Coded OFDM in Fiber-Optics Communication Systems With Optimum biasing of Laser

Er. Kamaljit Singh Bhatia *kamal_er@rediffmail.com*
Dept. of ECE,
Rayat-Bahra Institute of Engineering & Nano-Technology,
Hoshiarpur (Pb.) India

Dr. R. S. Kaler *rskaler@yahoo.com*
Dept. of ECE, Thapar University,
Patiala-147004, (Pb.) India

Dr. T.S.Kamal *tskamal@yahoo.com*
Dept. of Electronics and Communication Engineering,
DIET, Kharar, (Pb.) India

Dr. Rajneesh Kaler *rajneesh@yahoo.com*
Dept. of Computer Science and Engineering,
RBIET, Patiala

Abstract

A novel high spectral efficiency all-optical sampling orthogonal frequency-division multiplexing scheme is proposed using space frequency Block coding (SFBC) techniques and nonlinear behavior of vertical-cavity surface-emitting laser diodes is exploited by relative intensity to noise (RIN).We show that in long-haul fiber optics communications, SFBC-coded OFDM increases spectral efficiency and reduces the influence of chromatic dispersion in optical-OFDM system if RIN is adjusted to -155 dB/Hz

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Relative Intensity to Noise Ratio (RIN), Space Time Block Coding (STBC).

1. INTRODUCTION

Space-time block coded orthogonal frequency-division multiplexing (STBC-OFDM) schemes have garnered much attention as a simple transmit diversity technique in combating frequency selective fading channels [1], [2]. Although STBC-OFDM using Alamouti code can improve the performance of OFDM, its second-order diversity gain is still insufficient for communication requiring high reliability over fading channels. Thus, recent works have considered STBCOFDM schemes aimed at achieving fourth-order diversity gain [3], [4].STBC-OFDM using *G*4 code with 1/2 rate and *H*4 code with 3/4 rate are the conventional schemes being employed to provide fourth-order diversity gain [5]–[7]. However, problems arise when the conventional schemes described in [6] and [7] are used in spatially transmit correlated fading channels. These conventional schemes have been designed without taking spatial transmit correlation in consideration, although it occurs in many practical applications. The spatial transmit correlation causes a deficiency of randomness and independence in channel [8], [9]. Therefore, increasing the spatial transmit correlation results in bit-error-probability (BEP) performance degradation for STBC-OFDM schemes targeting a fourth-order diversity gain [10].Space-frequency coded OFDM (SFC-OFDM) schemes have been proposed to exploit both spatial and frequency diversity [11]–[13]. The authors of [12] proposed a type of SFC-OFDM without permutation from a simple mapping process using STBC. As with STBC-OFDM schemes, however, the SFC-OFDM design described in [12] fails to consider spatial transmit correlation, so that it suffers from spatially correlated channels. By precoding the incoming information symbol across OFDM subcarriers, the SFC-OFDM with permutation proposed in [13] attains both full transmission rate and frequency diversity over independent channels. However, exploiting the frequency diversity with this approach also limits the BEP performance in spatially correlated channels and requires high decoding complexity. This is because the SFC-OFDM described in [13] uses the precoding method instead of STBC for the full transmission rate. Therefore, a new STBC-based scheme using frequency diversity that can improve the performance in spatially correlated channels is still needed. Later on STBC-based transmit diversity scheme using frequency diversity was introduced that is more robust against spatial correlation than the STBC-OFDM schemes and the SFC-OFDM schemes, and which achieves fourth-order diversity gain. From the upper bound of BEP performance over spatially transmit-correlated channels, it was shown that performance can be improved by increasing the determinant of the channel correlation matrix. In order to exploit both frequency and spatial diversity and thereby increase the determinant, attempt was made to design an STBC-based transmit diversity scheme. The merged determinant condition for robustness is derived from detailed analysis of the determinant.

In this paper, the proper biasing conditions of Laser are proposed for 1Tx-1Rx, coded Optical-OFDM system that yields better BEP performance than the STBC-OFDM schemes and the SFCOFDM schemes. We have carried out the simulative analysis for averaging out the optimal value of RIN for better performance in high bit rate coded optical-OFDM direct transmission link. The impact of linewidth and its limiting value is investigated for optimal performance.

2. THEORY

The output of semiconductor laser exhibit fluctuations in its intensity, phase and frequency even when the laser is biased at constant current with negligible current fluctuations. The two fundamental noise mechanisms are spontaneous emission and electron hole recombination. Noise in semiconductor lasers is dominated by spontaneous emission. Each spontaneously emitted photon adds a small field component to the coherent field (established by stimulation emission), which is random in nature and thus perturbs the both amplitude and phase in a random manner. The occurrence rate of such a spontaneously emitted random field is about 10^{12} s^{-1}. Because of which intensity and phase of emitted light exhibit fluctuations over a time scale as short as 100ps. Intensity fluctuations lead to the limited signal to noise ratio (SNR) where as phase fluctuations leads to the finite spectral linewidth when semiconductor lasers are operated at constant current. Clearly such fluctuations lead to the degradation of system performance, therefore it is important to estimate their magnitude. Amplitude fluctuations are characterized by a factor called as Relative Intensity to Noise ratio (RIN).

3. SYSTEM DESCRIPTION

The transmitter and receiver configurations of an Optical-OFDM system with direct detection and the system set up for optical-OFDM system are shown in Figures 1a–c, respectively. On the transmitter side, the information-bearing streams at 10 Gb/s are encoded using identical SFBC codes. The outputs of these SFBC encoders are demultiplexed and parsed into groups of B bits corresponding to one OFDM frame. The B bits in each OFDM frame are subdivided into K subchannels with the ith subcarrier carrying b_i bits.The bi bits from the i_{th} subchannel are mapped into a complex-valued signal from a $2b_i$-point signal constellation such as M-ary QAM and M-ary PSK. For example, b_i = 2 for QPSK and bi = 4 for 16-QAM. The complex-valued signal points from sub channels are considered to be the values of the FFT of a multi carrier OFDM signal. By selecting the number of sub channels K sufficiently large, the OFDM symbol interval can be made significantly larger than the dispersed pulse width of an equivalent single-carrier system, resulting in ISI reduction.

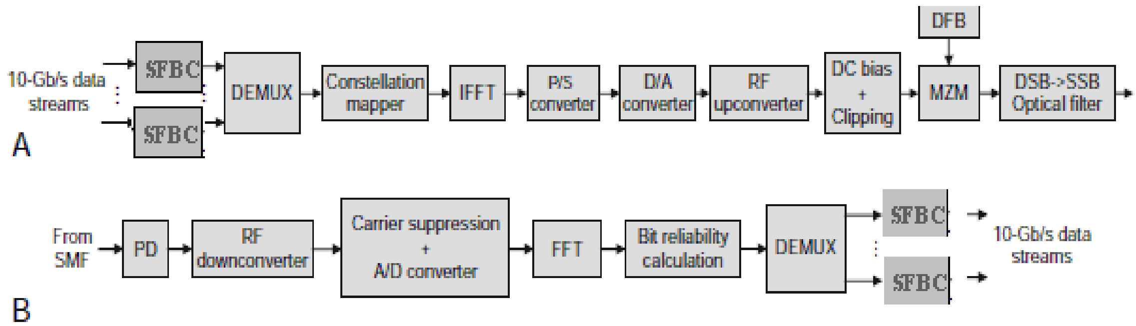


FIGURE 1: (a) Transmitter configuration **(b)** receiver configuration

The simulation set-up for optical-OFDM system is shown in **Figure 1c**.

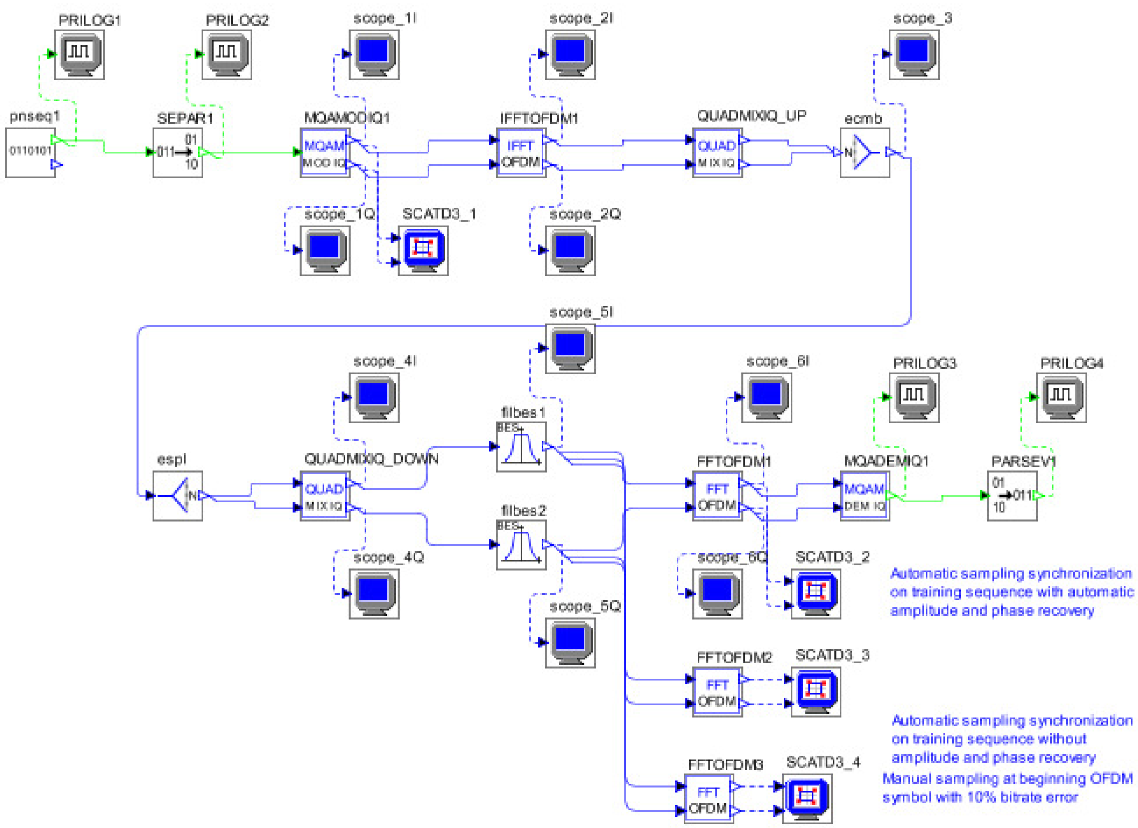


FIGURE 1: (c) system setup for Direct detection Optical-OFDM sytem

N_G nonzero samples are inserted to create the guard interval, and the OFDM symbol is multiplied by the window function. The purpose of cyclic extension is to preserve the orthogonally among subcarriers even when the neighboring OFDM symbols partially overlap due to dispersion, and the role of windowing is to reduce the out-of-band spectrum. For efficient chromatic dispersion and PMD compensation, the length of the cyclically extended guard interval should be longer than the delay spread due to chromatic dispersion and PMD. After D/A conversion and RF up-conversion, the RF signal can be mapped to the optical domain using one of two options: (1) The OFDM signal can directly modulate a DFB laser, or (2) the OFDM signal can be used as the RF input of a Mach–Zehnder modulator (MZM). A DC bias component is added to the OFDM signal to enable recovery of the incoherent QAM symbols.

4. PERFORMANCE ASSESSMENT OF CODED OFDM FIBER-OPTICS COMMUNICATIONS

A pseudo random sequence length of bits taken one bit per symbol is used to obtain realistic output values at the receiver. Firstly, to observe the impact of RIN upon system performance, simulation results are obtained for linewidth. It is investigated that it causes a sudden fall in optical power with gradual increase in the linewidth for the pulse. It was observed that increase in linewidth causes degradation of system performance as BER, timing jitter and Q values degraded drastically. Output electric power correlated with linewidth and results are shown in Figure 2. The output electrical power remains almost constant up to linewidth value of 6-7MHz but as the linewidth value is increased further and approaches14 MHz, there is a loss of optical power measuring 50% and even more.

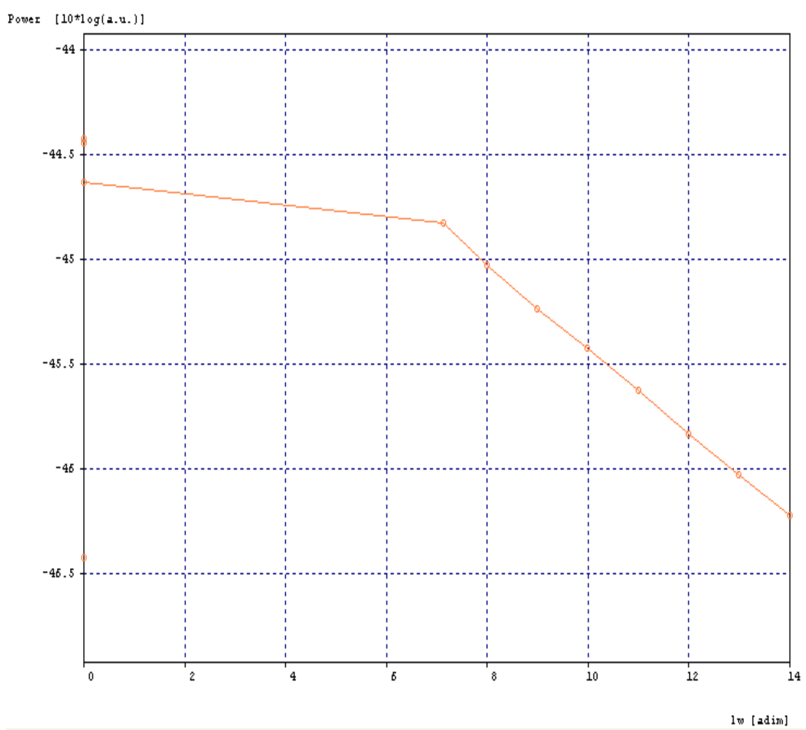


FIGURE 2: Response of electrical Power w.r.t linewidth

For positive values of RIN, Q value is found to be very less as compared with the negative values of RIN. In this paper we have iterated the values of RIN from 10dB/Hz to -180 dB/Hz and different parameters are observed. We found that Q value remains constant for negative values of RIN up to around -120 dB/Hz with further decrease in its value Q value decreases and again tends to be constant up to -160.dB/Hz.

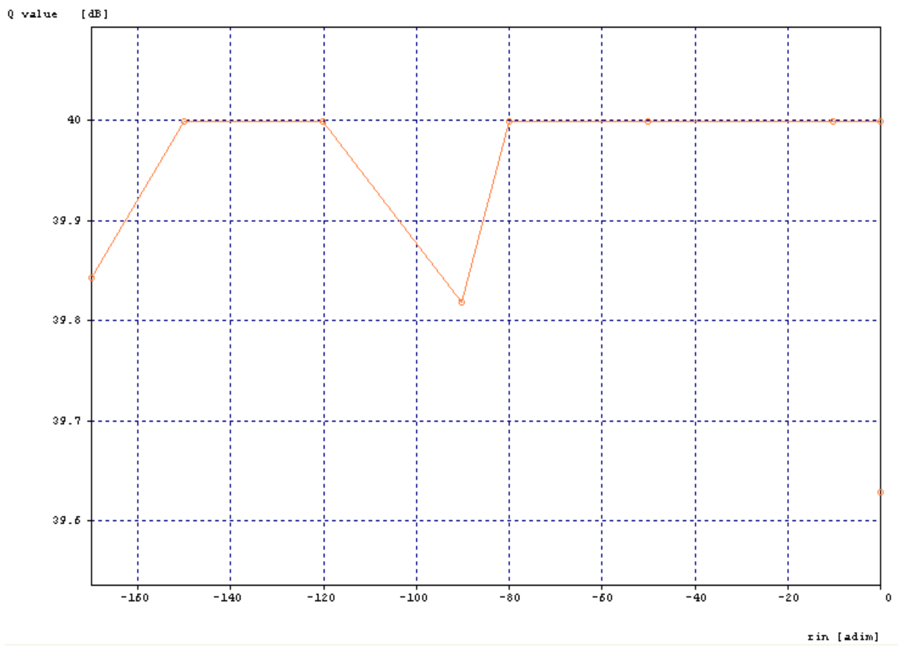


FIGURE 3: Response of Q-value w.r.t RIN

OFDM is suitable for long-haul transmission for three main reasons: (1) improvement of spectral efficiency, (2) simplification of the chromatic dispersion compensation engineering, and (3) PMD compensation. We have shown that Optical-OFDM provides the best power efficiency–BER performance compromise, and as such it is adopted here.

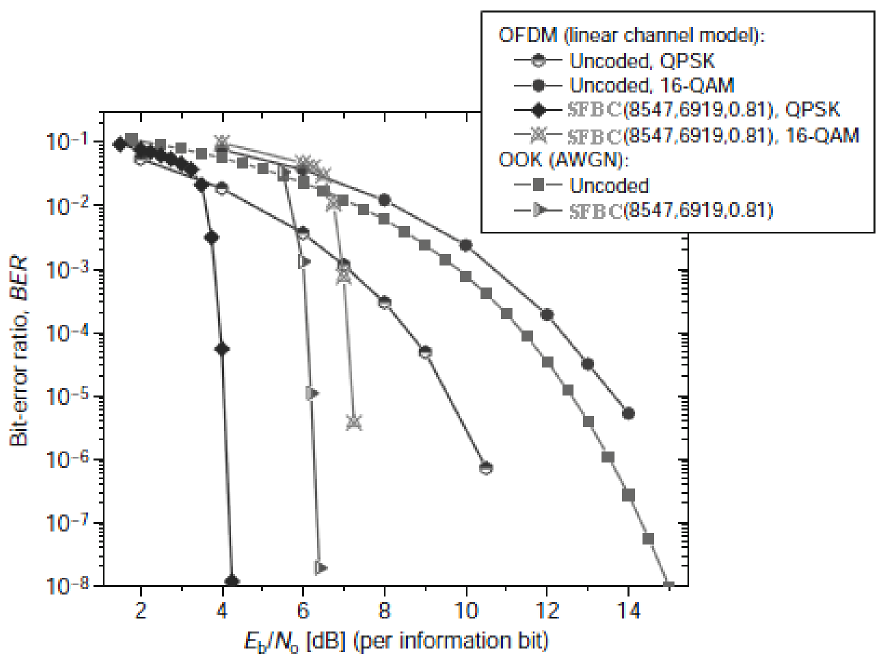


FIGURE 4: BER Performance for the system

The BER performance of this scheme (with an aggregate data rate of 40 Gb/s) against the conventional SFBC-coded RZ-OOK scheme (operating at 40 Gb/s) is given in Figure 4 for the thermal noise-dominated scenario. The SFBC-coded QPSK U-OFDM provides more than 2dB coding gain improvement over uncoded RZ-OOK at a BER of 10^{-8} . We have shown that SFBC-coded OFDM provides much higher spectral efficiency than SFBC-coded RZ-OOK.

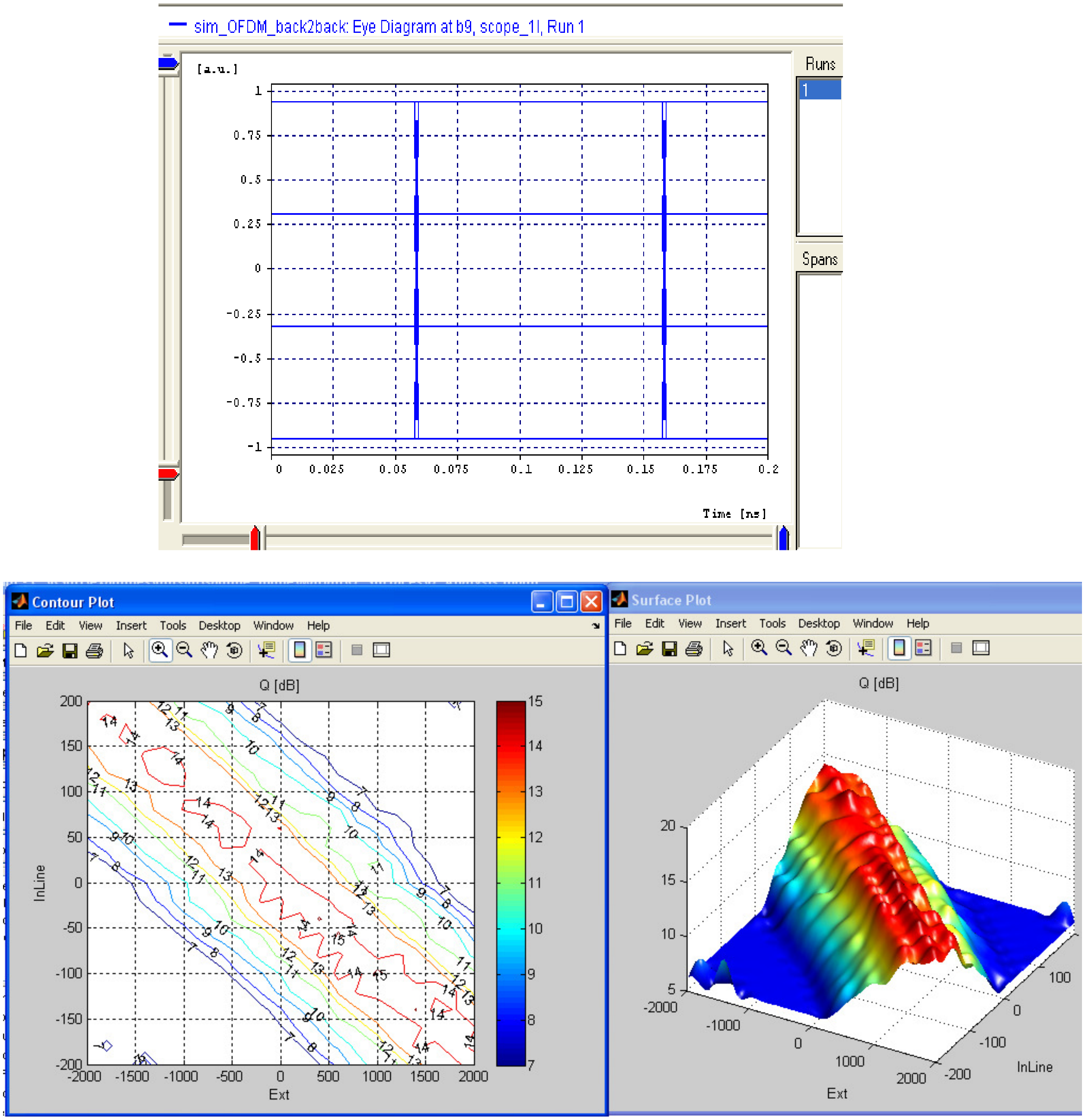


FIGURE 5: Dispersion map under study.

For the dispersion map described in Figure 5, the BER curves for the uncoded 100 Gb/s OFDM transmission using BPSK are shown in Figure 6, and fiber parameters are given in **Table 1**.

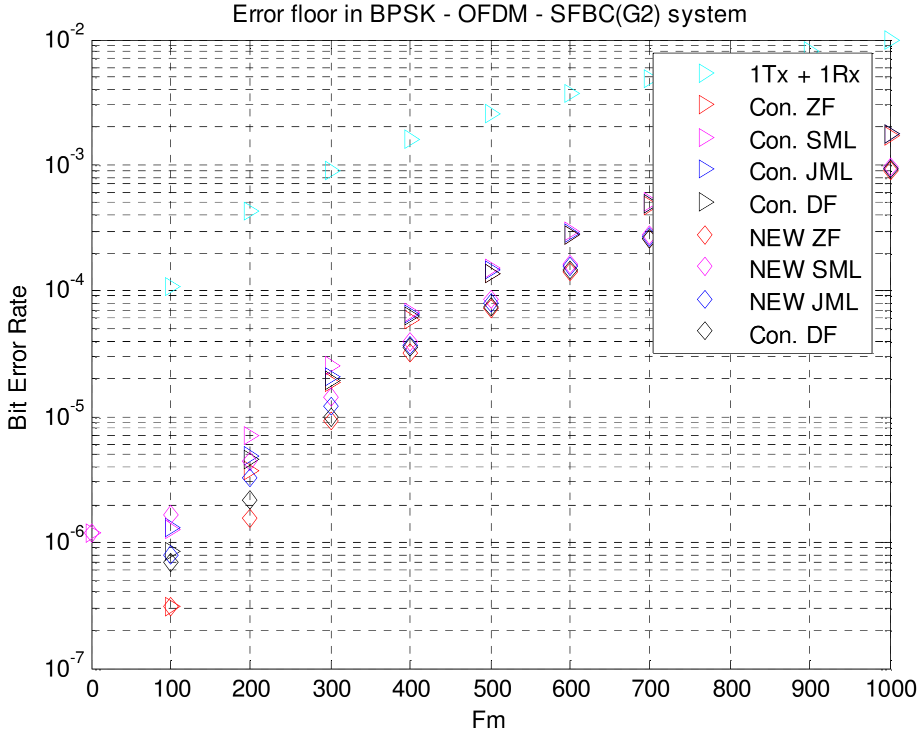
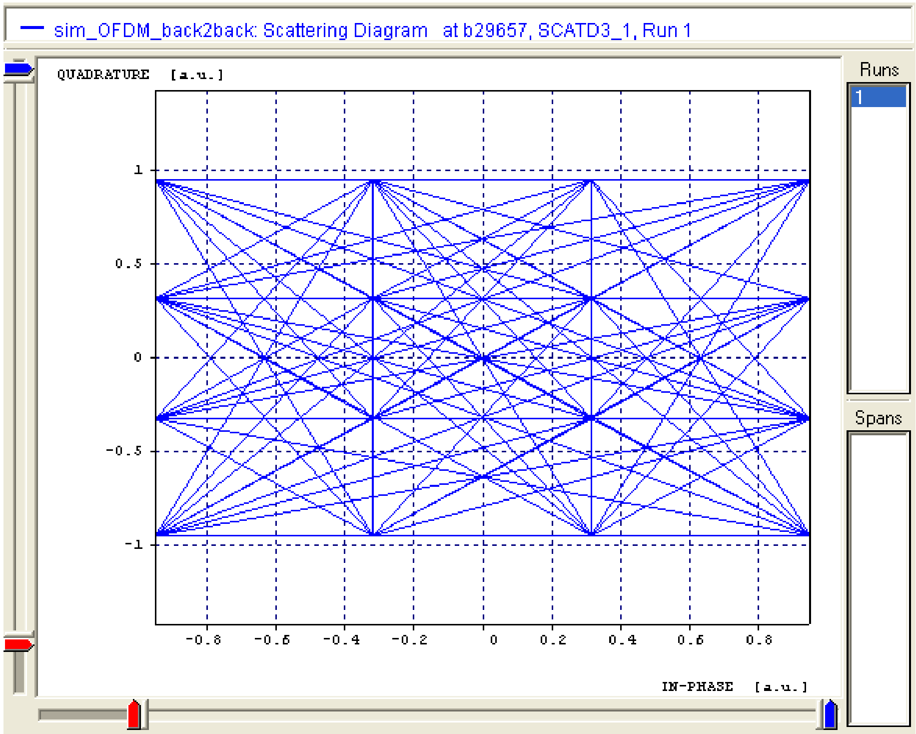


FIGURE 6: BER curves for BPSK-OFDM –SFBC system

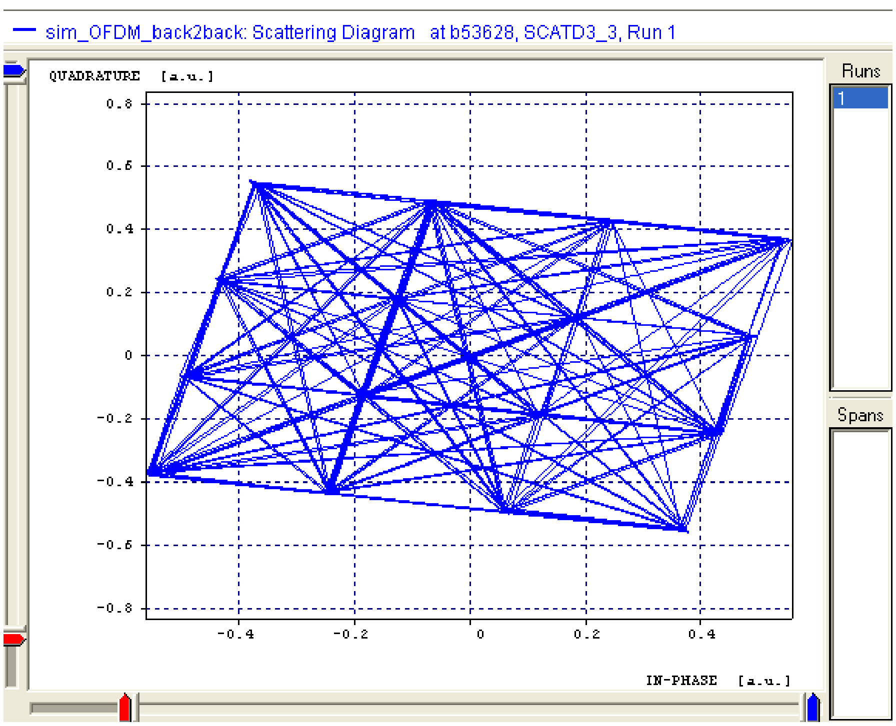
The dispersion map is composed of N spans of length L=120 km, consisting of 2 L/3 km of D_ fiber followed by L/3 km of D_ fiber, with precompensation of -1600 ps/nm and corresponding postcompensation. The propagation of a signal through the transmission media is modeled by a nonlinear Schro¨dinger equation (NLSE).

	D_+ Fiber	D_ Fiber
Dispersion (ps/(nm km))	20	−40
Dispersion slope (ps/(nm^2 km))	0.06	−0.12
Effective cross-sectional area [μm^2]	110	50
Nonlinear refractive index (m^2/W)	$2.6 \cdot 10^{-20}$	$2.6 \cdot 10^{-20}$
Attenuation coefficient (dB/km)	0.19	0.25

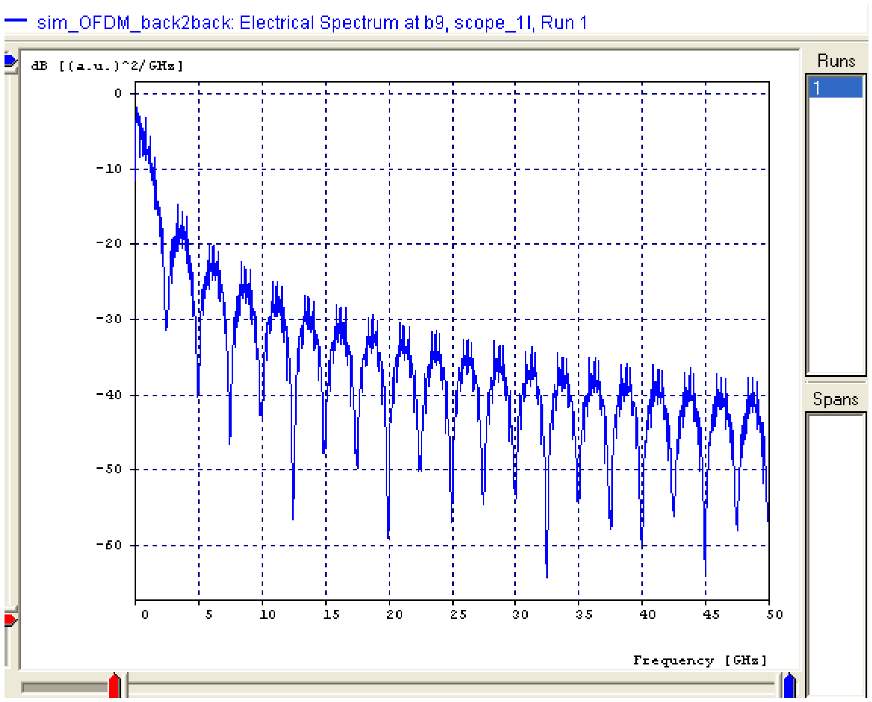
TABLE1: Parameters for the system


sim_OFDM_back2back: Scattering Diagram at b29657, SCATD3_1, Run 1
QUADRATURE [a.u.]
IN-PHASE [a.u.]
Runs
Spans

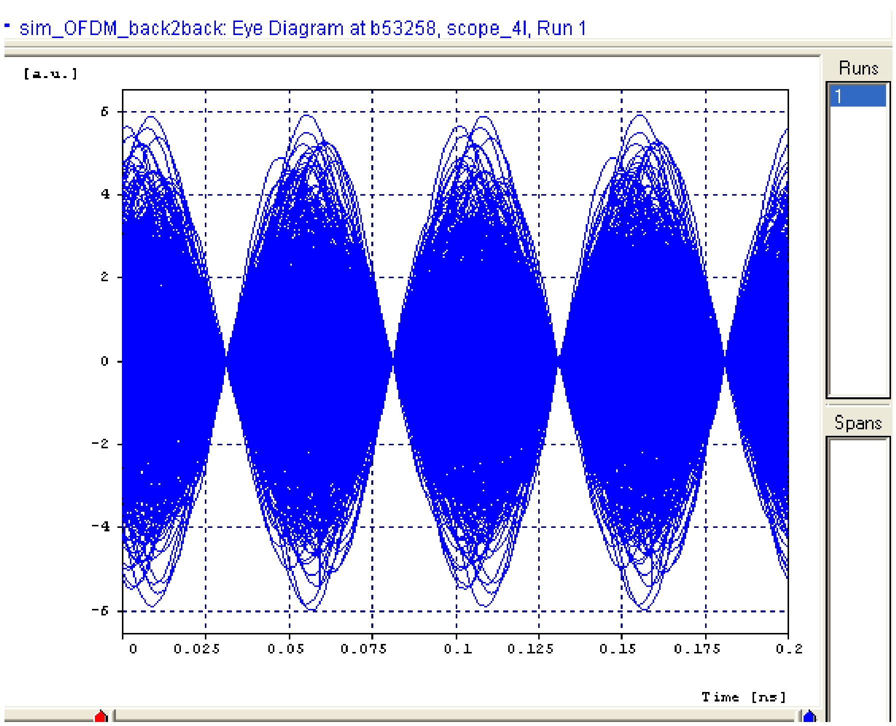
(a)


sim_OFDM_back2back: Scattering Diagram at b53628, SCATD3_3, Run 1
QUADRATURE [a.u.]
IN-PHASE [a.u.]
Runs
Spans

(b)



(c)



(d)

FIGURE 7: (a), (b) Signal scattering (c) Electrical spectrum (d) Eye diagrams

The signal scattering, electrical Spectrum and eye diagrams, are shown in Figure 7 before and after applying the channel estimation, for coded Optical-OFDM system with optimum biasing of laser. They correspond to the worst-case scenario (k = 1/2) and 10 Gb/s aggregate data rate. Therefore, the channel estimation-based OFDM is able to compensate for DGD of 1600 ps.

5. RESULTS AND DISCUSSION

The results of PMD simulations for Optical-OFDM and thermal noise-dominated scenario are shown in Figure 7 for different DGDs and the worst-case scenario (k = 1/2), assuming that the channel state information is known on a receiver side. The OFDM signal bandwidth is set to BW = 0.25 B (where B is the aggregate bit rate set to 10 Gb/s), the number of subchannels is set to NQAM = 64, FFT/IFFT is calculated in NFFT =128 points, the RF carrier frequency is set to 0.75 B, the bandwidth of optical filter for SSB transmission is set to 2 B, and the total averaged launched power is set to 0 dBm. The guard interval is obtained by cyclic extension of NG= 2*16 samples. The Blackman–Harris windowing function is applied. The 16-QAM OFDM with and without channel estimation is observed in simulations.The effect of PMD is reduced by (1) using a sufficient number of subcarriers so that the OFDM symbol rate is significantly lower than the aggregate bit rate and (2) using the training sequence to estimate the PMD distortion. For DGD of 1/BW, the RZ-OOK threshold receiver is not able to operate properly because it enters the BER error floor. Note that 16-QAM OFDM without channel estimation enters the BER floor, and even advanced FEC cannot help much in reducing the BER.

We investigated the optimal values for linewidth and RIN for a coded optical-OFDM system for its better performance. The limiting value of linewidth should be 6.5MHz up to which optical power remains almost constant and RIN value corresponding to this linewidth is measured to be -155 dB/Hz. and the average value of RIN is measured to be -125 dB/Hz.

6. REFERENCES

[1] D. Agrawal, V. Tarokh, A. Naguib, and N. Seshadri, “Space-time coded OFDM for high data rate wireless communications over wideband channels,”in *Proc. IEEE Veh. Technol. Conf.*, Ottawa, ON, Canada,May 1998,vol. 3, pp. 2232–2236.

[2] Y. Gong and K. B. Letaief, “Low complexity channel estimation for spacetime coded wideband OFDM systems,” *IEEE Trans. Wireless Commun.*,vol. 2, no. 5, pp. 876–882, Sep. 2003.

[3] C. B. Papadias and G. J. Foschini, “A space-time coding approach for systems employing four transmit antennas,” in *Proc. Int. Conf. Acoust.,Speech, and Signal Process.*, Salt Lake City, UT, May 2001, vol. 4,pp. 2481–2484.

[4] H. Cheon and D. Hong, “Performance analysis of space-time block codes in time-varying Rayleigh fading channels,” in *Proc. Int. Conf.Acoust., Speech, and Signal Process.*, Orlando, FL, May 2002, vol. 3,pp. 2357–2360.

[5] R. Gozali and B. D. Woerner, “On the robustness of space-time block codes to spatial correlation,” in *Proc. IEEE Veh. Technol. Conf.*,Birmingham, AL, May 2002, vol. 2, pp. 832–836.

[6] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, “Space-time block codes from orthogonal designs,” *IEEE Trans. Inf. Theory*, vol. 45, no. 5, pp. 1456–1467, Jul. 1999.

[7] G. Ganesan and P. Stoica, “Space-time block codes: A maximum SNR approach,” *IEEE Trans. Inf. Theory*, vol. 47, no. 4, pp. 1650–1656,May 2001.

[8] J. Salz and J. Winters, “Effect of fading correlation on adaptive arrays in digital mobile radio,” *IEEE Trans. Veh. Technol.*, vol. 43, no. 4, pp. 1049– 1057, Nov. 1994.

[9] S. L. Loyka, “Channel capacity of MIMO architecture using the exponential correlation matrix,” *IEEE Commun. Lett.*, vol. 5, no. 9, pp. 369–371,Sep. 2001.

[10] L. T. Younkins, W. Su, and K. J. R. Liu, “On the roustness of spacetime coding techniques based on a general space-time covariance model,”*IEEE Trans. Veh. Technol.*, vol. 55, no. 1, pp. 219–233, Jan. 2006.

[11] Z. Liu, Y. Xin, and G. B. Giannakis, “Space-time-frequency coded OFDM over frequency-selective faiding channels,” *IEEE Trans. Signal Process.*,vol. 50, no. 10, pp. 2465–2476, Oct. 2002.

[12] C.Crognale, “RIN induced by dispersion at first –order dispersion wavelength in single mode fiber transmission lines” *Electronic Letter* online No. 19951124,6 June 1995.

[13] C. Crognale, “Small signal Frequency Response of a linear Dispersive Single-Mode Fiber Near Zero First –order Dispersion Wavelength,” *Journal of Lightwave Technology*, Vol. 15, No. 3,March 1997

[14] K. Peterman , “Laser diode modulation and noise,” (*Kluwer academic publishers, Dordrecht, and KTK Scientific Publishers*, tokyo, 1998).

[15] K. Peterman, J. Wang, “Large signal analysis of FM-AM conversion in Dispersive optical fibers and its applications to PCM systems”, *Electronics letters*, vol.27 No.25, December 1991.

[16] M. Movassaghi, M.K. Jackson and V .M Smith, “DFB Laser RIN Degradation in CATV Lightwave Transmission” *Journal of Lightwave Technology*, Vol. 15, No. 8,March 1996.

[17] Cartexo Adolfo V. T, “Influence of fiber Nonlinearity on the phase noise to intensity noise conversion in fiber transmission: Theoretical and Experimental analysis,” *Journal of Lightwave Technology*, vol. 16, no. 7, pp. 1187-1194.

[18] Adolfo V .T. Cartaxo, and Jose A.P Morgado, “Rigorous Assessment of Small-Signal Analysis for Linear and Dispersive Optical Communication Systems Operating Near Zero-Dispersion Wavelength,” *Journal of Lightwave Technology* ,Vol .17,No. 1, Jan 1999.

[19] R.S Kaler , T.S Kamal ,A.K Sharma, S.K Arya and R.A Aggarwal , “Large Signal Analysis of FM-AM Conversion in Dispersive Optical Fibers for PCM systems including Second Order Dispersion,” *Fiber and Integrated Optics Incorporating International Journal on Optoelectronics*, vol. 21, no. 3, pp. 193-203, May 2002.