# Investigation of Nonlinear Effects in 100 Gbit/s Optical 16QAM Transmission Systems

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**Abstract:** In this paper, we investigate the BER performance of optical 16QAM transmission systems using polarization multiplexed pilot-carrier technology at 100Gbits/s per channel in the presence of fibre nonlinearity.

## 1 Introduction.

Quadrature amplitude modulation and coherent detection are currently seen as key technologies to increase the spectral efficiency of optical transmission and to overcome the future capacity limitations of the currently installed fibre infrastructure. Current approaches to demodulating optical QAM signals are mainly based on optical heterodyne detection using high-speed DSP. However, in order to achieve a BER of $10^{-4}$, the linewidth limit for a 40Gbits/s 16QAM heterodyne detection system is 1kHz [1].

To overcome the problem of high reliance on lasers with narrow line-width and to simplify the demodulation scheme, self-coherent optical transmission system using polarization-multiplexed pilot-carrier has been developed [2]. Such systems may be required to operate over installed standard single-mode fibre. However, in cascaded amplifier systems, nonlinear effects appear as the result of long transmission distances even if the amplifier output power is not high. In particular, XPM may influence the error rate performance, when phase-sensitive signal formats are employed. Also the receiver sensitivity may be degraded due to FWM [3].In this paper, we report the impact of fibre nonlinearity in 100Gbits/s 16QAM WDM systems with laser linewidths up to 10MHz. The simulations were performed using the Split-Step Fourier algorithm carried out with Optism 4.0 software.

## 2. System Configuration.

Fig.1 shows the system configuration of the 16QAM transmission systems investigated. The laser source is split into two orthogonal linear polarized beams of the same phase and the same power by a polarization beam spitter. One of the orthogonal polarized beams passes through a QAM modulator which is driven by two sets of NRZ four-level electrical 25Gsymbol/s 16-QAM signals. The 16-QAM patterns for Data-I and Data-Q were generated from two sets of random bit sequences. The other orthogonal polarized beam is used as the pilot carrier. Then, the modulated optical signal and orthogonal polarized pilot carrier are combined and passed though the fibre link.The fibre link contains 50km standard single mode fibre of approximately 16 ps/nm.km dispersion with in-line compensation achieved by 10km Dispersion Compensating Fibre of -80 ps/nm.km dispersion. The nonlinear coefficient for each fibre was 1.3 $W^{-1}$ $km^{-1}$ and 5.1 $W^{-1}$ $km^{-1}$ respectively, and the PMD is $0.1ps/km^{1/2}$. Between each fibre, we employ a fixed output power EDFA with optimized launch power of 0.4mW (for single channel, 1.5mW for 8WDM, and 4.5mW for 16WDM).

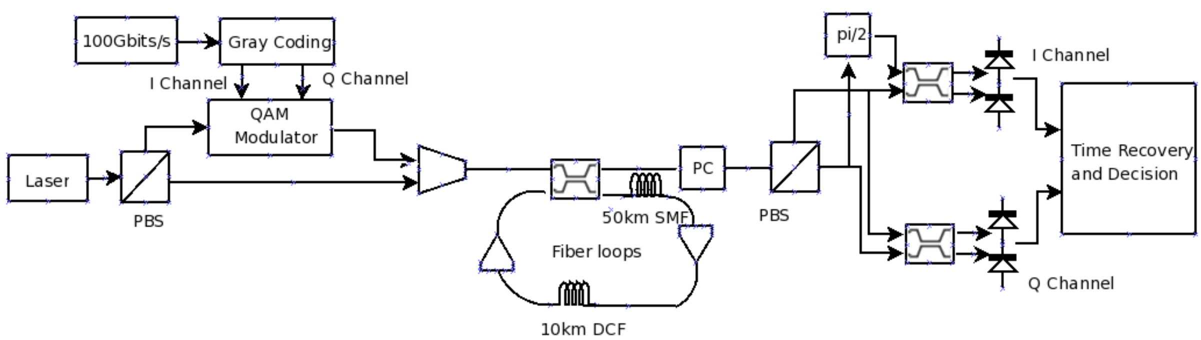


Fig.1 Experimental setup of the single channel 16QAM system with 60-km fibre per span.

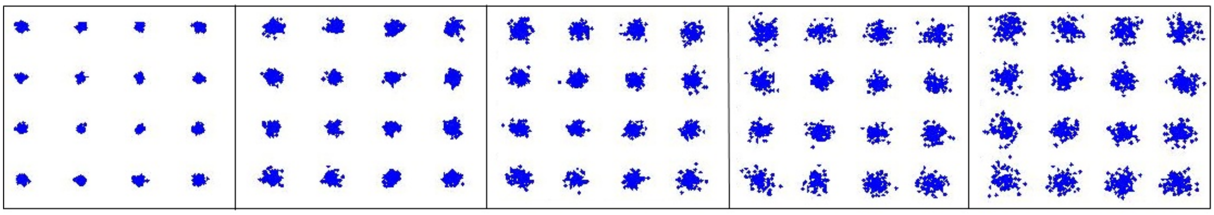


Fig. 2. Constellation of the received 100Gbit/s 16-QAM signals with 60km (a), 180km (b), 300km (c) , 420km (d), and 540km single channel transmission (e).

The receiver contains a polarisation controller, polarisation beam splitter (PBS), and an optical homodyne demodulator. The polarisation controller allows the relative polarisation states of the signal to be adjusted. The PBS splits the signal into two orthogonal linear polarized beams which are 16QAM modulated optical signal and the pilot carrier(the polarization state is rotated by 90 degree before coupling to the optical signal). According to[4], the I-arm signal is given by:

$$I_I = \frac{\eta e}{2h\upsilon}\sqrt{P_S P_L}\cos(\phi_L - \phi_S) \qquad \text{Eq. 1}$$

and the Q-arm signal is given by:

$$I_Q = \frac{\eta e}{2h\upsilon}\sqrt{P_S P_L}\sin(\phi_L - \phi_S) \qquad \text{Eq.2}$$

The I-arm and the Q-arm signals are then processed off line with Matlab. Fig.2 shows the constellation diagrams of the demodulated 16QAM signals following transmission through 1 to 9 fibre spans. The channel spacing of the WDM systems investigated is 100GHz and all the channels are co-polarised.

## 3. Results.

To investigate the system performance relating to laser linewidth and nonlinear effect, the bit error ratios were calculated based on the sum of the BER on each signal point using Gaussian distribution. This allows to measure the total BER when noise is varying on different signal points in the constellations, which can be observed in Fig.2. We believe the noise variance is caused by ASE noise as well as fibre nonlinearities.

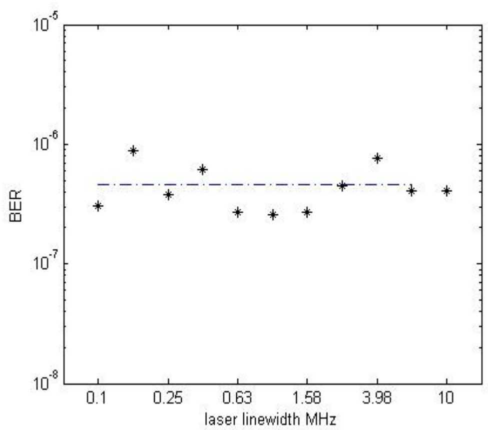


Fig.3 BER vs. Laser Linewidth (single channel)

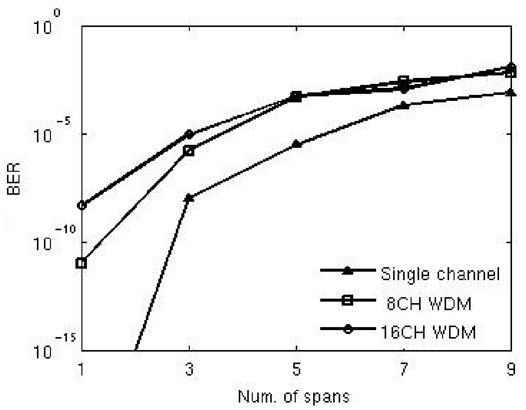


Fig.4 BER vs Number of spans at optimized launch power

Fig. 3 shows the relations between system performance and the laser linewidth in single channel 16QAM transmission systems. The result was obtained at the launch power of 0.4mW and fibre length of 5×60km. As expected, a laser linewidth independent characteristic is achieved by employing the polarisation multiplexed carrier. BER performance is around $10^{-6}$ in the linewidth region between 0.1MHZ and 10MHz without significant variation.

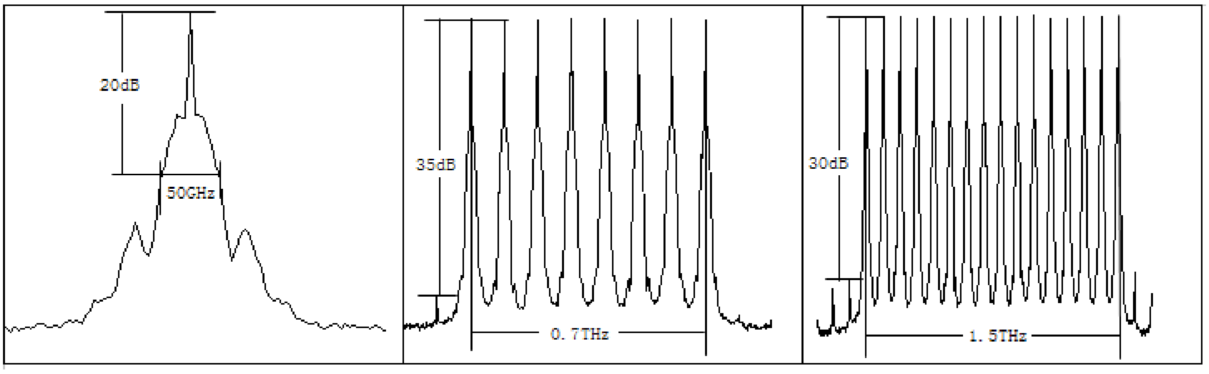


Fig.5 Spectrum of single channel(left), 8 channels WDM (center)and 16 channel WDM(right) with launch powers of 0.4mW for single channel, 1.5mW for 8 channels and 4.5mW for 16 channels.

The impact of nonlinearities are quantified by comparing BER performances of single channel and 8/16 channel WDM systems. Fig. 4 shows approximate two orders of magnitude degradation in BER when multi-channel system is implemented for 180km transmission. The main sources of the performance degradation are XPM induced timing jitter and FWM induced amplitude distortion. The out-of-band noise due to FWM effects can be observed in Fig. 5 as well. The result also shows that BER performance of 8 channel WDM system is about 100 times and 10 times better than those for the16 channel system with fibre length of 60km and 120km respectively. A BER of $10^{-3}$ can be achieved by 8/16 Channel WDM systems at approximately 300km fibre length.

## 4. Conclusions.

We numerically demonstrated 100Gbits/s 16QAM single channel and 8/16 channel WDM fibre transmission systems using pilot-carrier based linewidth tolerant self-homodyne demodulation scheme. To investigate the nonlinear effect in multi-channel systems, we measured the BER degradation of 8/16 channel WDM systems. A BER of $10^{-3}$ can be achieve by 8/16 channel WDM transmission for 300km and error free transmission( $BER<10^{-9}$) can be achieved with a single channel for 120km. The laser linewidth independent characteristic of this optical 16QAM transmission system was also confirmed by simulation.

## Acknowledgements

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## References.

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