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RZ-DPSK Optical Modulation For Free Space Optical Communication by Satellites

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Abstract— **We demonstrate up to 4 dB improvement in optical receiver sensitivity using Return-to-Zero Differential Phase Shift Keying (RZ-DPSK) modulation compared with Non-Return-to-Zero On Off Keying (NRZ-OOK) in free space optical communication from satellite to ground at 40 Gbit/s data rate. This has been assessed using simulation software. An experiment is taking place to validate this result for 10 Gbit/s.**

Keywords-component : Free space optical communication, Optical Transmitters, OOK, DPSK, NRZ, RZ, PRBS, pulse carver.

I. INTRODUCTION

Optical communication links between satellites and ground stations undergo perturbations due to the propagation of the laser beam through the atmosphere. Although studies and experiments have demonstrated the feasibility of such optical links [1], research is still needed to identify technical solutions adapted to the specific constraints imposed to these high-speed links (up to 1 Tb/s for telecom applications) to ensure the required level of performance. Proposals for flight demonstrations in the 2020 horizon begin to be considered [2]. While radiofrequency transmissions need a breakthrough to solve the bandwidth saturation, optical technologies need to be further developed in order to exploit its wide bandwidth. Optical community knows that all-optical signal regeneration is one of the desired functionalities to increase the transmission performance and data rate in optical communication link. One of optical communication advantages is high bit rate using wavelength division multiplexing (WDM) and typically, wavelengths multiplexed are around 1550 nm.

In this paper, we demonstrate up to 4 dB gain of receiver sensitivity using 50 % RZ-DPSK communication compared with NRZ-OOK modulation at 40Gbps data rate. RZ-DPSK modulation scheme exhibits a sensitivity improvement compared to NRZ-OOK and NRZ-DPSK. It has been verified using simulation software and an experimentation is about to take place to validate this result at 10 Gbit/s.

II. CONTEXT AND MOTIVATION

For the radio frequency communication through the atmosphere, several constraints and limitations remain unsolved as the saturation radio frequency bandwidth or low information transmitted rate during the communication.

The principal aim of this study is to consolidate optical communication architectures using different modulation formats including duty cycles to increase data rate. Recently, demonstrations have proven the feasibility of optical communication at low bit rate : 622 Mbit/s using 4-pulse position modulation (4-PPM) between Optical Ground Station OGS and NASA's Lunar Atmospheric and Dust Environmental Explorer (LADEE) [3] or 10 Mbit/s using OOK modulation between a Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO) [4].

The consultative committee for space data systems (CCSDS) defined recommendations for data systems standards to use on free space optical communication. All modulation formats studied in this paper are potential options to be considered in a standard [5].

The design of a free space communication link must consider all relevant effects in a quantitative manner and establish a link budget which incorporates all relevant contributing factors, in order to reliably predict the performance of the space link [4]. In addition, the 4.4 dB sensitivity improvement could relax the budget link and enable to reduce the transmitted power required on board.

III. OPTICAL COMMUNICATION ARCHITECTURES SIMULATED

For all our transmitters, data used is a pseudo random binary sequence (PRBS) of length 2^{30}-1. The Mach Zehnder modulator (MZM) transfers this electrical signal containing data on an optical carrier with a continue wavelength to produce a modulated optical signal.

To simulate the propagation channel, we used firstly a linear variable attenuator to assess the impact of different parameters on the optical communication chain performance and in particular the sensitivity (through the BER performance). In the future simulations, the architecture will be upgraded with the integration of more realistic atmospheric turbulence emulator which will be integrated in theses architectures.

A. OOK link

An OOK transmitter made up with an intensity modulator driven by the electrical data signal. This link is known as an intensity modulation with direct detection (IMDD) and the receiver includes a pre-amplification section based on an Erbium Doped Fiber Amplifier (EDFA) as shown in fig.1:

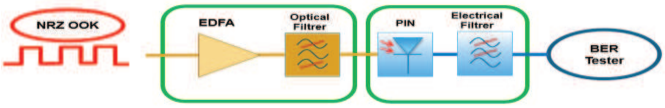

Figure 1. Pre-amplified optical receiver

B. DPSK link

After generating the PRBS sequence and due to the absence of an optical phase reference, a differential encoder is used to provide a DPSK waveform: the operation principle is that the phase reference has to be provided by the signal itself (each bit acts as a phase reference for another bit).

The receiver used to decode a DPSK modulation contains an optical delay line interferometer (DI) and a balanced photo receiver. The scheme of the receiver used is shown in Fig.2:

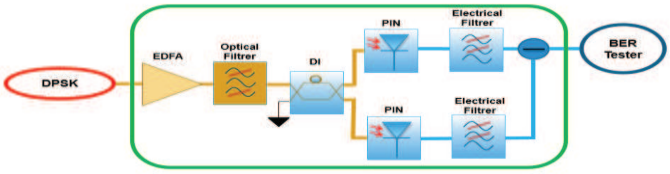

Figure 2. Structure of a DPSK optical receiver

C. RZ-DPSK link

The primary advantage of RZ pulses is the higher peak power on time duration less than bit time with the stronger confinement of pulses. Similarly to the DPSK transmitter, the RZ-DPSK transmitter needs to change optical pulses from NRZ pulses to RZ pulses. This transformation is obtained by inserting a second MZM modulator named 'pulse carver' after DPSK optical modulation signal [6]. The receiver remains the same as DPSK link based on a delay line interferometer and a balanced photodetector.

IV. BIT-ERROR-RATE CURVES

Before getting interested to the sensitivity of each modulation, we investigate the dependence of receiver sensitivity to the optical receiver bandwidth in order to optimize the receiver performances. Fig.3 shows the sensitivity variation as a function of the optical bandwidth for NRZ-OOK, DPSK, 33% RZ-DPSK and 50% RZ-DPSK modulation formats for R = 10 Gbit/s bit rate.

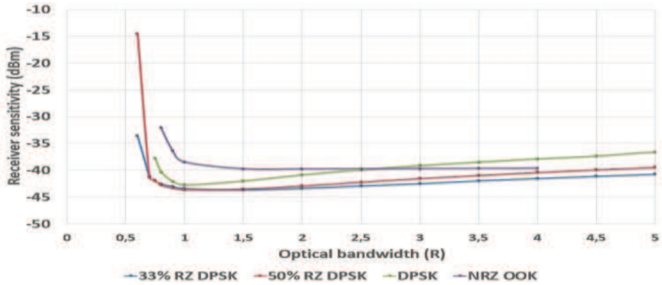

Figure 3. BER evolution as a function of optical bandwidth for NRZ OOK, DPSK, 33% RZ-DPSK and 50 % RZ-DPSK at 10 Gbit/s.

Fig.4 shows the results of BER for 40 Gbit/s as a function of the average received power (measured at the input of the pre-amplified receiver) for the three communication links detailed before.

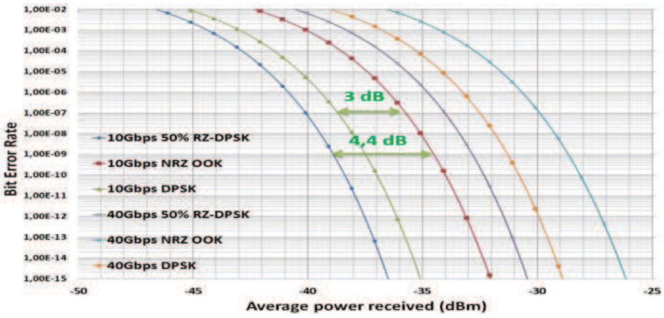

Figure 4. BER evolution as a function of average power received for NRZ OOK, DPSK and 50 % RZ-DPSK at 10 Gbit/s and 40 Gbit/s

V. DISCUSSION

We remark that optical receiver sensitivity at a fixed bit error rate using 50 % RZ-DPSK modulation is the best compared with DPSK and NRZ-OOK modulations. At 10^{-9} BER, the sensitivity improvement from NRZ-OOK to DPSK is equal to 3 dB, and increases up to 4.4 dB from NRZ-OOK to 50 % RZ-DPSK.

VI. CONCLUSION

The 50 % RZ-DPSK format proves to perform better than DPSK and NRZ-OOK formats, partially due to inter-symbol interference reduction when RZ pulses are used. An optical transmission laboratory set-up supporting the three modulation formats is under development to assess these options experimentally and transmission experiments will be carried out, thus allowing to compare simulated and measured performance. These results and comparisons will be presented during the conference.

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