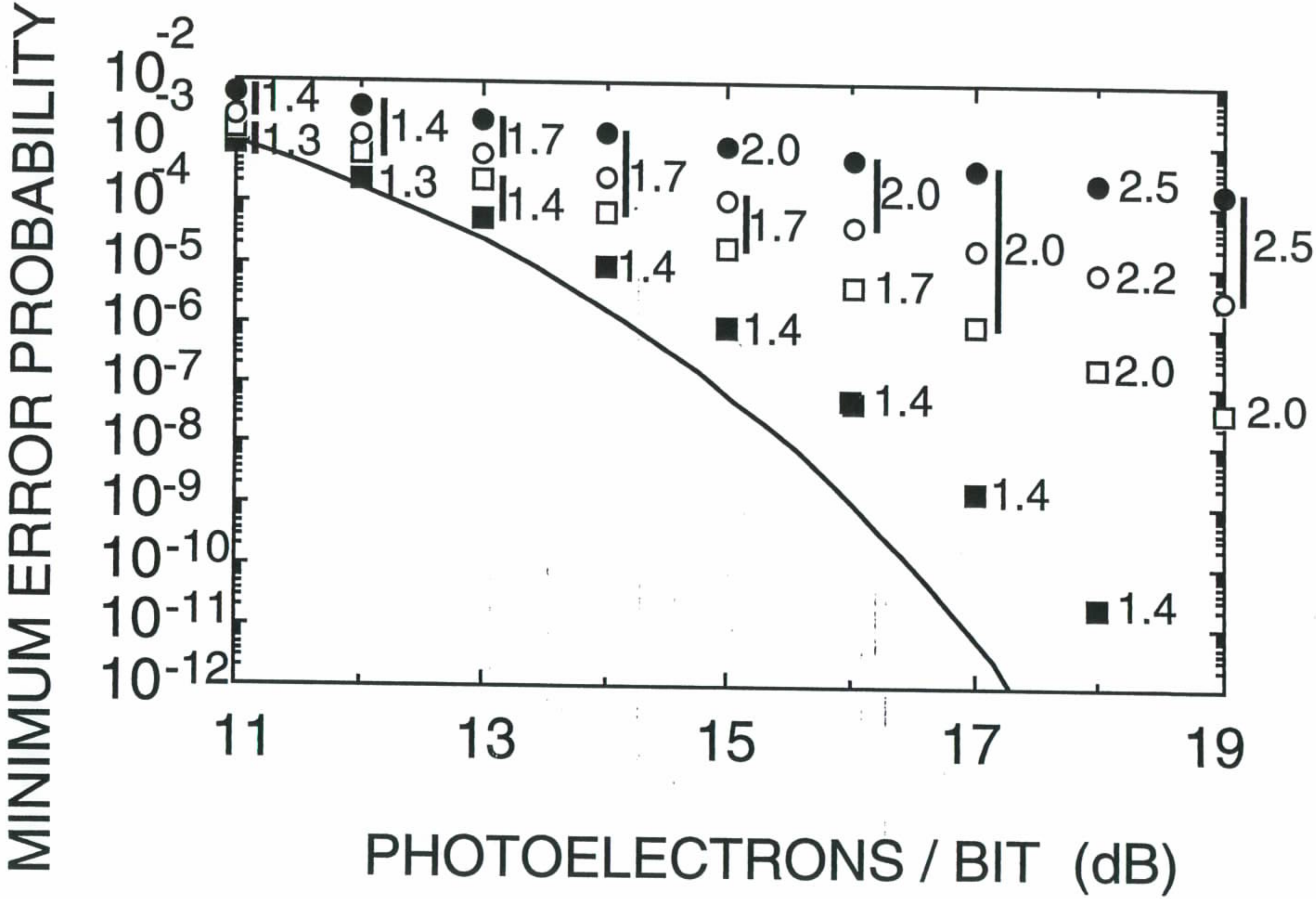

MINIMUM ERROR PROBABILITY
PHOTOELECTRONS / BIT (dB)
11
13
15
17
19
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
1.4
1.3
1.4
1.3
1.7
1.4
1.7
1.4
2.0
1.7
1.4
2.0
1.7
1.4
2.0
1.4
2.5
2.2
2.0
1.4
2.5
2.0

Fig. 2