Investigating the Influence of Non-linear Effects in the Bidirectional Fiber System

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Research Article

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Investigating the influence of non-linear effects in the bidirectional fiber system

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Abstract

To investigate the influence of non-linearity in the bidirectional optical link which enables simultaneous uplink and downlink transmission of 16-QAM data signal. We analyze non-linear effects like self-phase modulation (SPM) and stimulated Brillouin scattering (SBS). The performance limitation due to the non-linear effects in the system is analyzed. The analysis shows that the SBS threshold for launch power is 16 dBm for unmodulated carrier signal and 6 dBm for modulated signal. At 6 dBm launch power, the system has an average Q of 44.

Keywords: Non-linear effects, Kerr effect, SBS, SPM, SBS threshold, Q factor, pump signal, stokes signal.

I. Introduction

The increase in data traffic using radio access services increases the need for high frequency transmission like mm-wave and microwave transmission. The RoF is a potential element to implement the mm-wave signal transmission[1]. The bidirectional transmission is employed in the RoF. The simultaneous uplink and downlink transmission takes place which increases the link budget[2]. The other methods to improve the link budget to accommodate large user is by increasing the launch power. Although increasing the launch power is a better choice to improve the performance, the non-linearity emerge[3][4][5].

Fiber propagation may involve the non-linearities such as Kerr effects of SPM, XPM, FWM and the scattering phenomena of SBS, SRS.[6][7][8] The other effects are negligible for bidirectional transmission and relatively low power transmission. The SBS effect generates additional stokes power backscattered in the fiber. The SPM in the SMF is studied numerically in [9].These studies show the complex behavior of SPM-GVD effect. The bidirectional transmission is not discussed in their work. The SBS effect is also not analyzed in the work.[10] discuss about the SBS in the RoF .The result analyze the transmission performance for LTE-RoF system with unidirectional transmission. The optimum launch power is estimated for direct modulation and external modulated LTE-RoF system. [11]discuss the SBST for various fiber types for transmission of 802.11 a/g WLAN signal in RoF system.

In this paper, we have investigated the influence of SPM and SBS in bidirectional fiber transmission system. The analytical characteristics for SPM, SBS in the system are examined. The SBST is estimated for optimum Q value for different launch power. The result demonstrates the appropriate selection SBST for improved system performances.

II. Non-linear effects

The non-linearity in the bidirectional fiber mainly occurs when the launch power is increased. This may restrict the length of the transmission system. The main non-linear effects are SPM,XPM,FWM which are due to the third order susceptibility which is non-linear in nature [12]. The scattering effects SRS, SBS are due to the non-linear scattering mechanism of the light inside a dielectric medium.[13] The propagation of electric field inside the fiber may induce polarization P which is represented by

$$P=\varepsilon_0(\chi^{(1)}E+\chi^{(2)}EE+\chi^{(3)}EEE) \quad (1)$$

Where $\chi^{(1)}$ is linear susceptibility , $\chi^{(2)}$ is insignificant for fiber communication and $\chi^{(3)}$ is the main contributing factor for the system [14].

A.SPM

The SPM effect induces additional phase due to the change in intensity as a function of time. The phase of signal is randomly changed by varying refractive index along the fiber length. The non-linear phase accumulated over the length of fiber is given by

$$\Phi=\frac{2\pi n_2 L P_{in}}{\lambda\, A_{eff}} \quad (2)$$

This induced phase when changes with time result in chirping.[15] The GVD which is delay of frequency component already present in time domain and it is given by

$$\Delta\tau^2=\tau^2+(D\ L\ \Delta\tau)^2 \quad (3)$$

$\Delta\tau$ is the spectral spread induced and τ is the spectral width, D is the dispersion coefficient, L is the effective length. The SPM occurs where different new frequency component of carrier arranged in the space. The largest spread in the pulse in the frequency domain due to SPM is given by

$$\Delta w=2\left(\frac{2\pi}{\lambda} n_2 \frac{dI}{dt}\right)L \quad (4)$$

$\frac{dI}{dt}$ is the change in intensity with time n_2 is the refractive index. λ is the wavelength of operation L is effective length.

B. SBS

SBS is the non-linear effect which is very serious in case of bidirectional fiber occurs by electrostriction which leads to compression of the material[16][17]. This compression generates acoustic wave which interacts with the incoming optical field. This interaction may generate a downshifted stokes frequency which propagates in the opposite direction of the input pump frequency[18]. This may be stimulated more as the pump power increases further. The frequency difference between the pump signal and the stokes signal is represented by

$$\Omega_B=2(\frac{2\pi}{\lambda} n_{eff} V_a) \quad (1)$$

The frequency difference usually is ranging between 11-13 GHz for SMF at 1550nm[19].The SBS occurs only beyond a threshold launch power of P_{th} for an effective length which is given by

$$P_{th} = \frac{21 A_{eff}}{g_B L_{eff}}(1+\frac{\Delta\gamma}{\Delta\gamma_B}) \quad (6)$$

Where g_B is Brillouin gain coefficient and A_{eff} is effective area of fiber and L_{eff} is effective length of fiber where the SBS effect is significant[20]. $\Delta\gamma$ is the linewidth of the pump and $\Delta\gamma_B$ is the linewidth of the stokes signal.

III. Experimental transmission setup

To examine the effect of SPM and SBS in bidirectional fiber and link for simultaneous uplink and downlink is implemented.

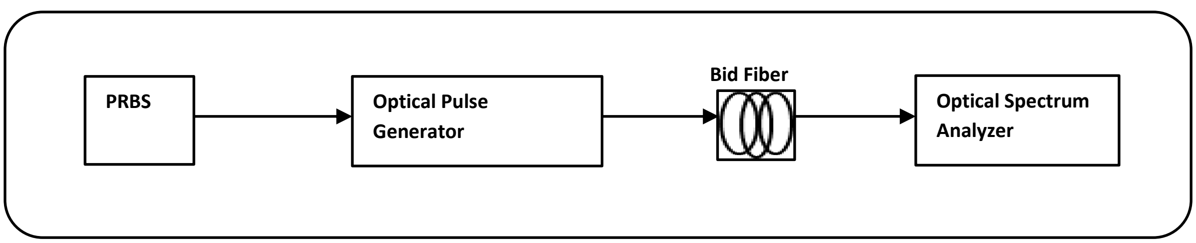
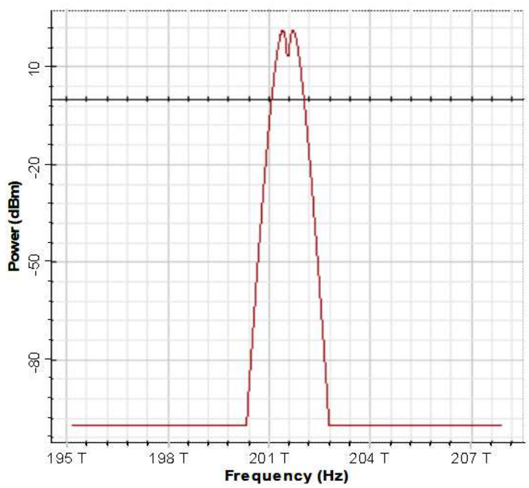


Fig. 1 Set up to observe the sprectal broadeing in bidirectional fiber due to SPM.PRBS:Pseudo Random Bit Sequence.

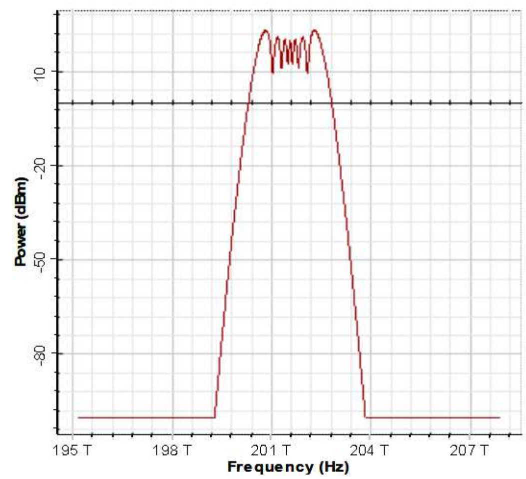
A. SPM analysis

To analyze the SPM effect, the data is modulated on optical carrier of frequency 1600 nm and power 1500 W and fed into bidirectional fiber of length 0.02096 km. The optical signal propagates through the fiber and as the power increases the non-linearity in the bidirectional fiber increases and the signal is chirped. This in turn may increase the spectral spread of the signal. The chirp in the optical data signal is shown for various signal power. The fig.2. clearly illustrates the spectral spread as power increases.

(i)



(ii)



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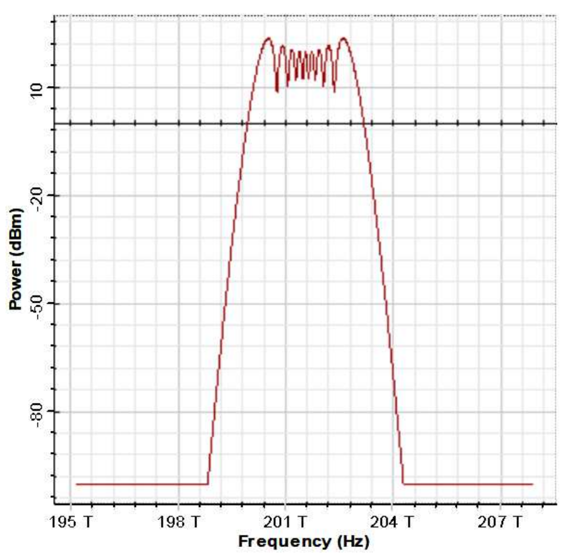

(iv)

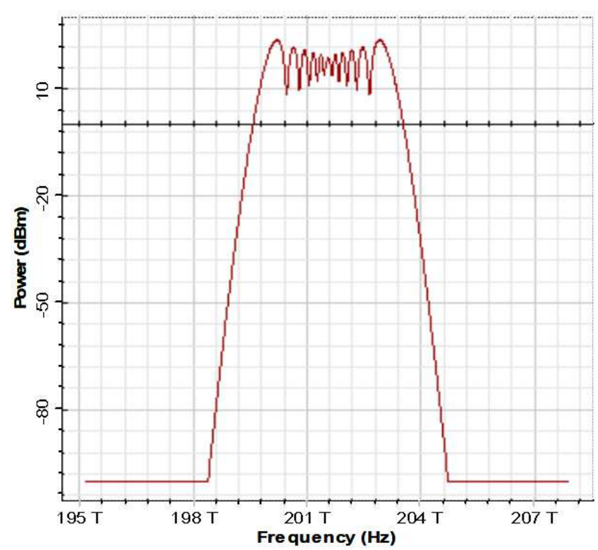

Fig.2.Spectral broadening with increase in launch power at (i) 0 dBm (ii) 5 dB m (iii) 10 dBm (iv) 15 dBm

B.SBS Analysis

The bidirectional fiber is fed with input from laser diode with center frequency 193.1 THz. The power meter is utilized at the transmitter and receiver side to estimate the transmitted and reflected power. The signal propagates through the bidirectional fiber. As the launch power increases the electrostriction occur and light wave collide with the acoustic wave and stokes signal backpropagates in the opposite direction. The downshifted signal is observed through optical signal analyzer (OSA). Fig.5. shows the total received power vs launch power for transmitted power and reflected power. As the launch power increases the transmitted power linearly increases. Beyond the SBS threshold (SBST) of launch power the reflected power increases exponentially illustrated in Fig.5. To maintain the power conservation transmitted power saturates. Fig.4. Shows the downshifted stokes signal with 11 GHz shift from the source input.

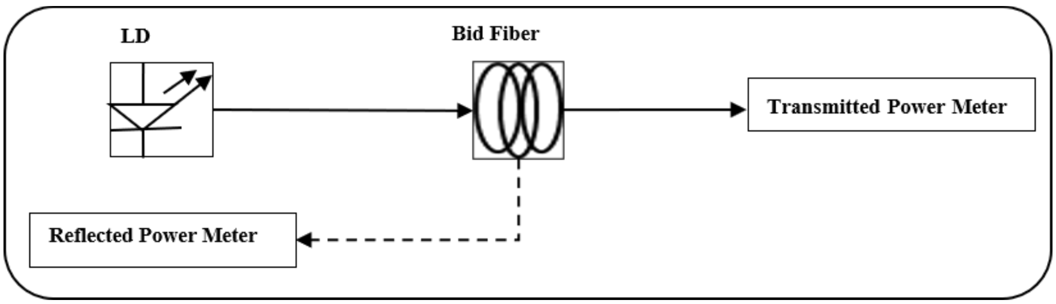

Fig.3. Setup for estimating transmitted and reflected power in bidirectional fiber with SBS; LD: Laser Diode

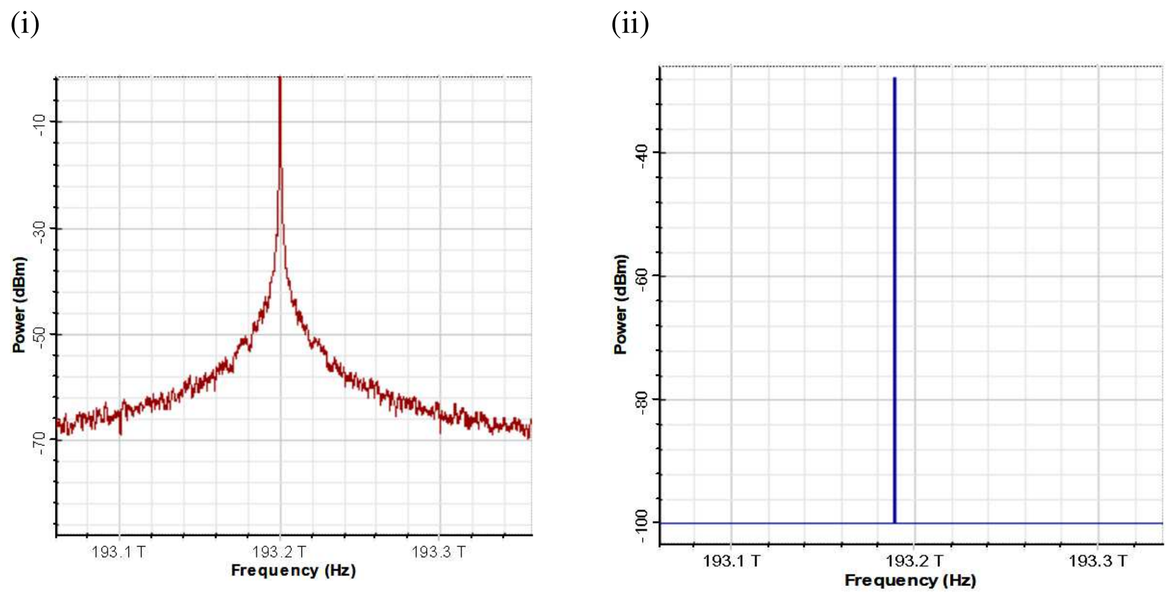

Fig.4. (i) Transmitted pump Signal (ii) Reflected stokes signal downshifted at 11 GHz from pump frequency

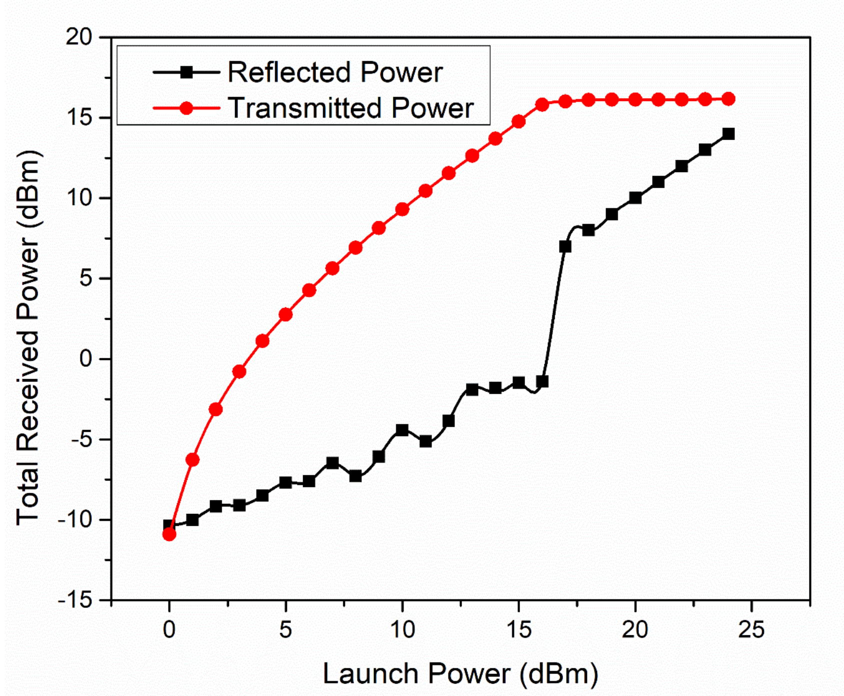

Fig.5.Transmitted power and received power for increasing launch pump power

B. System performance analysis

Fig.6. shows the experimental setup to estimate the system performance. The bidirectional link has a central station and a base station each having transceiver unit. The central station has a source and a modulator. At CS, the laser diode of frequency 193.1THz and power of 0dBm emits carrier signal. The downlink signal of 5Gbps modulates the optical carrier with an external modulator MZM. The modulated signal propagates through the fiber of length 20 km. The downlink signal is received at the base station. The received downlink signal is converted to electrical signal by a photodiode and system performance is analyzed with a BER analyzer.

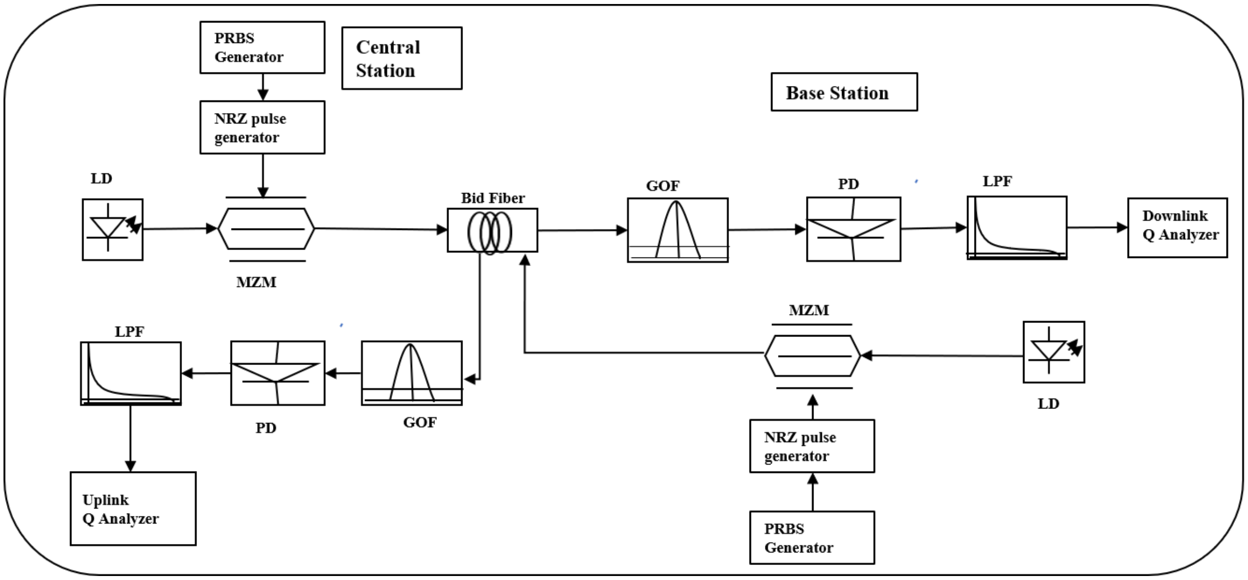

Fig. 6. Setup for system performance analysis with bidirectional fiber with SPM, SBS to estimate the Q factor for various launch power; LD: Laser Diode, MZM: Mach Zehnder Modulator, PRBS: Pseudo Random Bit Sequence, GOF: Gaussian Optical Filter; LPF: Low Pass Filter; PD: Photo diode.

The uplink transmission from user end is performed simultaneously. At BS the laser diode with center frequency 193.2THz is used to modulate the uplink data of 5Gbps. Uplink signal is co-propagated through the bidirectional fiber simultaneously along with downlink signal. When the launch power of the laser diode is increased beyond the SBS threshold the reflected power downshifted at 11 GHz interacts with uplink signal and this may degrade the performance of the uplink. The Q factor is plotted for increasing launch power. The Q factor degrades for downlink signal beyond threshold launch power. This also affects the uplink Q factor which degrades beyond SBST because of the crosstalk between stokes signal and uplink pump signal.

IV. Discussion

From the results it is clear that the additional phase is induced which changes with time and grows with increase in power. The GVD induces the delay in frequency which can be avoided by SPM in negative dispersion systems[21]. This gives rise to soliton effect which can be tailored properly by proper parameter selection. The phase introduced by dispersion exactly compensate the phase induced by SPM. This can be used in shortening of the pulse by dispersion delay and non-linearity induced broadening. Femto second laser can be designed with this principle which are of category ultrafast lasers.The non-linearity discussed above can be compensated by selection of fiber material with minimum refractive index change. This can lead to very high complexity. The DSP available for compensating these effects can be employed which reduces the cost and complexity of the system design.[22][23]

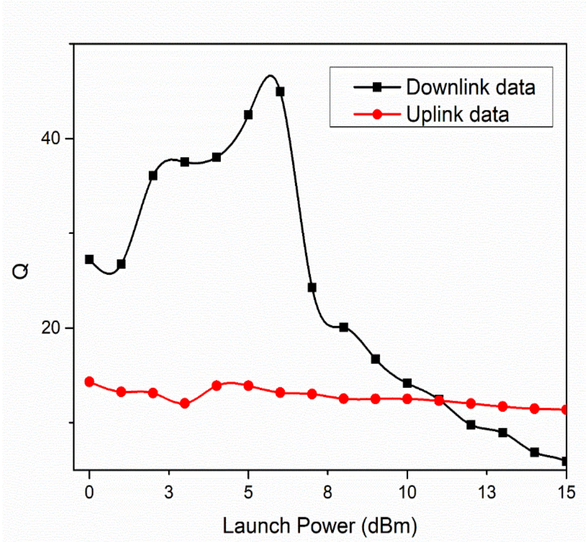

Fig.7.Q value variation for increasing launch power in bidirectional link with SPM, SBS.

Conclusion

The impact of non-linear effect in bidirectional fiber and bidirectional link has been investigated. The SPM increases with increase in launch power. The launch power beyond 16 dBm generates SBS effect in unmodulated source. For bidirectional link for simultaneous uplink downlink transmission the launch power must be kept within 16 dBm for minimum non-linear effect. For the examined launch power, the Q factor is 44 for a transmission distance of 20 km bidirectional link. The impact of the non-linear effect can be compensated by using signal processors.

Acknowledgement

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Figures

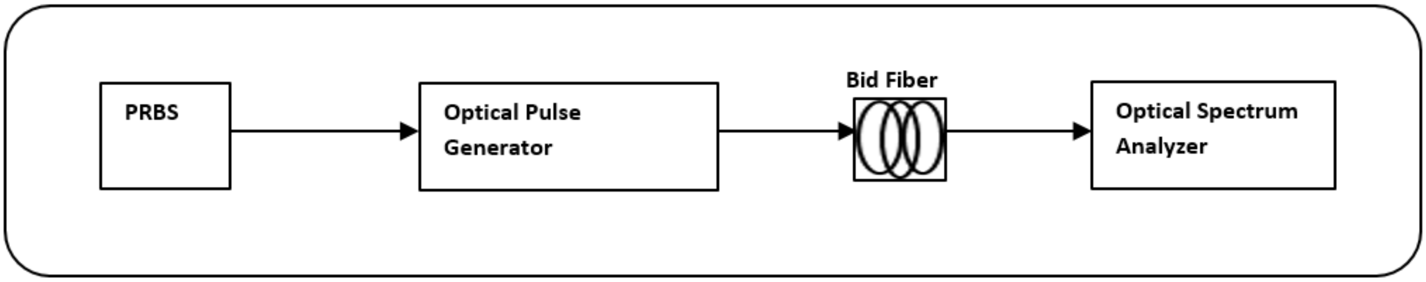

Figure 1

Set up to observe the sprectal broadeing in bidirectional fiber due to SPM.PRBS:Pseudo Random Bit Sequence.

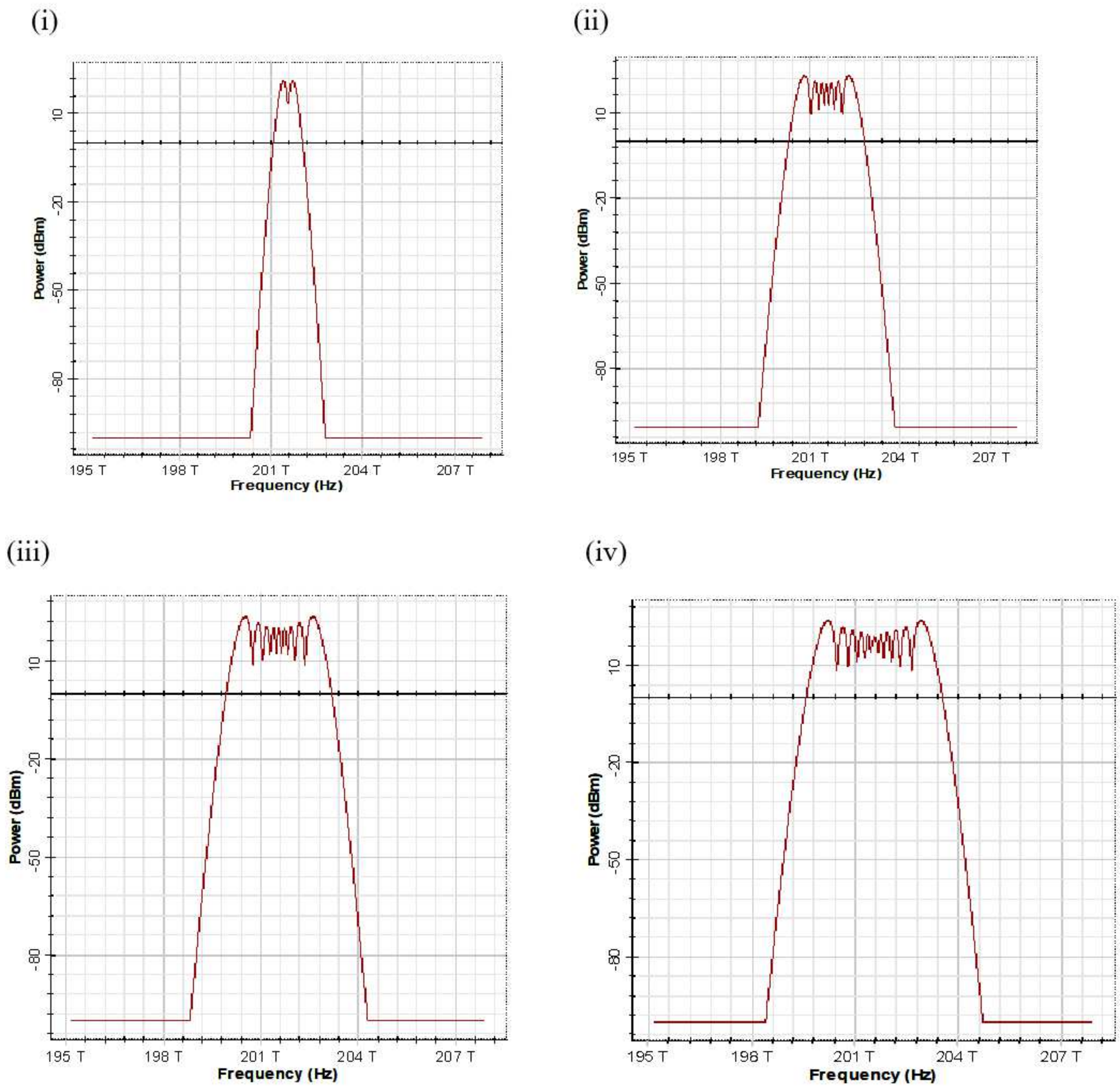

Figure 2

Spectral broadening with increase in launch power at (i) 0 dBm (ii) 5 dB m (iii) 10 dBm (iv) 15 dBm

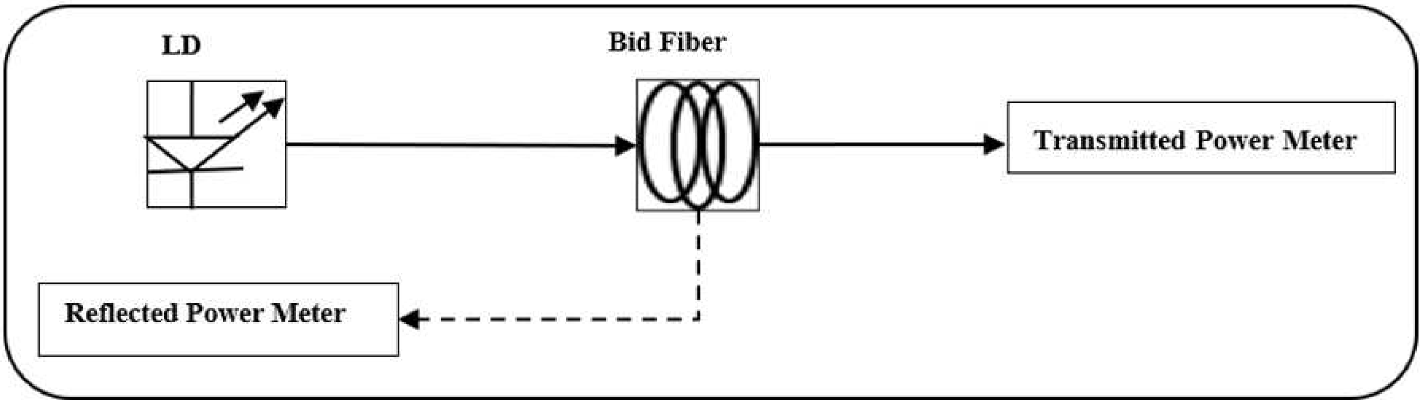

Figure 3

Setup for estimating transmitted and reflected power in bidirectional fiber with SBS; LD: Laser Diode

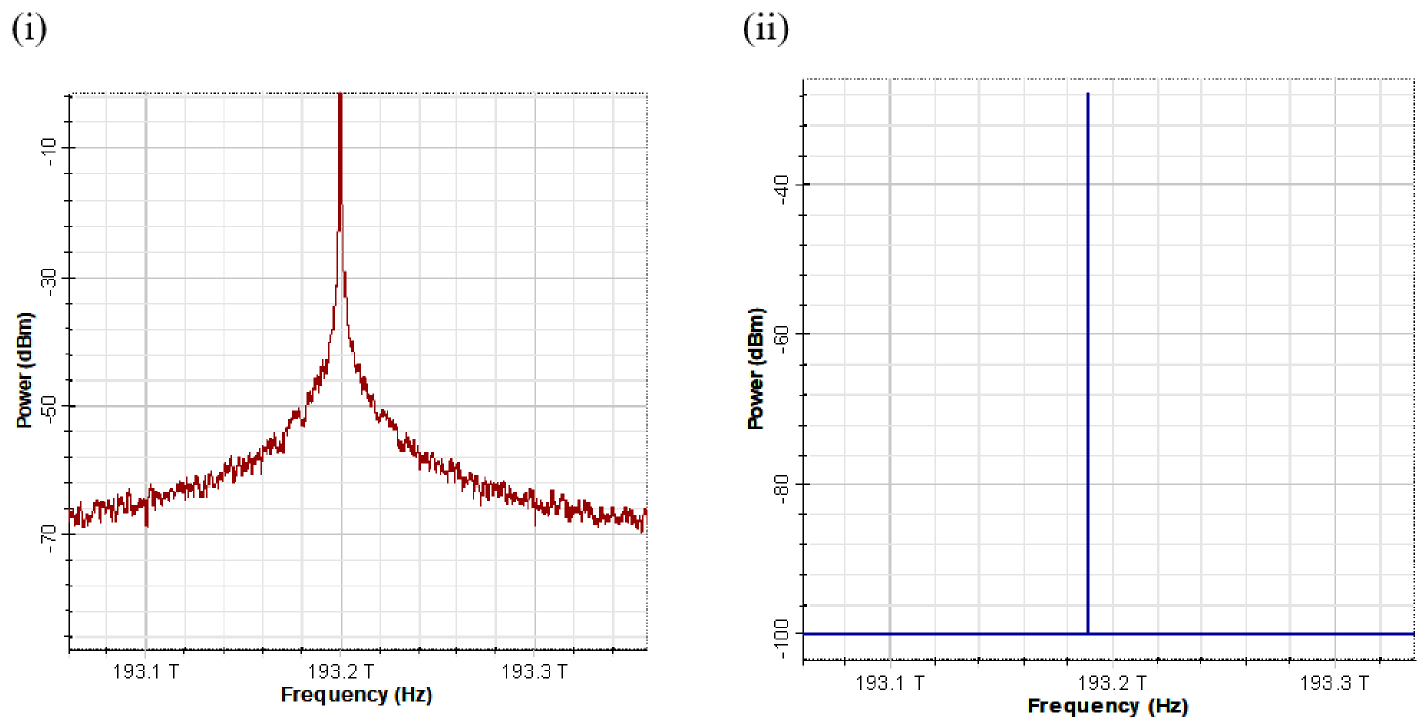

Figure 4

(i) Transmitted pump Signal (ii) Reflected stokes signal downshifted at 11 GHz from pump frequency

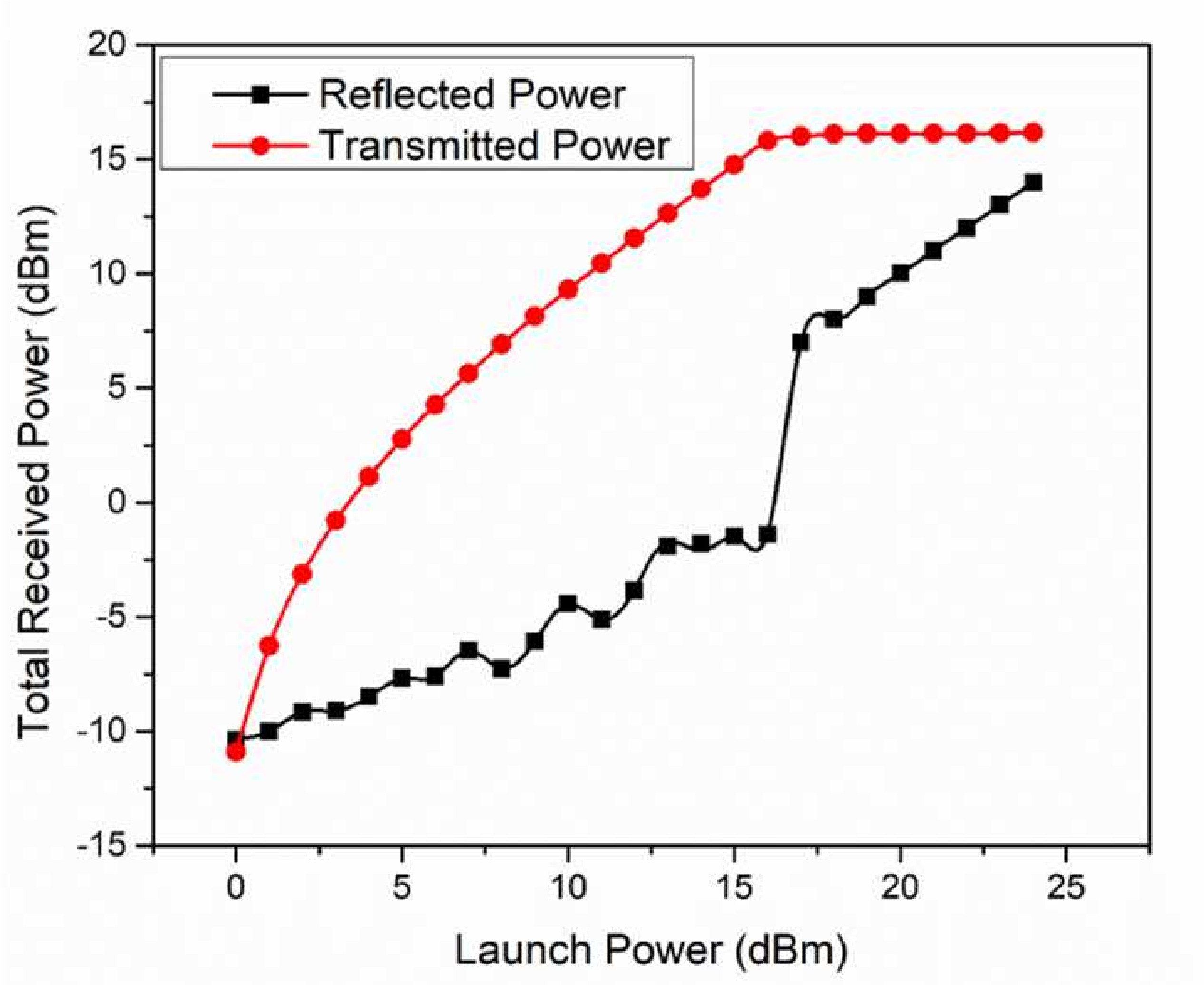

Figure 5

Transmitted power and received power for increasing launch pump power

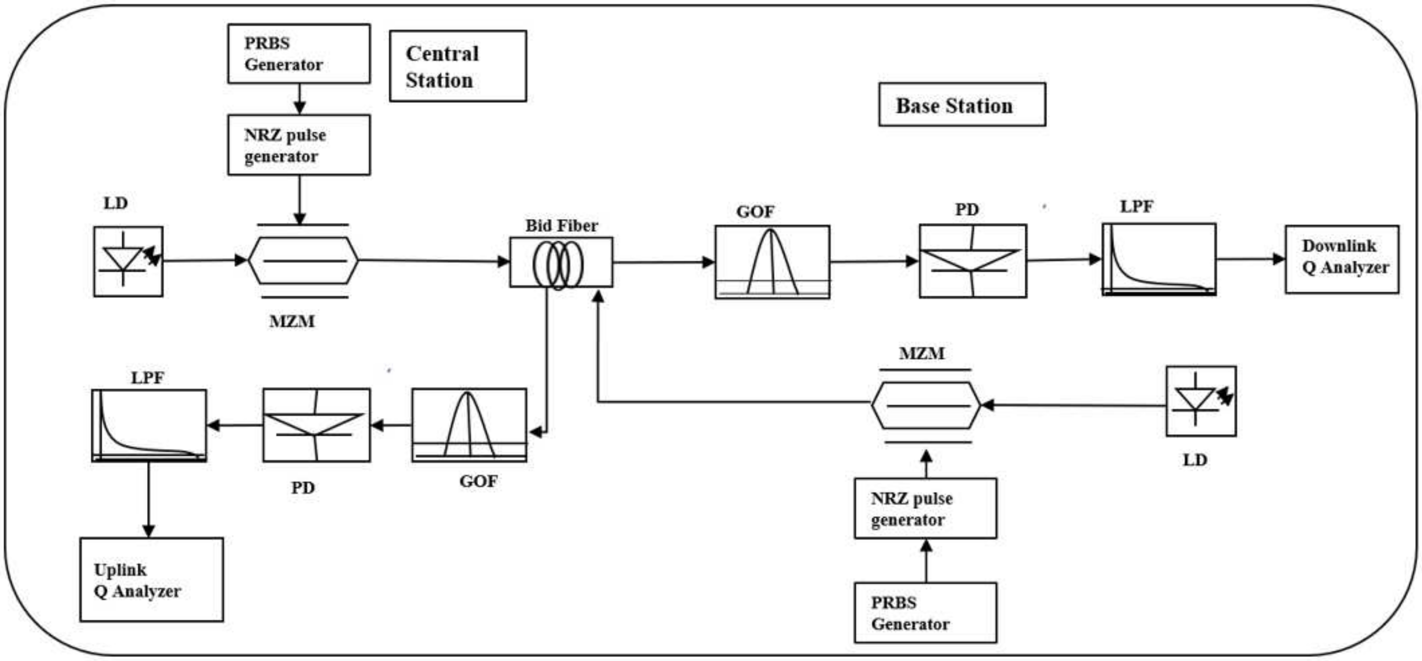

Figure 6

Setup for system performance analysis with bidirectional fiber with SPM, SBS to estimate the Q factor for various launch power; LD: Laser Diode, MZM: Mach Zehnder Modulator, PRBS: Pseudo Random Bit Sequence, GOF: Gaussian Optical Filter; LPF: Low Pass Filter; PD: Photo diode.

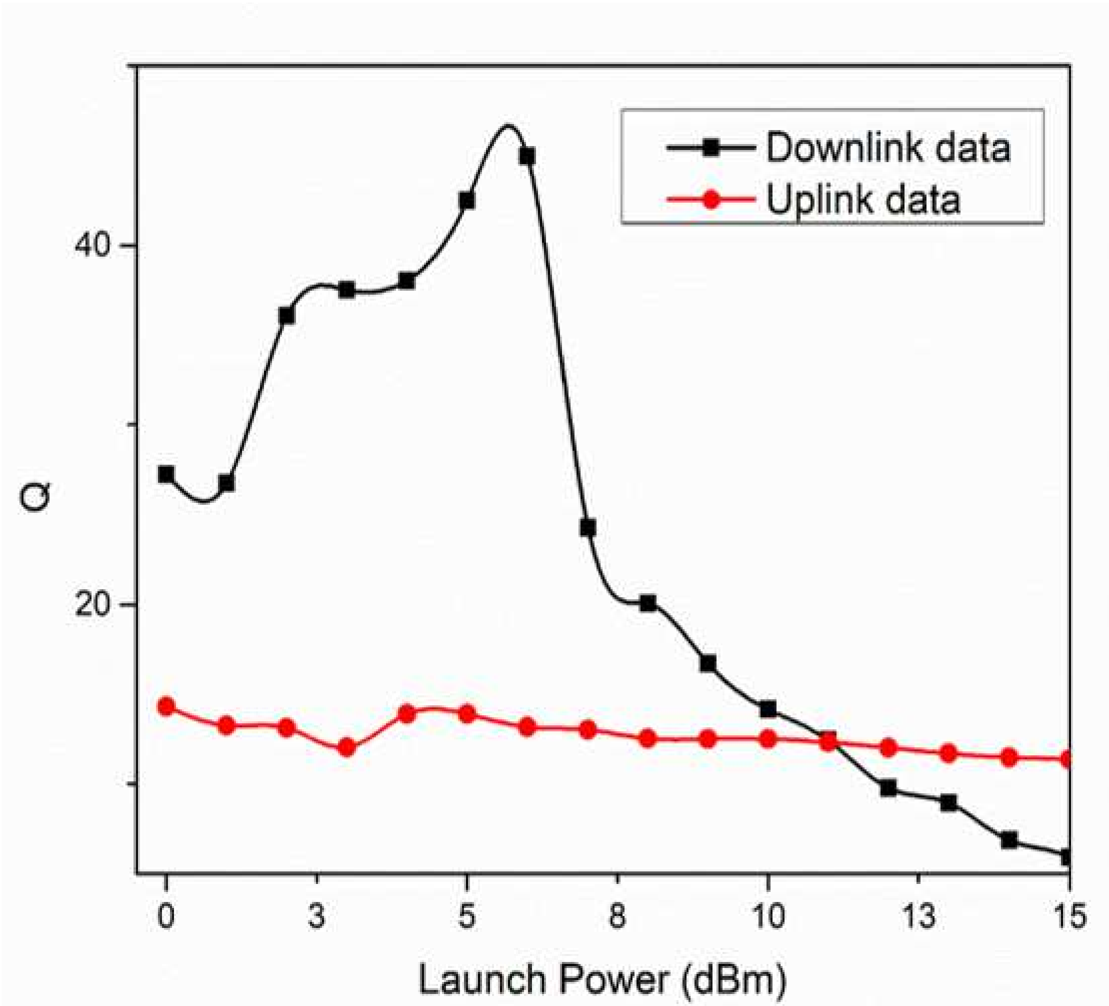

Figure 7

Q value variation for increasing launch power in bidirectional link with SPM, SBS.