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Optically preamplified receiver with low quantum limit

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An optically preamplified receiver configuration resulting in a very low quantum limit is presented.

**Introduction:**

Optical amplifiers are proven to efficiently enhance the receiver sensitivity of optical communication systems. In optical communications, it is common practice to compare the system’s ultimate sensitivity in terms of the quantum limit. The (standard) quantum limit is defined as the average number of photons per bit in the optical signal needed to achieve a bit error probability of \(10^{-9}\) assuming ideal detection conditions, which for a preamplified receiver means that a large amplifier gain is assumed. In this Letter we present an optically preamplified OOK/DD receiver scheme with a very low quantum limit, which is predicted to outperform previously studied configurations.

![Fig. 1 Optically preamplified OOK receiver](image)

**System model:** The schematic diagram of the studied receiver is illustrated in Fig. 1. The preamplifier is an EDFA (erbium-doped fibre amplifier) which is modelled as a linear optical field amplifier with gain \(G\) and AWG (additive white Gaussian) noise \(n(t)\) representing the ASE (amplified spontaneous emission) noise. The spectral parameter of \(n(t)\) is given by \(n_s = n_0(G - 1)\nu\), where \(n_0\) is the amplifier spontaneous emission factor, \(h\) is Planck’s constant, and \(\nu\) the optical frequency. An optical filter \(r(s)\) is used to limit the effect of ASE on the system performance, and in the case of WDM (wavelength division multiplexing) systems, to select the desired channel. The incoming signal is a binary sequence of rectangular pulses \(S(t)\). At the output of the filter \(r(t)\), the signal is denoted by \(Y(t)\) and the resultant coloured Gaussian noise by \(N(t)\).

The postdetection filter is assumed to be an integrate-and-dump filter. The integration interval \(T\) is chosen to be \([T - \Delta T/2, T + \Delta T/2]\). The parameter \(d\) is selected so as to yield the lowest bit-error probability.

**Performance analysis:**

For the performance analysis we need a complete statistical description of the receiver decision variable. The moment generating function (MGF) provides us with such statistical information. The MGF for the receiver decision variable \(Z\) is given by \(M_\Lambda(s) = M_\Lambda(e^{s-1})\), where \(\Lambda\) is the so-called Poisson parameter [1]. For an integrate-and-dump postdetection filter \(\Lambda = \frac{1}{2}\int \int \frac{Y(t) + N(t)}{dt} dt\). Based on the MGF for the decision variable \(Z\), error probabilities are expeditiously computed by the so-called saddlepoint approximation [2, 3].

The general mathematical form for the MGF of \(\Lambda\), \(M_\Lambda(s) = E(e^{s\Lambda})\), is well known, e.g. [2], and can be represented as

\[
M_\Lambda(s) = [D(s)]^{-1} \exp[F(s)]
\]

where \(F(s)\) and \(D(s)\) are found by solving the so-called Fredholm integral equations, e.g. [2, 4]. For the present case we have

\[
F(s) = s\int_{0}^{\infty} H_1(s) \left[ \int_{0}^{\infty} H_2(t) \right] \int_{0}^{\infty} H_3(t) dt
\]

with

\[
H_1(s) = \frac{8}{\beta \cos \beta} \left[ \sin x(2d - 4) + \sin \beta(4 - d^2/2 - 2d) \right]
\]

References

We have shown that if the optical filter is a finite-time integrator and the postdetection filter an integrator over a small interval centred around the end of each bit interval then a quantum limit of 16.2 photon/bit can be achieved. Although a finite-time integrator optical filter (corresponding to a filter with a sinc shaped transfer function) is probably difficult to realise, the presented receiver configuration outperforms previously studied schemes. An interesting question, open for study, is which value constitutes the ultimate theoretical lowest quantum limit for optically preamplified OOK/DD receivers.

References


OTDM applications of dispersion-imbalanced fibre loop mirror


Improvement of the signal quality from 10GHz directly-modulated sources and crosstalk suppression in an 80Gbit/s OTDM system are demonstrated for the first time by means of nonlinear switching in a dispersion-imbalanced fibre loop mirror (DILM).

The nonlinear transformation of optical pulses in fibre interferometers has long been of interest for the purposes of high-capacity data transmission. Recently, a novel approach has been applied to the generation of high-quality optical pulses from simple, directly-modulated sources in a compact fibre device based on self-switching in a dispersion-imbalanced fibre loop mirror (DILM) [1, 2]. High quality femtosecond and picosecond pulse generation has been demonstrated from an ordinary gain-switched laser diode, making it possible to faithfully retrieve the data even from an inadequately demultiplexed data stream. We demonstrate that while high capacity systems may be implemented using multiple high specification components [4–6], the DILM allows either a significant relaxation of the component specification, or alternatively, offers the potential for greatly increased capacity.