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Impact of High Speed Differential Quadrature Amplitude Modulation using Hybrid Optical Amplifier for Super Dense Wavelength Division Multiplexing System

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In this paper, a Differential Quadrature Amplitude Modulation (DQAM) technique for 200 x100 Gbps Super Dense Wavelength Division Multiplexing (SD-WDM) system is proposed. Optimized rating outcome in terms of the quality factor, bit error rate, crosstalk, and acceptable minor effect of the channel spacing with the support of RAMAN-EDFA-RAMAN Hybrid Optical Amplifier (HOA) is reported.

Keywords: Differential Quadrature Amplitude Modulation, Hybrid Optical Amplifier, quality factor, bit error rate (BER), crosstalk, output power

1 Introduction

Transmission of high spectral efficiency optical signal from one place to another place with less loss and good rating of quality factor is also an interesting challenge for a researcher. Many researchers have proposed the different modulation techniques such as Amplitude Modulation (AM), Frequent Modulation (FM), Phase Modulation (PM) and much more. But these are the basic modulation technologies which have some limitations in term of optical signal transmission. In fact, low power signal is converted into a high power signal with the help of the carrier signal. Moreover, the optical carrier signal is generated from the CW laser and boost up the level of the optical signal in terms of the modulation signal for long haul distance. Many researchers are focusing to raise the transmission speed up to 100 Gbps or more with the support of different advanced modulation technology for optical communication such as M-ary Differential Phase Shift Keying (DPSK)[1], Optical Differential Quadrature Phase Shift Key (ODQPSK)[2], Differential Quadrature Phase Shifting Keying (DQPSK)[3] and Symmetrical Differential Phase Shift Keying (SDPSDK)[4] etc. Unfortunately, the effect of the hybrid optical amplifier is not considered in the literatures, which is an important consideration for long haul optical communication. Super dense wavelength division multiplexing system is the advanced technology to transmit the higher capacity optical signal[5-7]. In the multiple play services, a number of channels are packed to provide the services such as high-quality video and communication[8]. But the effect of the fiber nonlinearity and amplified spontaneous (ASE) emission can be dismissed with the help of different Hybrid Optical Amplifiers (HOAs)[9].

High spectral efficiency is the hot demand for the optical network. Chung *et al.*[10]. have explored the new technology for 16 x 10 Gbps for the transmission distance of 1040 km with the help of RAMAN amplifier, but this model only highlighted the data transmission speed up to 10 Gbps which does not fulfill the demand of high capacity transmission. Downie *et al.*[11] have evaluated the error free data transmission of 43Gbps for the transmission distance of 1200 km with 50 GHz channel spacing, but the effect of the hybrid amplifier is not shown in this literature which is an important effect in terms of low bit error and good rating quality factor for single span optical communication system.

In this paper, we have used a very advanced modulation (DQAM) technology for optical transmission. Transmission of 100 Gbps is shown by the support of RAMAN-EDFA-RAMAN hybrid optical amplifier (HOA). Moreover, the layout of the

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paper is represented in the five sections. Literature review and evaluation of existing technology are shown in section one, description of proposed modulation transmitter and receiver are given in section two, description of simulation setup is given in section three, results and discussion are given in section four and paper is ceased with the analysis in section five respectively.

2 Description of proposed transmitter and receiver

The transmitter of proposed DQAM is shown in Fig. 1. The differential quadrature amplitude modulator delivers the transmission of two data streams of 50 Gbps from the data sources and provides the best outcome in terms of spectral efficiency and enhanced dispersion tolerance[12]. In this way, the resultant bit rate is coming out with the rate of 100 Gbps. Modulation is accomplished with the help of two MZM (*Mach-Zehnder*) modulators. Each of the MZM is fed with the data (generated from the data source and NRZ electrical drive) and further modulated with the carrier signal. The carrier signal is generated from CW laser, which is further applied to MZMs with the help of an optical splitter (OS). The resultant signals in phase and quadrature arms are combined with the phase difference of $\pi/2$ to generate the DQAM modulated signal. Further, this modulated signal is transmitted through the optical fiber with the help of the HOA.

To detect such a high capacity signals, we required a very advanced receiver which is shown in Fig. 2. The received optical signal is applied to two parallel *Mach-Zehnder* demodulator with the help of an optical splitter. The optical delay is set with the period of 2/B. To remove the intersymbol interference (ISI), the phase difference of $\pi/4$ and $-\pi/4$ are set to upper and lower arms respectively. Each MZM demodulator received the balanced bit rate of 50 Gbps. Two PIN photodiodes with low pass filters are placed after the MZM demodulator for optical-to-electrical (O-E) conversion. The input signal is in the form of $E_0 [\cos(w_0 t\delta_1) + j \sin(w_0 t\delta_2)]$ and output after the PIN photodiodes are in the form of $\cos(\delta_1) + \sin(\delta_2)$ and $\cos(\delta_1) - \sin(\delta_2)$ respectively. In this way, high rating signal of 100 Gbps is received at the receiver side.

3 Simulation setup

Our complete proposed simulation setup including high spectral efficiency transmitter and receiver for 200 x 100 Gbps are shown in Fig. 3.

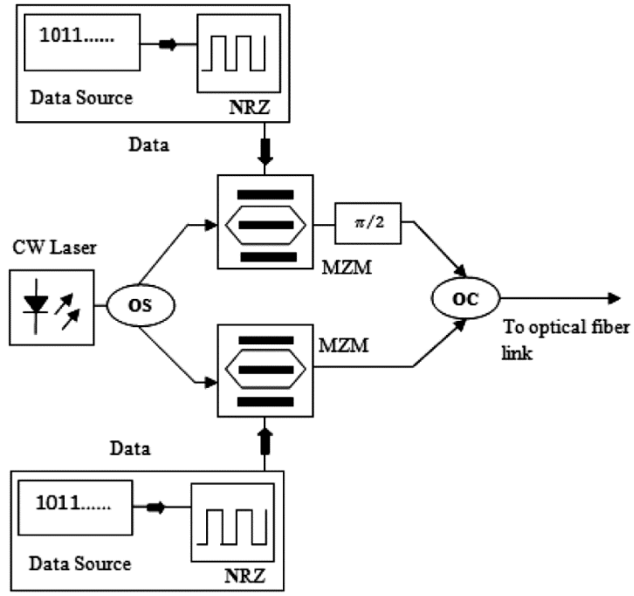

Fig. 1 — Schematic representation of DQAM transmitter

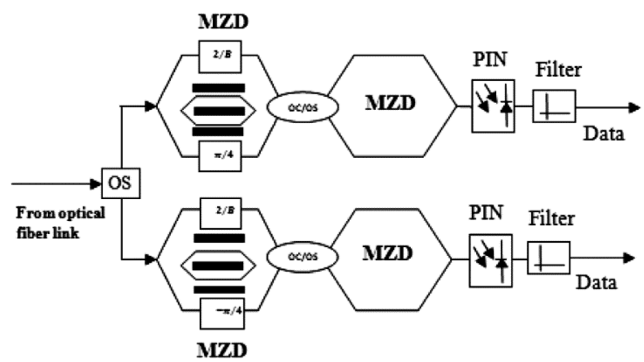

Fig. 2 — Schematic representation of DQAM receiver

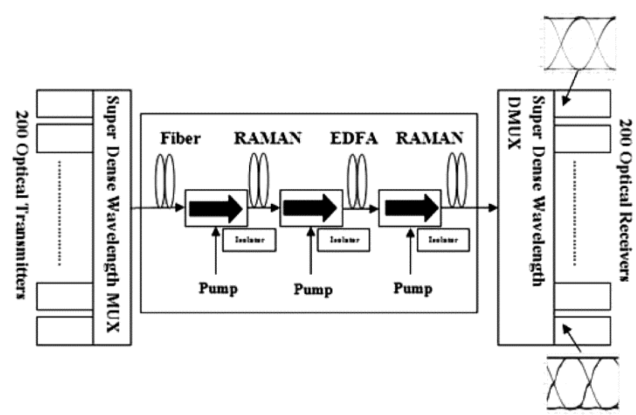

Fig. 3 — DQAM simulation setup with hybrid amplifier

Simulation is going to establish with the help of 200 CW laser sources. The beam of laser sources is generated at 180.9 to 193.4 THz. 200 channels are placed with 12.5 GHz channel spacing and input signal spectrum occupies the bandwidth of 6.4 THz.

RAMAN amplifiers are pumped by 1480 nm at 760 mW. EDFA is set to fix output power of 32mW and noise figure of 4.5 dB to amplify the signal. The total gain of cascade amplifier is given by equation (1)[13]

$$G_{RER} = G_{Raman1} G_{EDFA} G_{Raman2} \quad \ldots (1)$$

PIN photodiodes with the quantum efficiency of 0.875 and dark current of 0.1 nA are used on the receiver section. Parameters of RAMAN amplifier are given as 12 km of Raman fiber length, 0.2 dB/km of Raman loss, 1453 nm of pump wavelength, 600 mW of pump power, 0.2 dB/km of pump attenuation, 2.15 ps/nm/km is set for reference frequency of dispersion, and 300 K of operating temperature respectively. In a similar manner, the parameters of EDFA amplifier are already explained in this paper. The evaluated rating of the received signal in terms of eye diagram is given as eye closure of 0.11570 dB and eye opening of.0106989 (a.u.) for channel 1, eye closure of 0.104414 dB and eye opening of 47.5934 (a.u) for channel 200 respectively. It is observed that insertion of data bits from the data source (which means more number of users or data bits induce more eye closure).

4 Result and discussion

The impact of channel spacing of 50 GHz and 100 GHz on the hybrid optical amplifier in terms of power variations is shown in fig. 4 (a) & 4 (b). The recorded values for the 50 GHz channel spacing lies between 7 dBm to 7.1 dBm for 0 dBm power, and -0.4 dBm to -0.6 dBm for -7 dBm power. In a similar way, the recorded values for 100 GHz channel spacing lies between 5 dBm to 5.3 dBm for 0 dBm power, and -0.3 to -0.02 dBm for -7 dBm power respectively. It is analyzed that the variation in power for 50 GHz channel spacing is greater than 100 GHz channel spacing due to degradation in power level. So it can be concluded that RAMAN-EDFA-RAMAN hybrid optical amplifier provides the best accepted rating outcome for 100 GHz channel spacing.

The illustration to show, the effect of crosstalk induced by RAMAN-EDFA-RAMAN HOA with respect to applied input power is shown in Fig. 5. The variations in crosstalk are given as -22 dB to -11 dB for the 50 GHz channel frequency, and -24 to -13 dB for 100 GHz channel spacing respectively. It is evaluated that variation in crosstalk is increasing with respect to increasing input power just because of internal gain saturation. Further, the recorded results have shown that the accepted rating outcome are better than the results obtained by Oberg *et al.*[14]

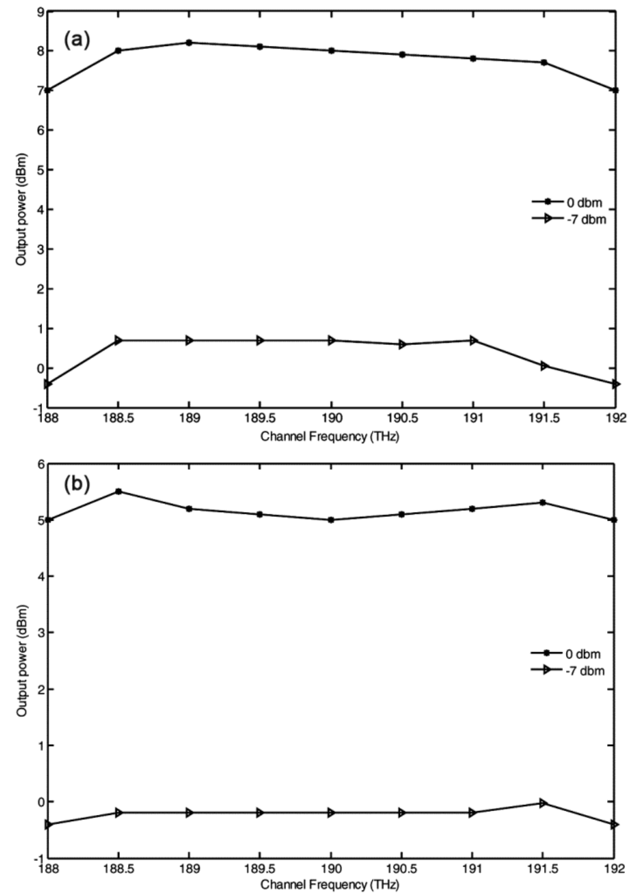

Fig. 4 — Output power versus channel spacing for DQAM, SD-WDM system (a) Power variations for 50 GHz channel spacing (b) Power variations for 100 GHz

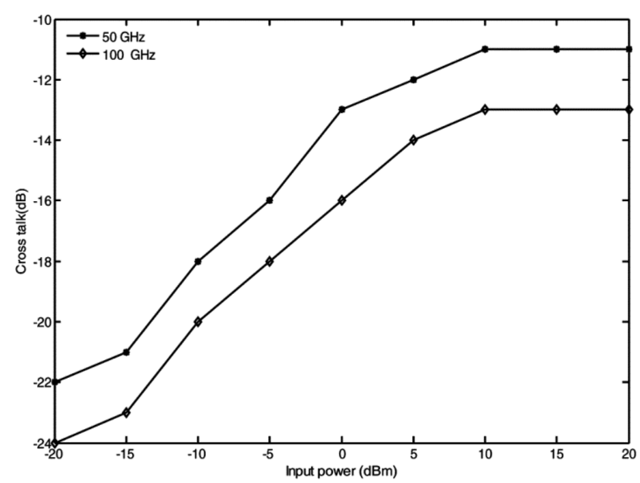

Fig. 5 — Crosstalk versus applied input power

To illustrate the performance of the proposed model in term of quality factor with respect to bit rate is shown in Fig. 6. It is observed that proposed HOA delivers the best outcome for 50GHz channel spacing

Table 1 — Variations of gain and quality factor with respect to channel spacing

Random number of channel	Variations of Gain				Variations of Quality Factor			
	50 GHz Channel Spacing		100 GHz Channel Spacing		50 GHz Channel Spacing		100GHz ChannelSpacing	
	0 dBm	-7 dBm	0 dBm	-7 dBm	0 dBm	-7 dBm	0 dBm	-7 dBm
1.0000	16.2000	15.5000	11.2000	9.2000	30.2000	25.5000	23.5500	24.3900
11.4737	16.1791	15.4843	11.1843	9.1843	29.8806	25.0601	23.0551	23.9035
21.9474	16.1581	15.4686	11.1686	9.1686	29.5611	24.6202	22.5602	23.4170
32.4211	16.1372	15.4529	11.1529	9.1529	29.2417	24.1803	22.0654	22.9305
42.8947	16.1162	15.4372	11.1372	9.1372	28.9222	23.7404	21.5705	22.4440
53.3684	16.0953	15.4214	11.1214	9.1214	28.6028	23.3005	21.0756	21.9575
63.8421	16.0743	15.4057	11.1057	9.1057	28.2833	22.8606	20.5807	21.4710
74.3158	16.0534	15.3900	11.0900	9.0900	27.9639	22.4207	20.0858	20.9845
84.7895	16.0324	15.3743	11.0743	9.0743	27.6444	21.9808	19.5910	20.4980
95.2632	16.0115	15.3586	11.0586	9.0586	27.3250	21.5409	19.0961	20.0115
105.7368	15.9905	15.3429	11.0429	9.0429	27.0055	21.1011	18.6012	19.5250
116.2105	15.9696	15.3272	11.0272	9.0272	26.6861	20.6612	18.1063	19.0385
126.6842	15.9486	15.3115	11.0115	9.0115	26.3666	20.2213	17.6115	18.5520
137.1579	15.9277	15.2958	10.9958	8.9958	26.0472	19.7814	17.1166	18.0655
147.6316	15.9067	15.2801	10.9801	8.9801	25.7277	19.3415	16.6217	17.5790
158.1053	15.8858	15.2643	10.9643	8.9643	25.4083	18.9016	16.1268	17.0925
168.5789	15.8648	15.2486	10.9486	8.9486	25.0888	18.4617	15.6319	16.6060
179.0526	15.8439	15.2329	10.9329	8.9329	24.7694	18.0218	15.1371	16.1195
189.5263	15.8229	15.2172	10.9172	8.9172	24.4499	17.5819	14.6422	15.6330
200.0000	15.8020	15.2015	10.9015	8.9015	24.1305	17.1420	14.1473	15.1465

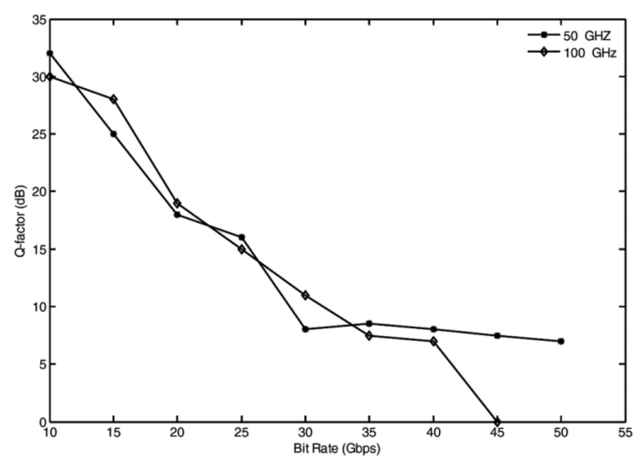

Fig. 6 — Quality factor versus bit rate

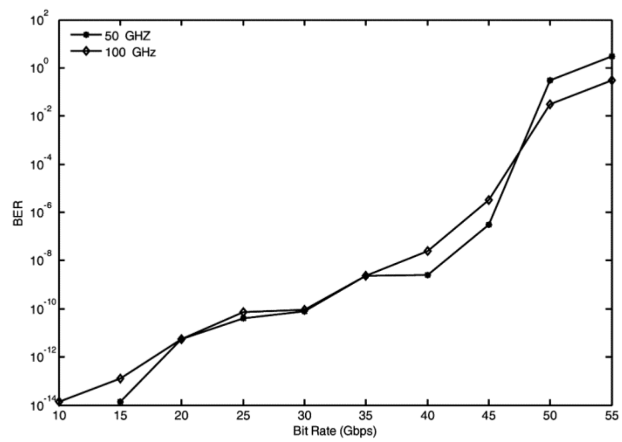

Fig. 7 — Variations of BER with respect to bit rate

in terms of 50 Gbps bit rate. Moreover, the performance of the system is degraded with 100 GHz channel spacing at 45 Gbps due to non usage of any dispersion compensation techniques.

Variations of bit error rate with respect to bit rate for different channel spacing is shown in Fig. 7. The observed values lies between 1.3e-13 to 3.1e-1 for 50 GHz channel spacing, and 1.4e-14 to 2.5e-1 for 100 channel spacing. So it is observed that the performance of proposed modulation shows the accepted BER (> 50) Gbps with the quality factor (> 30) dB.

The variation in gain and quality factor for different channel spacing and input power are shown in Table 1. It is observed that the quality factor of received signal is affected by increasing the channel spacing. It occurs due to the addition of its own nonlinearity and crosstalk by each amplifier in the arrangement of HOA. But it can also be resolved by placing the isolator in the middle of two optical amplifiers.

5 Conclusion

We have evaluated the impact of DQAM modulation technology for the 200 x 100 Gbps SD-

WDM system with the help of RAMAN-EDFA-RAMAN HOA in term of varying channel spacing, the influence of crosstalk, quality factor, and bit error rate respectively. The accepted rating outcome is reported with the comparison of references[15-20] in the scenario of reduction in crosstalk, improvement in quality factor, channel spacing, gain ripple, cost, and speed, etc. Moreover, it has also observed that proposed model has shown the better outcome in terms of higher spectral efficiency (> 100 Gbps) with fiber (>200 km) for the commercial research.

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