Impact of Non-zero Extinction Ratio on Optically Pre-amplified Receivers

L. F. Botelho Ribeiro*, J. R. Ferreira da Rocha*, J. Lemos Pinto**
DETUA*, DFUA**

Resumo- **Em sistemas práticos de comuicações ópticas os lasers emissores são polarizados com uma dada corrente. Surge assim um patamar de potência óptica no receptor. O presente trabalho inclui este fenómeno numa formulação analítica de descrição estatística de um sistema de detecção directa com pre-amplificação óptica.**

Abstract- **In practical optical communication systems, the transmitter laser is polarised with a finite current. A given optical power plateau is, thus, observed at the receiver. This contribution includes this phenomenon in an analytical formulation for statistical description of a optically preamplified direct-detection system.**

I. INTRODUCTION

Direct detection optical communication systems can be studied quite accurately and without excessive computing effort by analytical means. One widely used tool to this purpose is the moment generating function (MGF) of the electric current at the receiver decision circuit. This function contains all the relevant statistical information and is well adapted to various techniques for evaluation of many parameters: bit error rate (BER) bounds, BER approximations, optimum decision threshold, output current mean level (conditioned on the symbol) or standard deviation (due to noise) are some examples.

Results have been reported describing the MGF for different types of receiver, where various assumptions on the noise statistical properties were made. Personick considered an optical amplifier with additive optical noise and avalanche photodiode (APD) detection, followed by an integrate-and-dump filter [1]. Yamamoto [2] has obtained expressions for the current average and noise variances after equalisation exclusively by physical considerations and then used Gaussian approximation (GA) to assess receiver sensitivity.

Da Rocha [3] used the MGF to study receiver optimization in the presence of intersymbol interference for receivers without optical amplification. A study on improved alternative performance evaluation methods is presented by O'Reilly [4], considering Chernoff bound (CB) and modified Chernoff bound(MCB) on the final BER.

Helstrom presented an alternative approximation for the system BER using the saddle-point approximation [5] which also requires the use of the MGF. This method gives lower BER than others but its accuracy depends on the specific receiver configuration. Fyath [6] has studied the importance of laser amplifiers for the sensitivity and power penalty of direct-detection receivers.

A formulation for the MGF of optically preamplified receivers was proposed by Fyath in [7]. A different approach was followed by Ribeiro [8] leading to a more rigorous expression for the MGF.

In this contribution we face the problem of input signals with non-zero extinction ratio. This is the case for most practical systems where lasers have bias current large enough to launch some power into the fiber even during the period of time corresponding to the symbol zero. This power, after attenuation in the fiber, optical pre-amplification, filtering and detection will be processed much in the same way as the pulses for the symbol one. The impact of non-zero extinction ratio on sensitivity, optimum decision threshold and optical power penalty is evaluated according to different methods: Gaussian approximation, Chernoff bound, modified Chernoff bound and saddlepoint approximation (SPA).

II. THEORY

Consider the receiver in Fig. 1. The optical pulse entering the optical amplifier is allowed to have non-zero power at symbol "0". Then, the optical power pulse $h_p(t)$ transmitted for symbol "1", is superimposed over $P_{"0"}$.

We define the normalised input pulse as follows,

$$\frac{1}{T}\int_{-\infty}^{+\infty} h_{pn}(t)dt = 1 \qquad (1)$$

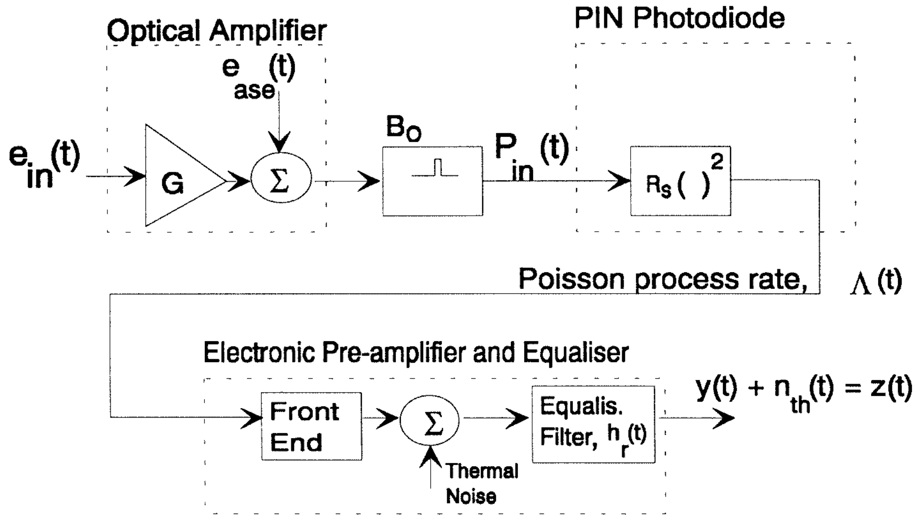

Fig. 1 - Optically pre-amplified receiver model

The actual power pulse to be used in the MGF formulation is related to the normalized pulse $h_{pn}(t)$, the average optical power S and the power extinction ratio ε according to,

$$h_p(t) = h_{pn}(t).2S\frac{1-\varepsilon}{1+\varepsilon} \qquad (2)$$

Where ε is the ratio of average powers on symbols "0" and "1", respectively, and the output pulse is normalised by $\max\{h_{out}(t)\}=1$. Finally we use an electronic pulse shaping filter providing an impulse response,

$$h_r(t) = \mathcal{F}^{-1}\left\{\frac{H_{out}(\omega)}{H_{pn}(\omega)}\right\} \qquad (3)$$

where $\mathcal{F}$ denotes Fourier transform and $H_{out}(\omega)$, $H_{pn}(\omega)$ are respectively the Fourier transforms of $h_{out}(t)$ and $h_{pn}(t)$. The average symbol conditioned powers are related to the extinction ratio and the average power by,

$$P_{"0"} = \frac{2\varepsilon S}{1+\varepsilon} \qquad P_{"1"} = \frac{2S}{1+\varepsilon} \qquad (4)$$

We now make use of the MGF derived in [8] to obtain the new symbol conditioned MGF where the input optical power contribution is reformulated to cope with the new assumptions,

$$M_{Y_i}(s) = \exp\left\{ \int_{-\infty}^{\infty} \left[\frac{RG\left(e^{sqh_r(t-\tau)} - 1\right)P_i(\tau)}{1 - RN_o\left(e^{sqh_r(t-\tau)} - 1\right)} \right] d\tau + \frac{\sigma_{th}^2 . s^2}{2} - \int_{-\infty}^{\infty} B_o . \ln\left[1 - RN_o\left(e^{sqh_r(t-\tau)} - 1\right)\right] d\tau \right\} \qquad (5)$$

Where N_O is the unilateral Amplified Spontaneous Emission noise power spectral density of the optical preamplifier, σ_{th} is the receiver thermal noise standard deviation, G is the optical amplifier gain, B_O is the optical filter bandwidth and $R=\eta/(h\nu)$. η is PIN quantum efficiency, h is Planck's constant and ν is the optical carrier frequency. The input time-dependent power is expressed as follows,

$$P_i(\tau) = P_{"0"} + a_i . h_p(\tau) \qquad (6)$$

where, for transmitted symbol "0" or "1", a_i takes the values 0 and 1 respectively. Once we have obtained the symbol conditioned MGF, methods in [2],[4],[5] can be used to assess system MCB, CB, SPA and GA on the BER. Also, noise variance and optimum decision threshold can be calculated.

III. RESULTS

Throughout this work we have considered a Gaussian input pulse $h_{pn}(t) = \exp(-t^2/\alpha^2)/(\alpha\sqrt{2\pi})$ with α=0.1T. The output pulse is a full-raised cosine. Consequently, the transfer function of the equalising filter was found by (3). For the analysis, we have considered σ_{th} = 1.366x10^{-5} A, G=25.6 dB and the ASE noise

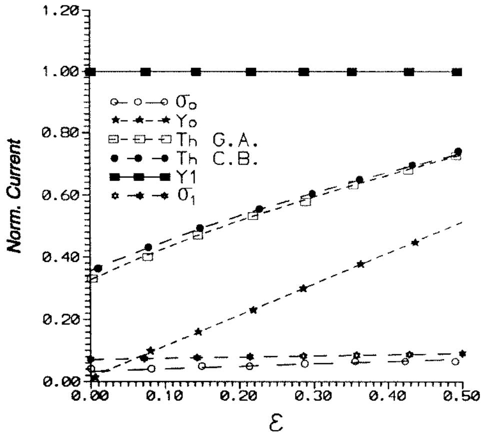

Fig. 2 - Normalised output current, optimum threshold and noise at sampling instant versus power extinction ratio ε.

density N_0=9.46x10^{-17} W/Hz. Parameter ε is varied from 0 to 0.5 keeping constant average power S=-29 dBm.

Output current for symbols "1" (Y1) and "0" (Y0) can be seen in Fig. 2 as well as optimum decision threshold-*Th* according to Gaussian approximation and Chernoff bound. σ0 and σ1 represent the total noise standard deviations for symbols "1" and "0" at the sampling instant. All results are normalized to the maximum output current.

As expected, the symbol conditioned average currents get closer as ε increases towards 0.5. Decision threshold estimates are quite near for both methods. Furthermore, the difference tends to decrease as ε increases. In this case, and for symbol "0", signal-dependent quantum noise dominates over spontaneous-spontaneous beat noise.

Looking at sensitivity results in Fig. 3, we conclude that significant performance degradation will arise for large extinction ratios. Although SPA method provides far more optimistic results, we observe approximately the same behaviour with ε for any method.

With the MCB method, the power penalty is found to be 7.1 dB, for an extinction ratio of 0.5.

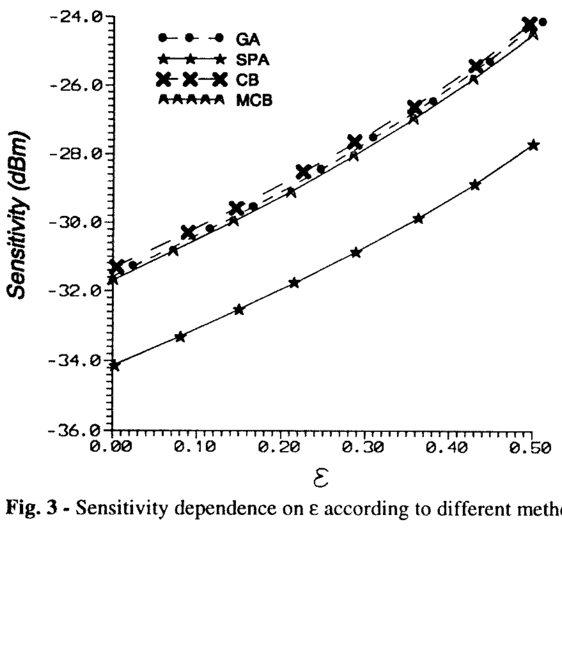

Fig. 3 - Sensitivity dependence on ε according to different methods.

IV. CONCLUSIONS

The power extinction ratio is a critical parameter in direct-detection communication systems. For high-speed operation, designers often choose to polarise the laser near/above threshold. If not sufficient energy is emitted for symbol "1", sensitivity degradation relative to a zero extinction-ratio system will become significant. With the new formulation, we have developed alternative analytical tools to quantify the expected degradation.

Future developments of the MGF formulation will include multiple cascaded amplifier repeaters and wavelength division multiplexing systems.

ACKNOWLEDGEMENT

This work has been supported by JNICT (Junta Nacional de Investigação Científica e Tecnológica) grant BD/619/IA.

REFERENCES

[1] S. Personick, "Applications for Quantum Amplifiers in Simple Digital Optical Communication Systems," *Bell Syst. Tech. J.*, vol.52, No.1, pp. 117-133, January 1973

[2] Y. Yamamoto, "Noise and Error Rate Performance of Semiconductor Laser Amplifiers in PCM-IM Optical Transmission Systems," *IEEE J. Quantum Electron.*, vol.QE-16, No.10, pp.1073-1081, October 1980

[3] J.R.F. da Rocha and J. O'Reilly, "Linear Direct-Detection Fiber-Optic Receiver Optimization in the presence of Intersymbol Interference," *IEEE Transactions on Communications*, vol. COM-34, No.4, pp.365-374, April 1986

[4] J.J. O'Reilly and J.R.F. da Rocha, "Improved Error Probability Evaluation Methods for Direct Detection Optical Communication Systems," *IEEE Transactions on Information Theory*, vol. IT-33, No.6, NOV/87, pp.839-848

[5] C.H. Helstrom, "Calculating Error Probabilities for Intersymbol and Cochannel Interference," *IEEE Transactions on Communications*, vol. COM-34, No.5, May 1986, pp.430-435

[6] R. Fyath, A. McDonald and J.J. O'Reilly, "Sensitivity and Power Penalty Considerations for Laser Preamplified Direct Detection Optical Receivers," *IEE proc. Part J*, vol.136, No.4, AUG/89, pp.238-248

[7] R. Fyath and J.J. O'Reilly, "Comprehensive Moment Generating Function Characterisation of Optically Preamplified Receivers," *IEE proc. Part J*, vol.137, No.6, DEC/90, pp.391-396

[8] L.F.B. Ribeiro, J.R.F. da Rocha and J.L. Pinto, "A New Statistical Formulation for Optically Preamplified Receivers," *BILCON'92 - Ankara-Turkey*, 27-28 July 1992, pp.109-115