Analysis of CSRZ and CSNRZ Coding for DQPSK and OQPSK Transmitter Configurations for Optical Microwave Generation Signals Based on Stimulated Brillouin Scattering

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ABSTRACT

The use of Carrier Suppressed Non-Return to Zero (CSNRZ) and Carrier Suppressed Return to Zero (CSRZ) modulation formats in Dense Wavelength Division Multiplexing (DWDM) channels at 1 Gb/s and 10 Gb/s is investigated. The results of simulated analysis using Differential Quadrature Phase Shift Keying (DQPSK) and Offset Quadrature Phase Shift Keying (OQPSK) formats are presented. We demonstrate that Stimulated Brillouin Scatteriring (SBS) is a major contribution of the back-scattering signal. At bit rate of 1 Gb/s and 10 Gb/s, CSRZ-OQPSK modulation format has a low threshold for SBS signal generation. For a data rate of 1 Gb/s, high SBS threshold of 19.76 dBm for CSRZ-DQPSK is recorded. The results can be used to suppress SBS in high power lasers which could be useful in high bit rate signal transmission.

Keywords: Carrier Suppressed Non-Return to Zero, Carrier Suppressed Return to Zero, Dense Wavelength Division Multiplexing, Differential Quadrature Phase Shift Keying, Offset Quadrature Phase Shift Keying, Stimulated Brillouin Scatteriring

1. INTRODUCTION

With demand for high bit rate and long-distance transmission,it has been observed that the main focus of several research studies is to improve the network flexibility and to increase the network size. The On-Off Keying (OOK) signal is mainly deployed in optical communication system which transfers information either in Return-to Zero (RZ) and Non-Return to Zero (NRZ) formats [1]. The OOK signals mainly used over a small distance meaning between backbone network and metropolitan area network [2]. The RZ format is widely used in Optical Time Division Multiplexing (OTDM) networks because it is more tolerant to Polarization Mode Dispersion (PMD) while NRZ is preferred in Wavelength Division Multiplexing (WDM) channels networks owing to its higher spectral efficiency, simplicity and tolerance to timing chitter [3]. Over the last decade, WDM has been upgraded to increase the channel capacity, which has been accomplished by two ways: first by decreasing the frequency spacing in the working bands (L-, S- and C- bands) and secondly by increasing the bit rate up to 200 Gb/s [4].

In order to fulfil the demand for high bit rate and long distance transmission, there is need for advanced type of modulation format. Increasing the bit rate per channel from 10 Gb/s to 40 Gb/s is an attractive way to achieve very high spectral efficiency in DWDM channels [5]. The transmission effects in optical fibre such as nonlinearity, PMD and Chromatic Dispersion (CD) should be overcome. In such a context, suitable modulation format become a critical issue because of the needed high-bandwidth efficiency. Besides the well-known RZ and NRZ formats, we consider the newly introduced CSRZ and CSNRZ modulation formats because it seems to be attractive for the signal transmission in a DWDM scenario. Development of wideband optical transmitters with less complexity along with efficient modulation schemes is one approach.

The most reliable modulation scheme for such an application is Carrier Supressed Return to Zero-Differential Quadrature Phase Sift keying (CSRZ-DQPSK) format. It provides better tolerance, robust perfomance towards non-linearities and improves the spectral efficiency in high bit rate system [6]. In this paper, the transmission properties of DQPSK and OQPSK at a transmission rate of 1 Gb/s and 10 Gb/s are theoretically studied. In particular, a comparison is made between RZ and NRZ in terms of tolerance to SBS and non-linear effects.

2. THEORY OF SBS AND MODULATION FORMATS

Previously, some investigations on the charactarisation of Stimulated Brilloun Scattering (SBS) upto 10 Gb/s have reported that the SBS threshold decreases more than 1 dB with respect to 2.5 Gb/s [7]. Also, 100 Gigabit Ethernet (100 GbE) is widely regarded as the next step in channel bit rate after 40 Gb/s due to the increasing demand for internet [8]. Highly spectraly efficient formats and coherent detection are almost certainly needed for 100GbE transmission over very long distances (over 1000 km) and ultra-dence WDM (25 and 50 GHz channels). However, for metro and regional network links with 100 or 200 GHz channel grids and pre-installed optical dispersion compensation, less advanced transmission techniques may be sufficient and indeed desirable.

Quadrature phase shifting keying(QPSK) is a form of Phase Shift Keying in which two bits are modulated at once, selecting one of fourpossible carrier phase shifts. It allows the signal

to carry twice as much information as an ordinary PSK using the same bandwidth.QPSK is one of the modulation schemes used in wireless communication system due to its ability to transmit twice the data rate for a given bandwidth [9]. Phase modulation with quadrature offset,often reffered to as OQPSK, is a variant of Phase Shift Keying modulation using different values of the phase to transmit. This technique reduces the effects on the amplitude of the signal due to any low-pass filtering [10].

The error probability P_b, in the phase and quadrature components applies to both QPSK and OQPSK. The P_b of OQPSK is given as:

$$P_b = Q \sqrt{\frac{2E_b}{N_o}} \qquad (1)$$

where E_b = is the energy in one bit and N_0 is the noise power while the odd (or even) bits are used to modulate the quadrature-phase component of the carrier. If the signal to noise ratio (SNR) is high, the probability of symbol error may be approximated as:

$$P_s = 2Q \sqrt{\frac{E_s}{N_o}} \qquad (2)$$

DQPSK requires two modulators which improves the performance in comparison to QPSK. Also the BER graphs of DQPSK give better results when probability of error is taken into account. The four level of DPSK has the advantage of better dispersion tolerance [11]. To get RZ-DQPSK signal, two phase modulators are cascaded for modulation of the optical phase by 0 to $\pi/2$ and 0 to $\pi/4$ applying binary modulation. The optical SNR ratio tolerance is higher than DQPSK hence resulting to better peformance in the context of signal quality. The modulation format most commonly employed in the low and moderate data rates communication is Binary-Phase Shift Keying (BPSK) [12]. This modulation format is a one dimensional signal constellation capable of error-free communication at high data rates. With a given bandwidth constrain, higher data rates can be achieved by resorting to higher-dimensional signals such as QPSK and OQPSK. Phase modulation is applied to the quadrature channel with intensity controlled by a parameter called the modulation index, O_m, with the rest of the power allocated to the residual carrier in the in-phase channel. With $\pi/2$, the carrier componet is completely eliminated, hence this case is reffered to as the 'suppressed carrier' modulation. With $0 \leq 0_m < \pi/2$, some power is relegated to the carrier, hence this case is called 'residual' modulation. SBS is non-linearity affecting narrow linewith fibre lasers and amplifiers and its management is of utmost importance. SBS causes backward scattered light at a slightly lower fequency to grow exponentially with the input signal power. It is often characterized in a system by a power threshold which is the power level at which the backward scatterred light reaches a certain fraction of the signal light. The Brillouin process has a Lorentzian gain profile $g_b(f)$ charectarized by a bandwidth, Δv_B which has a value in tents of MHz for silica fibres [13]. This bandwidth is a measure of the response time of the process and is related to acoustic photon lifetime, T_B by the expression;

$$\Delta v_B = \frac{\Gamma_B}{2\pi} = \frac{1}{2\pi \Gamma_B} \qquad (3)$$

where Γ_B is the gain bandwidth in angular frequency. The SBS gain bandwidth Δv_B gives us an intrinsic time scale. This also provides an equivalent length scale, L_B defined as the length travelled by light in the fibre in a time window of size $\left(\frac{1}{\Delta v_B}\right)$ and is given by:

$$L_B = \frac{c}{n_{fibre}\Delta v_B} \tag{4}$$

where n_{fiber} is the effective refractive index of the optical fibre.

The spectrally dependent gain for the SBS process is an exponential fuction of the signal spectrum. For a spectrally flat optical noise seeding process, the stokes light will acquire a spectral shape corresponding to an exponential spectrum of the light signal.Depending on the incident light,we may either get spontanous scatterring for low intensities or stimulated scatterring for high intensties. During scatterring process, the stokes field grows exponetially with space in the backward direction and its intensity is given by:

$$I_2(L) = I_2(0)e^{[G_B I(0)L_{eff} - \alpha L]} \tag{5}$$

where L is the interaction length in the medium, α is the fibre loss (dB/km) and G_B is brilloun gain coefficient.

$L_{eff} = \frac{1 - e^{-\alpha L}}{\alpha}$ is the effective interaction lengthand $I_2(L)$ is the intensity of the stokes field at $Z = L$. When $\propto \to 0$, $L_{eff} \to L$ while when $\propto L \gg 1$, $L_{eff} \to \frac{1}{\alpha}$. Once the SBS threshold is reached,a large part of incident light power is transferred into stokes wave and the pump wave becomes depleted [14]. The dependance of the SBS on strain and temperature is key for SBS shaping and supression. A strain and temperature alter the speed of sound in a medium during transmission. Hence, the Brilloun frequency, distributed sensing of these quantities over a long fibre by measuring SBS spectrum is possible [15].

3. SYSTEM DESIGN

In this paper we investigate the cost effective 10 Gb/s and 1 Gb/s DQPSK and OQPSK with and without suppression transmitter schemes. The SBS threshold and received data characteristics for RZ are determined for proposed schemes compared to NRZ. The simulation parameters are provided in Table 1.

Table 1. Simulation parameters

Bit rate (Gb/s)	1 Gb/s and 10 Gb/s
Fibre Length (Km)	40
Effective Area, $A_{ff}(\mu m^2)$	80

| Nonlinear refractive index, n^2 (m^2/W)	$2.6e^{-20}$
Loss coefficient α (dB/km)	0.2
Brillion line width (MHz)	100
Central wavelength λ (nm)	1550
Dispersion slope $(ps/nm^2/k)$	0.075
Frequency shift (GHz)	11

3. 1. Simulation Set-Up

There are several schemes for generating DQPSK and OQPSK. Here, we consider standard three Mach-Zehnder Modulators (MZM) based transmitters. A precorder is required to generate the differential operation between the consecutive bits. The precoded in-phase data and quadrature phase components are given as inputs to the first and second MZM, to generate four phases $(0, \pi/2, \pi/4, \pi)$ required for the QPSK signal. The third MZM acts as a pulse carver which provides the required carrier pulse shaping signal. The signal generation for all the transmitter schemes as shown in figure 1 are simulated and studied for non-linear tolerance.

**Figure 1.** Transmitter configurations used in the Optisystem tool for simulation.

The simulation set up deployed for demonstration of OQPSK and DQPSK formats is illustrated in Fig. 2. An optical communication system used in simulation was developed using OptiSytem software platform (OptiSystem, 2008). A comparison between OQPSK and DQPSK modulation formats using RZ and NRZ with and without suppression is investigated. Pseudo-random binary sequence (PRBS) directly modulated a DQPSK and OQPSK by a 1 Gb/s and 10 Gb/s data rate with NRZ and RZ. The PRBS generates the random data form i.e '0' and '1' bit stream. The DQPSK and OQPSK signals is generated by an ideal MZM transmitter, in which two bit sequences are pre-coded for differential detection and used to drive two MZM's (I and Q quadtarure). The NRZ and RZ generates signal of beat stream pulses. A continous wave (CW) laser generates CW light at wavelength of 1550 nm with the input power varying from 0 dBm to 20 dBm. Two MZM are cascaded with each other and modulates the generated NRZ/RZ signals. The signal is then passed through the third modulator to provide signal suppression. The central peak at the carrier frquency will suppress the frequecny spectrum of CS signal.
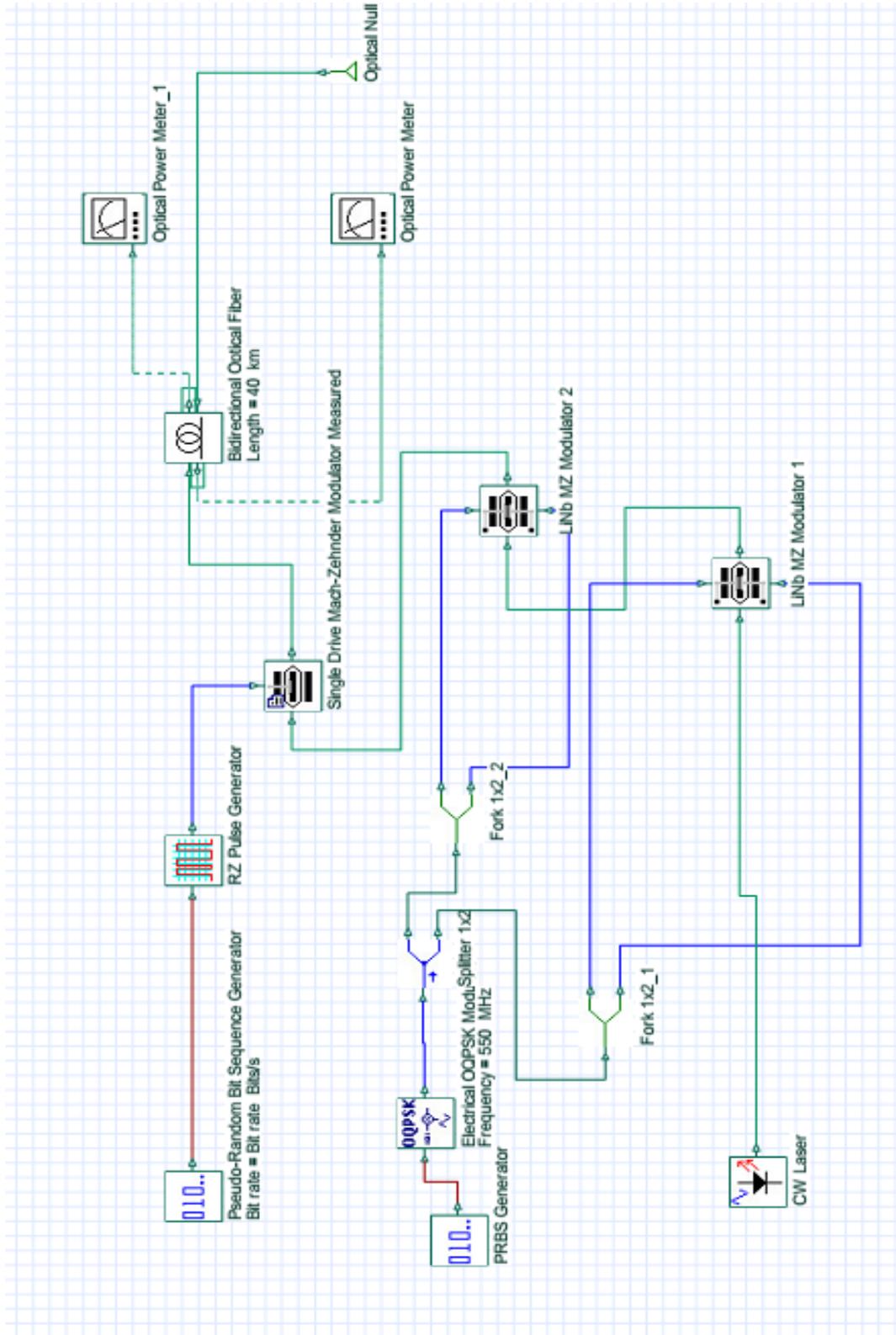
Figure 2. Simulation set up for measuring the SBS threshold and evaluating backscattered light using OQPSK modulated with NRZ format.

4. RESULTS AND DISCUSSIONS

We investigate the SBS tolerance of two cost effective 10 Gb/s and 1 Gb/s DQPSK and OQPSK using RZ and NRZ modulation formats. The SBS threshold and received data characteristics for RZ scheme are determined compared to NRZ.
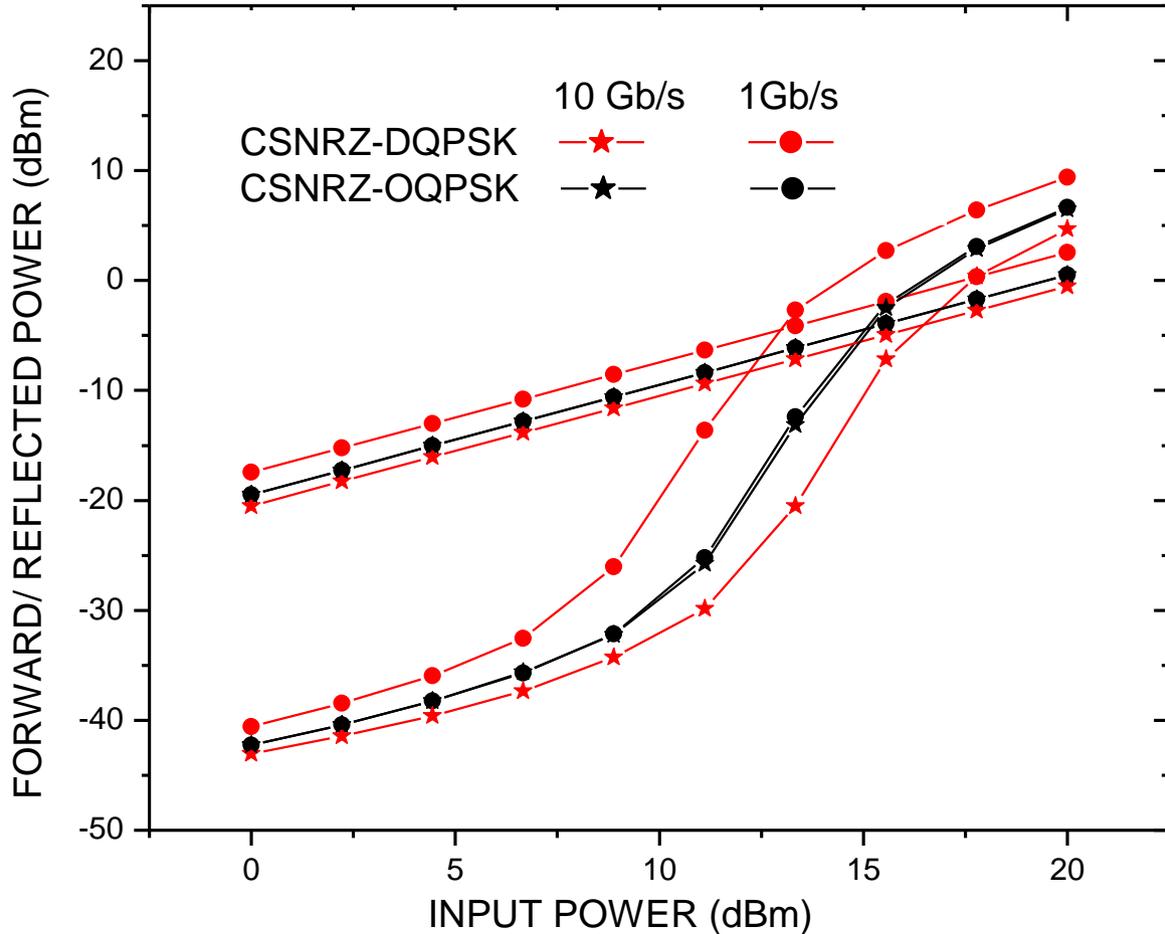
Figure 3. Forward and reflected power for CSNRZ-DQPSK and CSNRZ-OQPSK at a transmission rates of 1Gb/s and 10 Gb/s

Figure 3 shows the simulated backscattered power of a 40-km SMF as a function of the input power when the transmitted signal is modulated at 10 Gb/s and 1 Gb/s. SBS is a major contribution of the back-scattering signal. Our model uses the OOK signal transmission. The rate of increase of the output power against input power first rises. The transmitted power at the output saturates at SBS threshold and barely increases with input power. From the figure, we can see that regardless of the transmission rate, OQPSK modulation format nearly saturates at the same input power of 15.18 dBm and 15.12 dBm at a bit rate of 10 Gb/s and 1Gb/s respectively. However, when DQPSK format was used, the system saturates at high powers when transmitted at a bit rate of 10 Gb/s. For example, the SBS threshold values are 16.48 dBm and 12.96 dBm at 10 Gb/s and 1Gb/s respectively. When the DQPSK signal is modulated at 10

Gb/s an approximately 3.48 dB increase of the SBS threshold with respect to 1 Gb/s. From the results in figure 3, we see that CSNRZ-OQPSK format show no significant change in SBS threshold regardless of the transmission rate. This therefore implies that; optical signal transmission can be achieved with 1 Gb/s and 10 Gb/s using this modulation format.
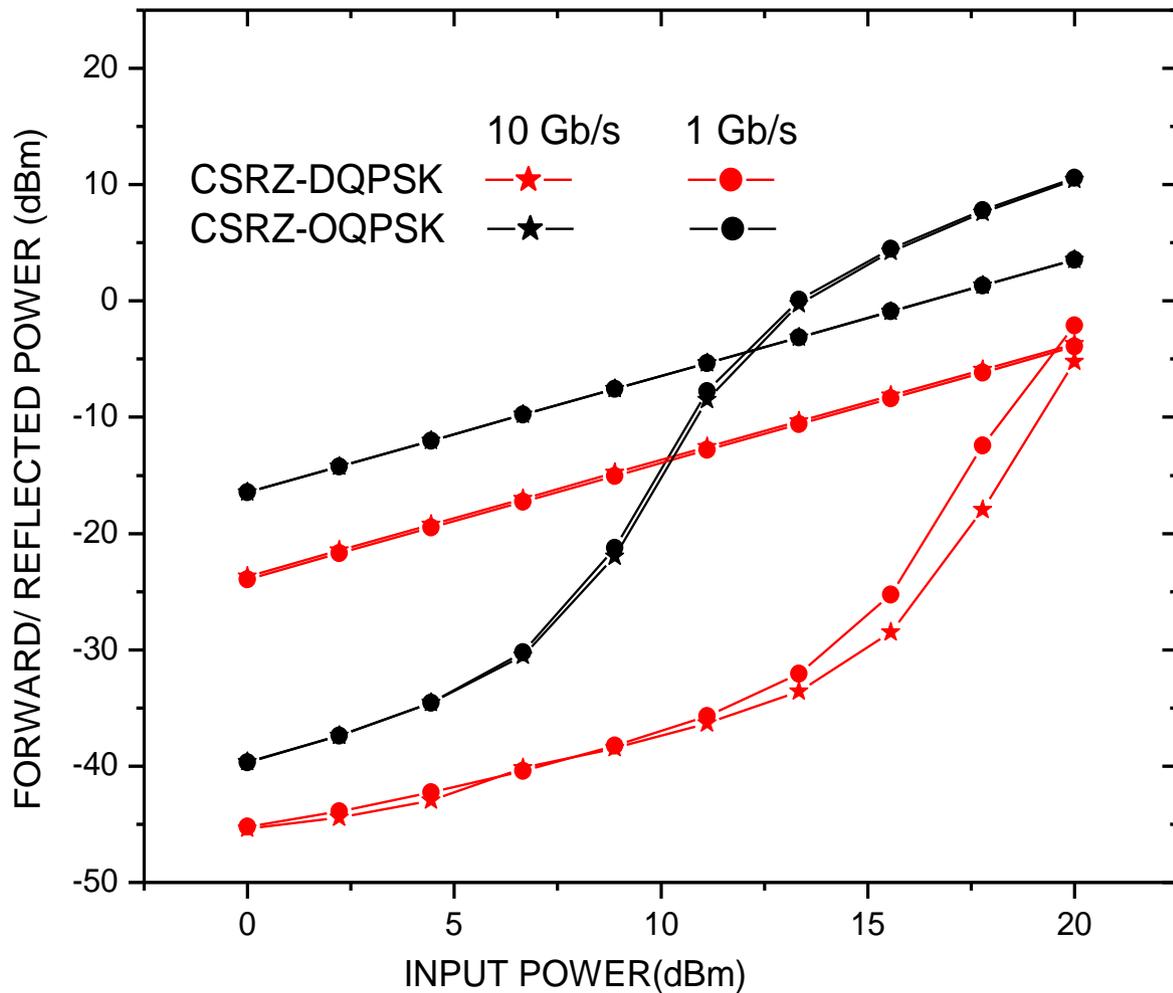
Figure 4. Forward and reflected power for CSRZ-DQPSK and CSRZ-OQPSK at a bit rates of 1Gb/s and 10 Gb/s

It is observed in Figure 4 that, CSRZ-OQPSK saturates at low input powers. At a transmission rate of 10 Gb/s and 1 Gb/s, the SBS threshold was found to be 12.29 dBm and 12.06 dBm respectively. However, for CSRZ-DQPSK modulation format, at a transmission rate of 10 Gb/s, the forward power does not saturate. For a data rate of 1 Gb/s, the SBS threshold for CSRZ-DQPSK is found to be 19.76 dBm. Contrary to the OQPSK modulation format, the DQPSK format does not suffer much from power increment. It saturates at high input powers. This is because of the fact that the reflected power in OQPSK format is much higher compared to DQPSK modulation format. Therefore, a small amount of SBS is present in OQPSK compared to DQPSK format.
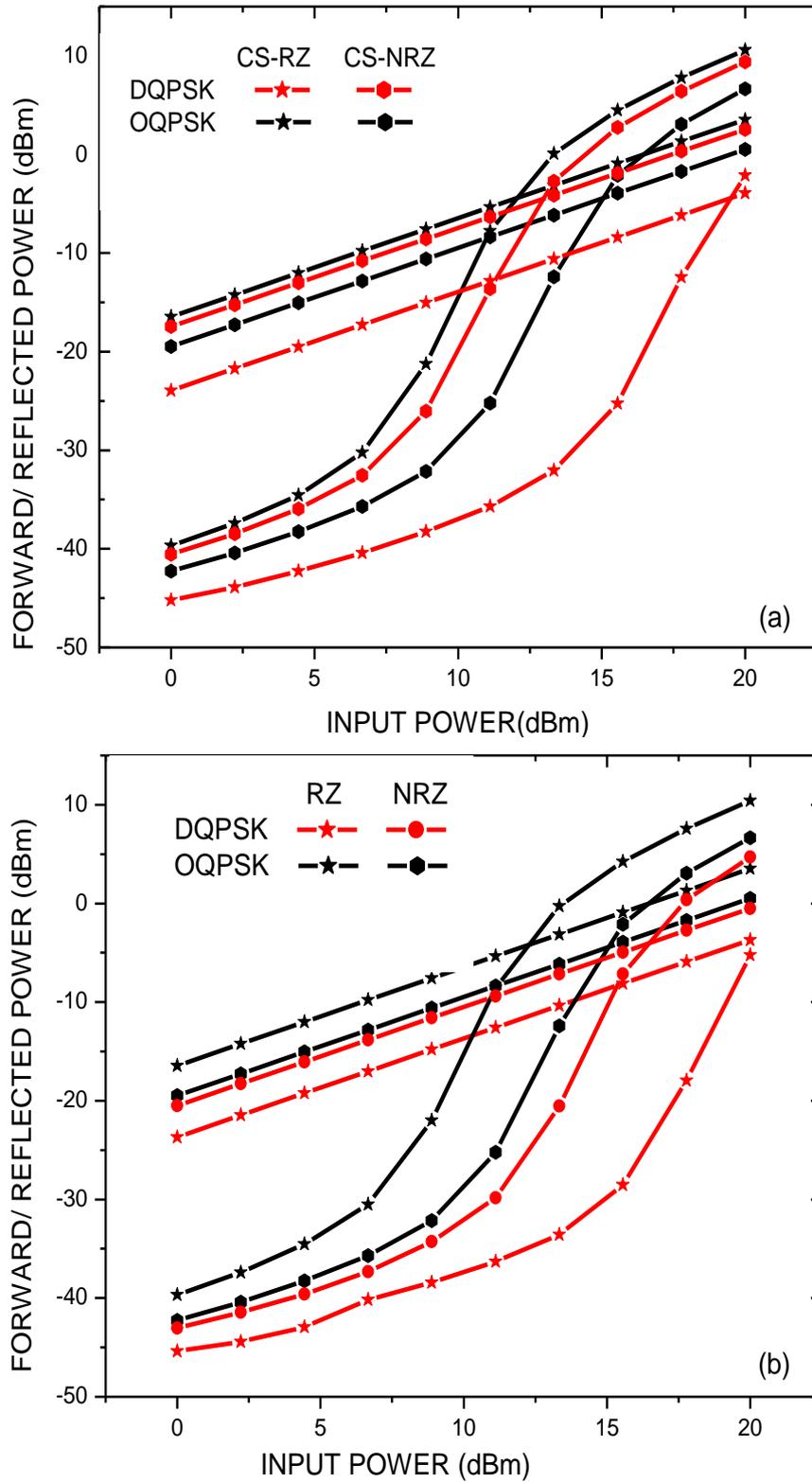
Figure 5. Forward and reflected power for (a) CS-DQPSK and CS-OQPSK (b) DQPSK and OQPSK at a transmission rate of 1Gb/s

Besides the impact of bit rate and suppression, we also compare RZ and NRZ performance on DQPSK and OQPSK modulation formats at 1 Gb/s. As it is observed in Fig. 5(a) and (b) that RZ modulation format with and without suppression using DQPSK format produces high SBS values compared to NRZ modulation format. For example, the SBS threshold is 19.76 dBm for CSRZ-DQPSK and does not suppress in RZ-DQPSK format. Comparing it with NRZ modulation format, low threshold values of 12.96 dBm and 16.55 dBm of CSNRZ-DQPSK and NRZ-DQPSK respectively were recorded.

Therefore, RZ format is suitable for DQPSK modulation scheme. RZ-DQPSK modulation format provides better tolerance to non-linearity and dispersion in optical fibres. High SBS threshold values are recorded when NRZ formats are used in OQPSK modulation scheme compared to RZ formats. When NRZ formats were used, high SBS values of 15.15 dBm and 15.24 dBm for CSNRZ-OQPSK and NRZ-OQPSK respectively were recorded. However, low SBS threshold values of 11.99 dBm and 12.35dBm for CSRZ-OQPSK and RZ-OQPSK respectively were recorded. Therefore, it is evident that NRZ modulation scheme is suitable for OQPSK modulation scheme.
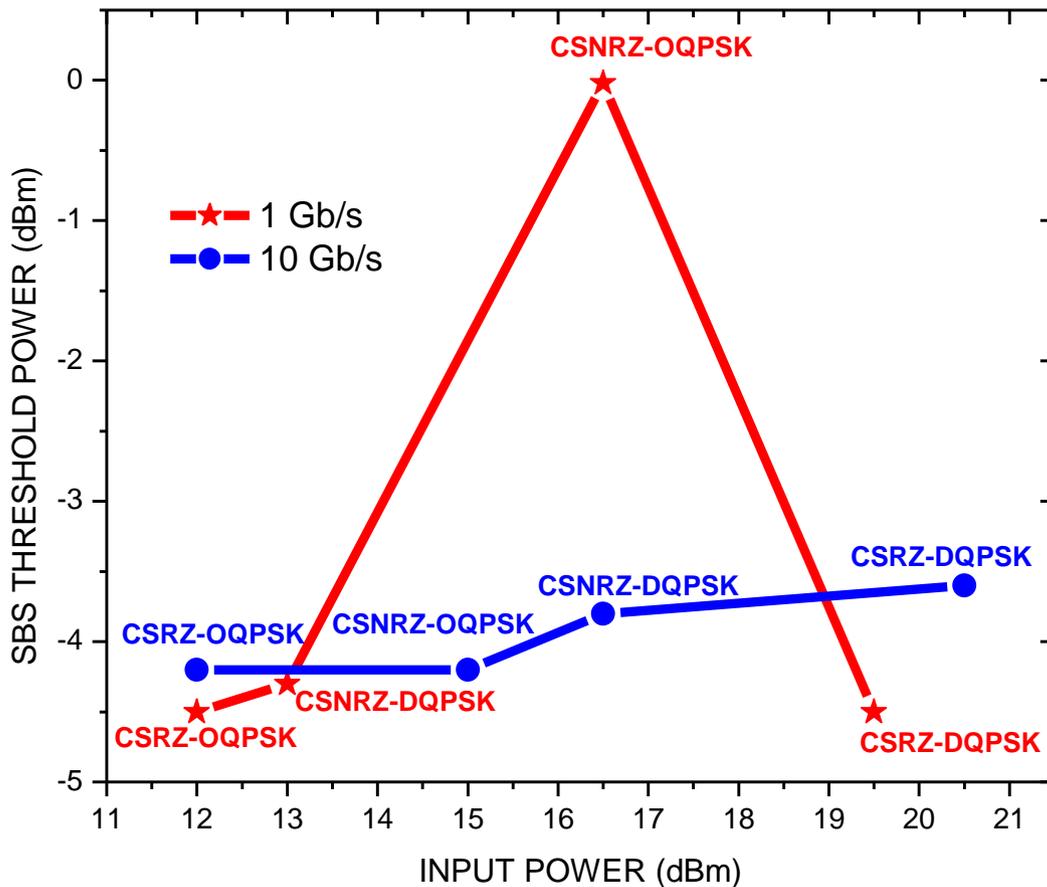
Figure 6. Variation of forward/ reflected power with SBS Threshold

We also analzed the performance of modulation formats with respect to SBS threshold as shown in figure 6. At 1 Gb/s transmission rate, CSRZ-OQPSK and CSNRZ-DQPSK saturated

at low input powers of 12.0 dBm and 13.0 dBm respectively. High SBS threshold value was recorded for CSNRZ-OQPSK at an input power of 16.5 dBm. However, CSRZ-DQPSK saturated at high input power of 19.5dBm. At 10 Gb/s, for CSRZ-OQPSK modulation format, a minimum input power of 12.0 dBm was required for the system to saturate compared to 20.5 dBm value for CSRZ-DQPSK at the same transmission rate. Therefore, at bit rate of 1 Gb/s and 10 Gb/s, CSRZ-OQPSK modulation format is very sensitive to SBS effect. It saturates at low input powers. The system can be used for optical amplification required for long distance signal transmission. However, at 1 Gb/s and 10 Gb/s, CSRZ-DQPSK modulation format shows better tolerance to SBS. It saturates at very high input powers of 19.5 dBm and 20.5 dBm respectively. It therefore means that this modulation format can be used for long distance signal transmission without amplification.

5. CONCLUSIONS

DQPSK and OQPSK is one of the efficient modulation formats for long-distance and high bit rate data transmission. In this paper, we studied the SBS tolerance for the two configurations transmitted at a bit rate of 10 Gb/s and 1 Gb/s. At 10 Gb/s and 1 Gb/s, CSRZ-DQPSK modulation format shows better tolerance to SBS. It saturates at very high input powers. At bit rate of 1 Gb/s and 10 Gb/s, CSRZ-OQPSK modulation format is sensitive to SBS effect. However, when DQPSK was used in CSNRZ modulation format, the system saturates at high powers when transmitted at a bit rate of 10 Gb/s with low SBS threshold at 1 Gb/s High SBS threshold value for RZ on DQPSK format is realized. However, at the same transmission rate, low SBS threshold values of 11.99 dBm and 12.35 dBm for CSRZ-OQPSK and RZ-OQPSK respectively were recorded. The SBS cause saturation of the transmitted power and increase noise in the transmitted signal. Thus, in order to prevent system performance degradation, optical fibre transmisiion have to operate under SBS threshold.

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