40 Gb/s optical transmission systems

This thesis investigates state of the art components and subsystems to be used in the next generation of high speed optical transmission systems at 40 Gb/s. The thesis will provide guidelines for the design and implementation of 40 Gb/s systems, investigating topics that could limit transmission: chromatic dispersion, Polarization Mode Dispersion (PMD), Self Phase Modulation (SPM) and linear or non-linear crosstalk among others. Regarding chromatic dispersion, sufficient evidence is presented for the need in 40 Gb/s systems of either modulation formats that allow for higher tolerance than the traditional Non Return to Zero (NRZ) or use of Tunable chromatic Dispersion Compensators (TDC). Two single channel TDCs are experimentally evaluated. The first one, based on temperature changes in a chirped fiber Bragg grating, allows to reduce significantly chromatic dispersion induced penalty in a series of different standard Single Mode Fiber (SMF) spans ranging from 21.5 km to 41 km. The second one, based on the controlled stretching of a nonlinearly chirped fiber Bragg grating, allows for unrepeated transmission in standard-SMF spans ranging from 45 km to 103 km minimizing chromatic dispersion induced penalty. An optical duobinary transmitter (Tx) is implemented and its increased tolerance to chromatic dispersion is verified in a direct comparison to an NRZ transmitter. The limitations induced by PMD in 40 Gb/s system design are investigated. It is found that even for a standardized Short haul application (maximum distance of 40 km) the maximum PMD coefficient allowed in the transmission fiber, 0.4 ps/\(\text{pkm}\), is below the values defined by actual standards, 0.5 ps/\(\text{pkm}\). The most promising PMD compensation methods are presented and their advantages and disadvantages are discussed. A PMD compensator based on a single fixed birefringent element is evaluated at 10 Gb/s and 40 Gb/s. It provides an improvement of at least a factor of two in the total PMD allowed in a link. However even when using the PMD compensator it is estimated that the maximum PMD coefficient in the fibers used in a five span link with 80 km per span is 0.25 ps/\(\text{pkm}\), still below the maximum value allowed by standards. Return to Zero (RZ) and Carrier Suppressed RZ (CSRZ) modulation formats are found to provide a significant advantage in multi-span transmission compared to the traditional NRZ or the optical duobinary modulation formats. Using a 9 ps pulsed RZ Tx, transmission is achieved over a 400 km link consisting of 5 spans of 80 km standard-SMF with a Quality (Q) factor of 17.7 dB, while for NRZ it is reduced to 15 dB. In another experimental verification over 40 km spans of standard-SMF, we could achieve transmission over 6 spans for the aforementioned RZ Tx with a Q of 18 dB, while for NRZ, transmission over 4 spans provides a Q of 17.5 dB. A simple analytical approach separating the limitations induced by Optical Signal to Noise Ratio (OSNR) and SPM in multi-span transmission is presented and verified in the comparison of NRZ and RZ for transmission over standard-SMF with 40 km span length. The performance of NRZ, RZ, optical duobinary and CSRZ modulation formats in a 100 GHz channel spaced 40 Gb/s WDM system regarding linear crosstalk is investigated by means of simulations. It is found that RZ is seriously limited in 100 GHz channel spaced systems while NRZ and CSRZ provide enough tolerances to allow for practical system implementation. The optical duobinary format provides the best performance indicating the possibility of even narrower channel spaced systems using this modulation format. Three Wavelength Division Multiplexing (WDM) experimental demonstrations are presented. The first one is a 100 GHz spaced 16 channel WDM system, using 40 Gb/s NRZ modulation over a 200 km link of standard-SMF. The second one is a 100 GHz spaced 32 channel 40 Gb/s WDM system, using CSRZ modulation over a 400 km link of standard-SMF and using Raman amplification. The third one is a 100 GHz spaced 6 channel WDM system, using NRZ as the modulation format, Semiconductor Optical Amplifiers (SOA) as the in-line amplifiers and in transmission over a 160 km link with span distances of 40 km standard-SMF, traditional target distance of metro WDM systems. Possible practical implementation of 40 Gb/s single channel and WDM systems are proposed and described following the methodology used by international standardization bodies.