Invited Paper # I0107

The Potential of Return-to-Zero Coding in Optically Amplified Lasercom Systems

Walter R. Leeb, Peter J. Winzer, Martin Pauer

Introduction: Despite of more than two decades of intensive scientific and engineering efforts towards intersatellite laser communication systems, it is still microwaves that dominates this application. However, with an eye on interconnecting satellites of the Iridium system type, the prospects for lasercom have gained new grounds. For such an application the classic requirements like high receiver sensitivity, reliability, robustness, etc. are accompanied by the quest for high production yield and good production economy. As a consequence, the interest has moved towards systems and components which already find wide application in terrestrial fiber transmission /1,2/. In this respect, the use of semiconductor lasers at a wavelength of 1.5µm in combination with Erbium-doped optical amplifiers (EDFAs) suggests itself also for space links.

What modulation format would then be best? Our investigations show that with optically preamplified direct detection and on-off-keying, attractive receiver sensitivities comparable to that of heterodyne DPSK should be possible by employing return-to-zero coding (RZ) at the transmitter instead of the more conventional non-return-to-zero coding (NRZ). An improvement over NRZ can be obtained even if the receiver bandwidth is that of the NRZ system, provided that the average receive power remains constant. After presenting the system model we will recall our findings /3/ in terms of signal-to-noise ratio (SNR), then report on our latest numerical results of bit error probability (BEP), and lastly point out questions still to be addressed.

System outline: Figure 1 gives the block diagram of the system under consideration. The transmitt laser is modulated at data rate R in RZ-coded format with a low duty cycle (i.e. bit duration/pulse duration typically D=3). The EDFA booster amplifier operates average-power limited, i.e. the output pulse energy is independent of D. The receiver consists of an EDFA preamlifier, an optical band pass filter to reduce amplified spontaneous emission (ASE), and a photodiode followed by an electrical low pass amplifier (bandwidth B_e). After appropriate sampling, a decision circuit yields the data signal, whose BEP depends on the eye diagram and on the SNR at its input. To achieve high receiver sensitivity, the *signal-dependent* signal-ASE beat noise term should dominate all other (*signal-independent*) noise terms, such as the ASE-ASE beat, or electrical noise. (A scenario with dominating *signal-independent* noise would be a link with conventional direct detection without optical preamplification).

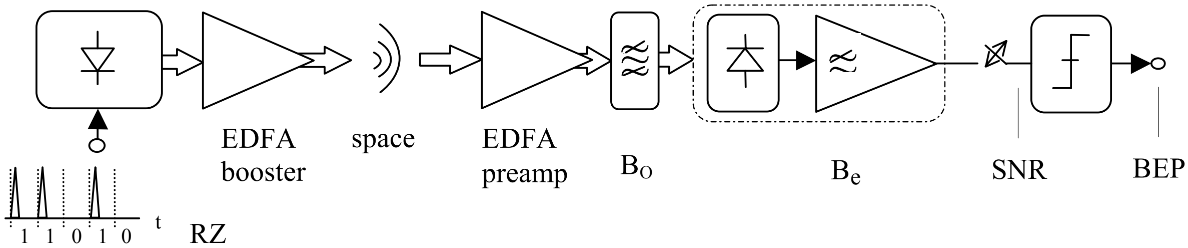

Figure 1: Lasercom transmission system

SNR as performance measure: In a previous paper /3/ we developed an analytical method to calculate the SNR for RZ-coded signals (The special case of RZ coding with a duty cycle of D=1 can be understood as NRZ coding; this is mathematically correct, e.g., for $\cos^2$-like or rectangular pulse shapes). The exact values of sensitivity gain depend on the - pattern dependent - effect of intersymbol interference (ISI). As expected, the influence of ISI becomes smaller with increasing B_e. The analysis yields limits for negligible and for worst case ISI. Here we cite typical results for dominating *signal-dependent* noise. For D=1, SNR turns out to be maximum for a normalized receiver bandwidth of $b_e = B_e/R \approx 0.6$, as could be expected. At D=2 and *the same* b_e, SNR and thus also the receiver sensitivity increases by some 2.7 dB. Further increasing D will yield only minor additional gain.

The SNR calculations thus indicated that RZ coding may result in appreciable sensitivity enhancement with respect to NRZ, even if the receiver bandwidth is not increased beyond its optimum for NRZ reception. With duty cycles as low as D≈3, the preamplified optical receiver could offer the same sensitivity as a transmission system employing heterodyne DPSK!

BEP as performance measure: For the digital transmission system considered, it is not SNR but BEP that eventually characterizes transmission quality. Especially if ISI has a non-negligible influence on BEP, BEP itself can - in general - not be deduced reliably from SNR. To investigate BEP in case of RZ coding we developed a software tool based on a quasi-analytical simulation /4/. It allows to specify the form, the energy, and the duty cycle (D) of the optical input pulse, the impulse response of the opto-electronic detection chain, including the data filter (and thus B_e), and the amount of signal-independent noise. For each case dealt with, the sampling instant within the bit period and the decision threshold are automatically determined so as to obtain the smallest possible BEP.

Figure 2 gives representative results for BEP as a function of optical input power, expressed in photons per mark. The relative receiver bandwidth was kept constant at b_e = 0.6 for all duty cycles D. For dominating *signal-independent* noise (cf. Fig.2a), RZ with D=3 yields a sensitivity improvement of some 2.6dB, compared to NRZ. A further reduction of pulse length is not effective, because for D≈3 the RZ pulse spectrum already completely fills the receiver spectrum; it is then the impulse response of the receive filter only, which determines the signal shape at the decision circuit. For dominating *signal-dependent* noise (Fig.2b) the sensitivity improvement is exhausted for D≥2. The sensitivity gain is *larger* than that of signal-independent noise, and also larger than predicted by our SNR-based analysis. It amounts to some 4dB. For the mixed case that neither noise term can be neglected, the BEP curves show a similar characteristic as for the *signal-independent* case, even if the portion of *signal-dependent* noise is considerable.

Conclusions and perspectives: Our investigations clearly show a sensitivity gain for low-duty-cycle RZ coding, even if the receiver bandwidth is not increased compared to that employed for NRZ signals. This improvement presupposes constant energy per pulse, i.e. that the transmitter - and hence any optical booster amplifier - is not limited by peak power but by average power. So far we have not included the influence of the exact shape of the optical filter. Also, for much higher data rates than assumed in our examples, the relation B_0>>B_e, as dictated by todays technology, will no longer hold and the NRZ scheme could fare relatively better. It remains to show, how large a gain will then be obtainable.

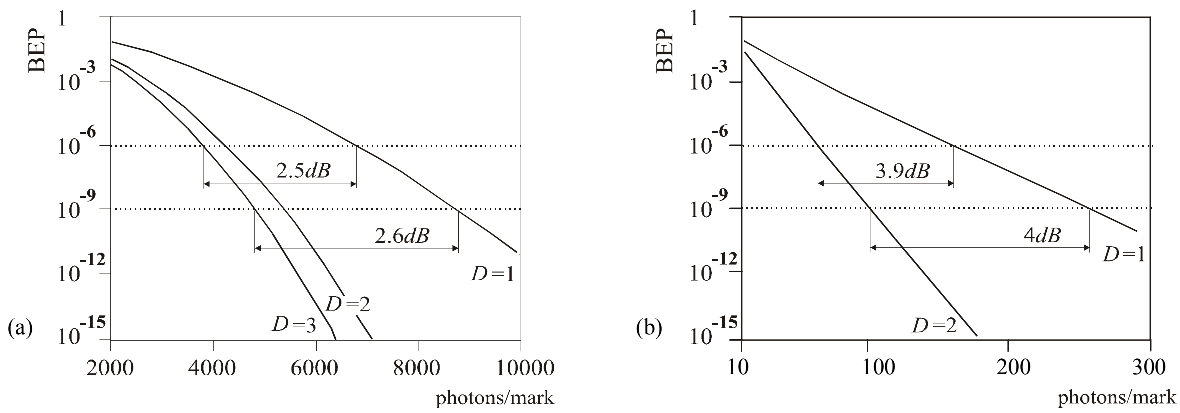

Figure 2: BEP as a function of number of received photons/mark for various duty cycles D (D=1 corresponds to NRZ). (λ=1.55µm, data rate R= 2.5 Gbit/s, infinite extinction ratio)

a) dominating signal-independent noise (no optical preamplifier, equivalent noise density= 6pA/√Hz)

b) dominating signal-dependent noise (optical preamplifier - cf. Fig.1, EDFA noise figure= 4dB)

References

/1/ S. Tanikoshi, K, Ide, T. Onodera, Y. Arimoto, and K. Araki, *High sensitivity 10 Gb/s optical receiver for space communications*, Proc. 17th AIAA Int. Commun. Satellite Syst. Conf., 178-183 (1998).

/2/ P. Winzer and A. Kalmar, Impulsive coding in optical free-space links: *Optimum choice of the receive filter and impact of transmitter booster amplifier*, Proc. SPIE, 3615, (1999).

/3/ P. Winzer and A. Kalmar, *Sensitivity enhancement of optical receivers by impulsive coding*, *J. Lightwave Technol.,* **8**, 171-177, (1999).

/4/ M. Pauer, P. Winzer, and A. Kalmar, *Bit error probability simulation for RZ-coded free space laser links*, this Conference Proceedings.