











Q-factor penalty was obtained. Simulations were also conducted, where 3rd order Butterworth low pass filters with 25 GHz cutoff frequency were used to mimic the bandwidth limitation of the transmitter and the laser phase noise was modeled as a Wiener process. As expected, in Fig. 7(a) the Q-factor penalty scales with the baud rate, which is proportional to the accumulated CD during the transmission. For the experimental results, the Q-factor penalty was 0.9, 1.2, 1.9 and 2.2 dB for 22, 28, 44 and 56 Gbaud DP-QPSK systems, respectively, which matches the simulation results with a deviation less than 0.17 dB. In Fig. 7(b), four DFB lasers with different estimated linewidths were used as the LO in the 56 Gbaud experiment. The penalty was only 0.2 dB for a 300 kHz linewidth DFB laser. With linewidth larger than 1 MHz, the performance degradation starts to be non-negligible ( $> 0.5$  dB). Again, our simulations almost match the experimental results.

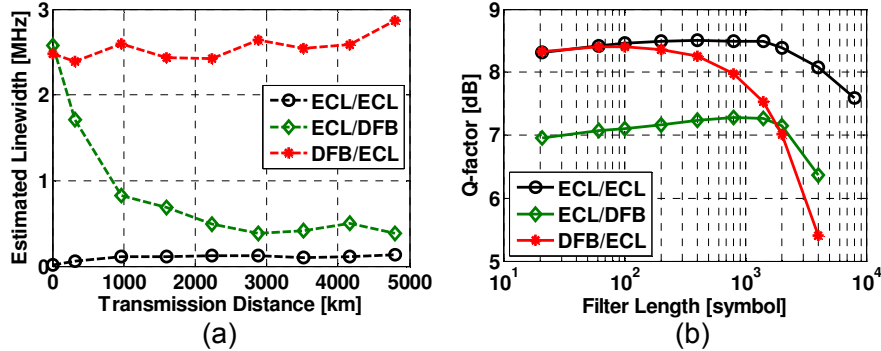


Fig. 6. (a) Estimated linewidth versus transmission distance and (b) Q-factor versus CPR filter length at 4160 km distance with different lasers at the two ends.

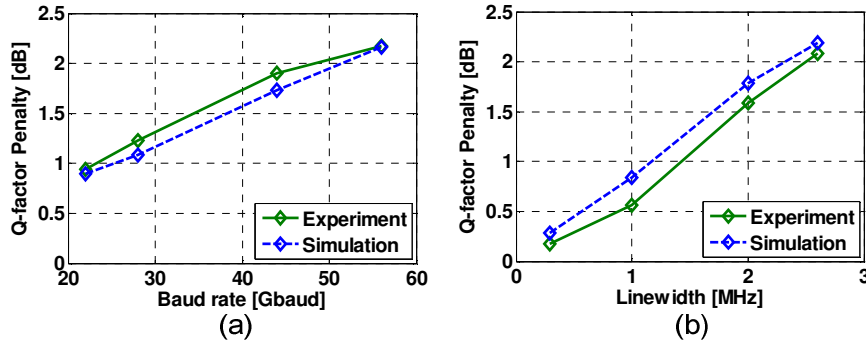


Fig. 7. Q-factor penalty of an ECL/DFB system (with respect to ECL/ECL) at 4160 km distance versus: (a) the baud rate and (b) the LO laser linewidth.

## 5. Summary

In this paper, we investigated the equalization-enhanced phase noise (EPPN) for 56 Gbaud dual-polarization (DP) QPSK long haul systems. We first illustrated the two effects of EPPN: 1) additional noise added to the symbols; 2) reduction of the symbol phase variance due to the chromatic dispersion (CD)-induced correlation of symbols. We then experimentally demonstrated that using a distributed feedback (DFB) laser with a 2.6 MHz linewidth as the local oscillator (LO) reduces the transmission distance from 4160 km to 2640 km compared to the system using a  $\sim 100$  kHz external cavity laser (ECL) as the LO. When the DFB laser was employed as the LO, we showed the reduction of the symbol phase variance for larger transmission distances, and we illustrated its impact on the carrier phase recovery algorithm. Finally, we experimentally demonstrated that the EPPN-induced penalty scales with the signal baud rate and LO laser linewidth, and confirmed our results by simulations.