Non-linear Effects of High Rate Soliton Transmission on DWDM Optical Fiber Communication System

Brian Pamukti
School of Electrical Engineering
Telkom University
Telekomunikasi Street,Indonesia (+6222) 7564-108
Email: bpamukti@students.telkomuniversity.ac.id

Doan Perdana
School of Electrical Engineering
Telkom University
Telekomunikasi Street,Indonesia (+6222) 7564-108
Email: doanperdana@telkomuniversity.ac.id

***Abstract*— The bit error rate (BER) decreasing of soliton transmission in dense wavelength division multiplexing (DWDM) system because of non-linear effects is investigated. Non-linear effects in DWDM are brought on by the Quadratic Electro-Optic effects (Kerr Effects) and inelastic scattering. The Kerr effects included self-phase modulation, four wave mixing, and cross phase modulation. Kerr effects can cause problems in the limited number of channels and bandwidth. In this paper, we analyzed the impact of Kerr-effect on 10 Gbps soliton transmission DWDM systems which found that the value of refractive index of non-linear (n_2) influences on reducing the number of input channel. The results show that soliton can increase quality of performance with Q factor more than 6. Several research with same bitrate using a length of 100 km, this paper analyzed longer distances have doubled, which is 200 km. Transmit power has a lower power value of about 35%, it is very important for issue of energy savings. In addition, the number of channels increasing up to 80 channels.**

Keywords—Non-linear Effect, Soliton, DWDM, BER, channel.

I. INTRODUCTION

Soliton pulse is a pulse of light that can move in a nonlinear medium without changing shape, as if moving pulses in dispersive non-linear media. The idea of soliton is often said to be started in the month of August 1934 when the Scottish physicist John Scott Russell, observing the phenomenon of water waves on the Canal Edinburgh-Glasgow [1]. The water waves propagate straight without experiencing significant change in the shape and speed for a long distance as well as the relatively long time span along the canal. Results of research conducted by Algety Telcom in 2001 proved that the 1 Tbps soliton pulses successfully transmitted up to a distance of 1000 km [2].

A deficiency in DWDM systems is a non-linear effect including Kerr effect and inelastic scattering that occurs in the optical fiber resulting in the limited number of channels that can be transmitted. Non-linear effect in DWDM, which is the result of the Kerr Effect, is Self-Phase-Modulation (SPM) which can modulation itself pulse under the influence of non-linear refractive index as in equation((1)), the impact of SPM causes Cross Phase Modulation (XPM) and Four Wave Mixing (FWM), whereas for inagulastic scattering is Stimulated-Raman-Scattering (SRS) and Stimulated-Brillouin-Scattering (SBS). These non-linear effects can reduce the quantity of channels.

In [3] has been discussed about the non-linear effects (XPM, FWM, SRS) in DWDM with Non Return to Zero (NRZ) modulation type. It shows how the non-linearitys increase in optical fiber communication system by increment in optical fiber communication system by expanding the info power and number of information channels. Using the analogy of PUMA in optical technologies have the effectiveness and efficiency are better with reference to the Convergence parameters like Delay, Packet Delivery Ratio and Packet Loss Ratio, can be used for consideration [4]. By using optical soliton transmission have been reported at [5] ,[6] ,[7]. The non-linear effect on the soliton systems have been studied in [7]. It is shown that solitons are resistant to polarization mode dispersion (PMD). In [6] and [7] have been evaluated the effect on optical fiber nonlinearities of soliton transmission on 16 and 32 channels.

This paper discusses more about the influence of nonlinear effects especially Kerr-effect on soliton transmission DWDM systems by changing the channel spacing and number of channels. This research is expected to analyze the nonlinear effects up to 80 channels, with the restriction that the BER value is 10^{-9}. First, on a system that has 32 channel and 100 GHz channel spacing, the Q-factor and BER are evaluated by changing the value of the refractive index of non-linear up to the worst conditions. Then, at the worst refractive index of non-linear, we investigate the Q-factor by changing the channel spacing. Further, still on the worst refractive index of non-linear, we investigate the value of the Q-factor on 64 channels with various channel spacing. Finally, a paper has the contrast of previous research like investigating the effect of non-linear fiber on 200 km length and 80 channels with various channel spacing.

The contribution of this research is using soliton pulse to overcome a few of non-linear effects in DWDM technology. The aim of soliton pulse is to keep shape of pulse same as at the first transmitted, until arrive in Photodetector. The novelty of this research is the soliton can increase quality of optical fibre transmission performance.

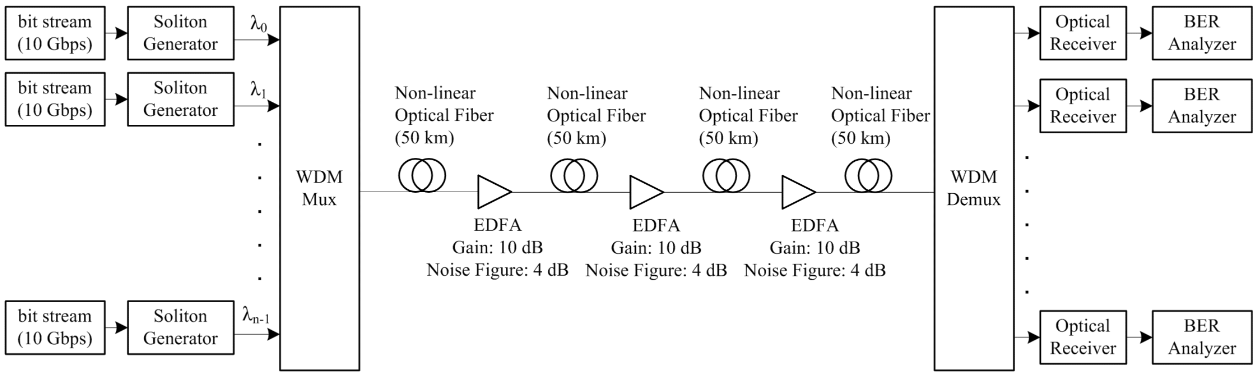


Fig. 1. Soliton Transmission DWDM System Over Non-linear Optical Fiber [8]

This paper is divided into four main sections. First, the introduction, discusses the background of the problems of Kerr Effect, and explain the sections of paper simply and convey the contributions that resulted from this research. Second, scenario of research about the soliton signal generator, block diagram of DWDM system, non-linear optical fiber generator, and the numerical parameter of simulation. Third, result and analysis, related to the calculation, simulation and discussion of the research results. The last, Conclusion is a summary of the results of research that has been done.

II. Scenario of Research

Non-linear effects in the optical fiber is asymmetric. This is because the material during the manufacturing plant had increased refractive index that is not the same in every side. The refractive index is not the same though small, will impact the transmission system, when a signal transmitted light with great intensity. The asymmetric nature of the refractive index into one of the scenarios in this study. When all the materials have asymmetric value on the refractive index, as well as in optical fibers. The nature of the optical fiber is used in the planning of the generation of solitons by taking the character of SPM and GVD. In addition, the scenarios were analyzed negative effects that arise and affect the working system DWDM networks.

In this research, implementation of the soliton transmission DWDM system over non-linear optical fiber is shown in Fig. (1). In the simulation, it is launched 10 Gb/s pseudo random bit sequence (PRBS) of soliton with pulse width equals to 17 ps and peak power equals to 7.075 dBm. We generate the soliton pulse for 32 channel, 64 channel, and 80 channel with the 193.1 carrier frequency. This channels are ordered to the wavelength division multiplexing (WDM), yielding the serial transmission over non-linear optical fiber. The length of communication link is 200 km by using three EDFAs (Erbium Doped Fiber Amplifiers).

The phenomena of non-linearity in fiber is represented by equation (1) [9]

$$n = n_0 + n_2 I \tag{1}$$

where n_0 is core refractive index, n_2 is refractive index of non-linear, and I is optical power intensity. The generation of non-linear effects such as FWM, SPM and XPM obtained through equation (2) [9]

$$(\phi) = \frac{2\pi n L}{\lambda} = \frac{2\pi(n_0 + n_2)L}{\lambda} \tag{2}$$

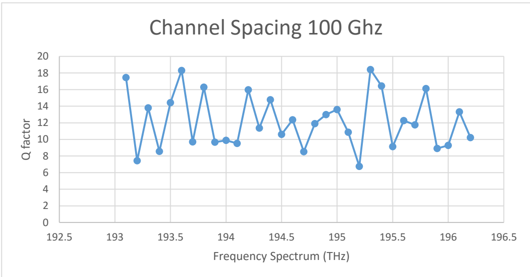
where ϕ is phase modulation, L is propagation length, λ is optical wavelength. The value of the refractive index of non-linear n_2 is determined initially by the following equation (3) [10]

$$n_2 = \frac{48\pi^2}{c{n_o}^2} X_{111} \tag{3}$$

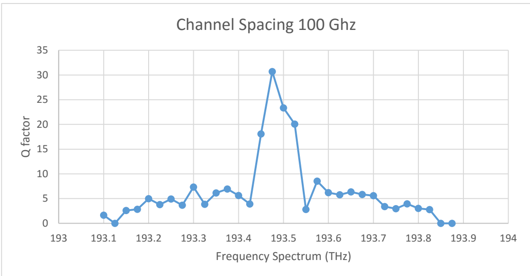
where X_{111} is third-order non-linear susceptibility. In this simulation, it is used S_iO_2 optical fiber with no equals to 1.4 and X_{111} equals to $6 \times 10^{-15} m^3 s/W$. Accordingly, by conducting equation (3), it is obtained that the value of n_2 is equal to 4.4526×10^{-21}. The value of the refractive index of non-linear n_2 (in units of m^2/W) is the range of 10^{-20} to 10^{-18} in the medium of glass. Based on the reference value and the calculation of the equation(3) , then there is a scenario to change the value of the refractive index of non-linear to the worst conditions i.e. 4.4526×10^{-20} ; 4.4526×10^{-19}; 4.4526×10^{-18}. In addition, here is also conducted other research scenarios that changing to the number of channels (32 channel, 64 channel, and 80 channel) and channel spacing (25 GHz, 50 GHz, 100 GHz). Accordingly, the performance of DWDM can be analyzed by changing the n_2

III. Result and Analysis

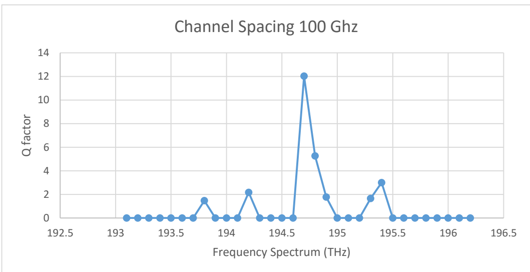
First of all, we investigate the soliton transmission on 32 channel with 100 GHz channel spacing. Analysis is conducted to see how many the numbers of channels that can survive when the refractive index changed to the worst conditions.



(a) $n_2 = 4.4526 \times 10^{-20}$



(b) $n_2 = 4.4526 \times 10^{-19}$

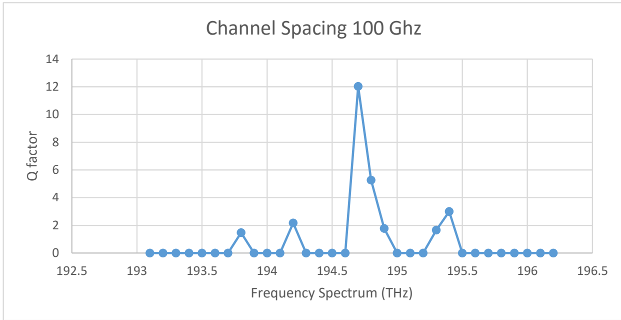


(c) $n_2 = 4.4526 \times 10^{-18}$

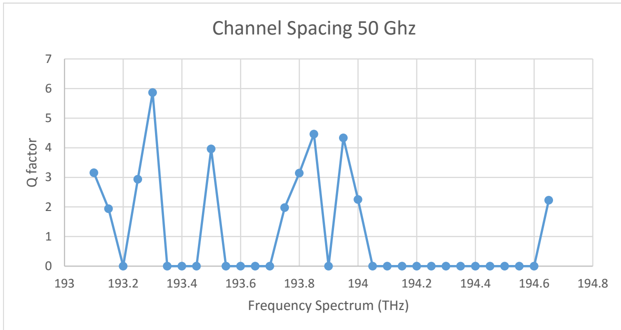
Fig. 2. Q-factor of 32 channel at different n_2

Fig.(2) shows a decline in the value of the Q-factor of the change in refractive index of non-linear n_2. It is shown that the increase in the value of the refractive index of non-linear results in an increase in the quantity of channels that can not be transmitted. Changes in the refractive index of non-linear, it means that changing in the core refractive index which is very influential in the transmission process, both in terms of dispersion and attenuation. That changing reduces the quantity of channels that can be transmitted.

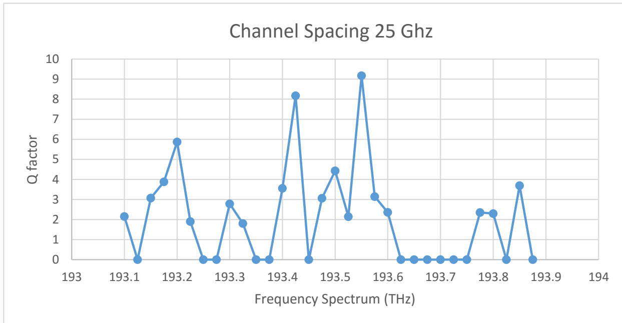
To increase the accuracy of this research, it is analyzed of the changes in channel spacing on 32 channels (see Fig. (3)). This analysis uses the non-linear fiber with the worst refractive index (4.4526×10^{-18}). We have seen that the performance of standard optical technology has BER of 10^{-9} or Q-Factor 6 [11].The Research using soliton pulses boost the Q factor of up to 50% when compared with the research [3].



(a) 100 Ghz



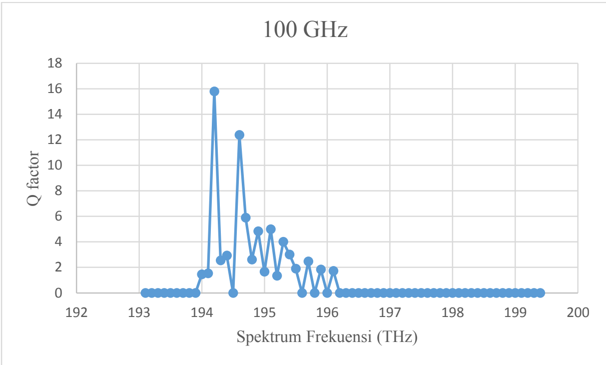
(b) 50 Ghz



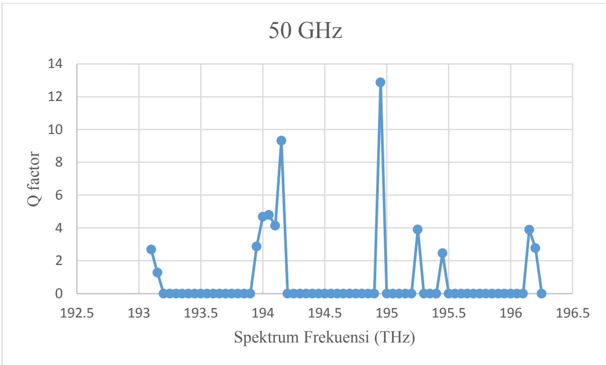
(c) 25 Ghz

Fig. 3. Q-factor of 32 channel at different channel spacing

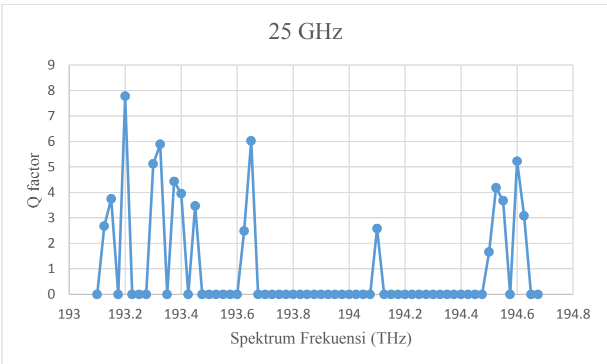
Fig.(3) shows the value of the Q factor on 32 channels with a refractive index of non-linear, $n_2 = 4.4526 \times 10^{-18}$. It can be concluded that the effect of channel spacing, which is very significant in reducing the number of channels that have the BER value over 10^{-9}. In the 25 GHz channel spacing, there is 3 channels with Q factor greater than 6 or BER less than 10^{-9}. Whereas, in the channel spacing of 50 and 100 GHz, there is only one channel that has a BER less than 10^{-9}.



(a) 100 Ghz



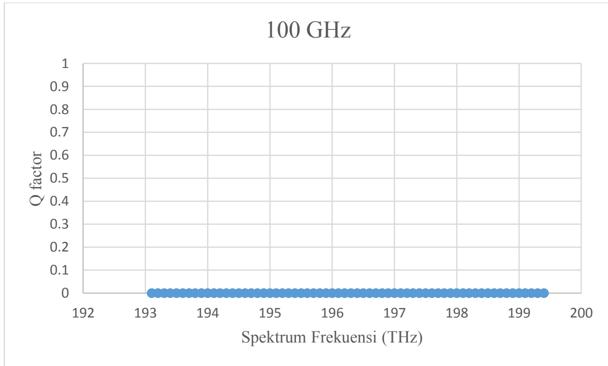
(b) 50 Ghz



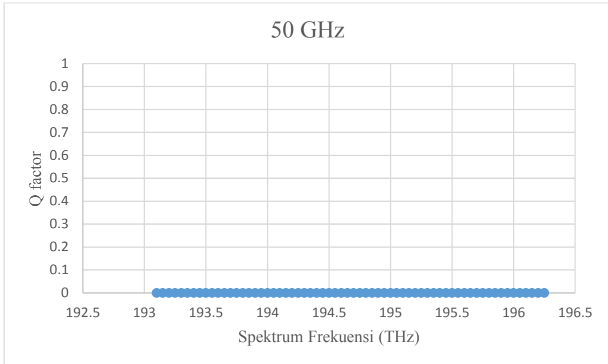
(c) 25 Ghz

Fig. 4. Q-factor of 64 channel at different channel spacing

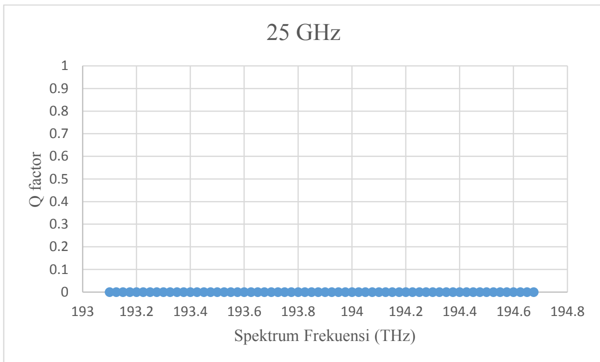
Furthermore, the analysis is performed on 64 channels with various channel spacing. Fig.(4) shows the value of the Q factor of 64 channels on the worst refractive index of non-linear. It shows more canals damaged by the effects of non-linear. Based on two previous scenarios, transmission of 32 channels and 64 channels, it can be concluded that if more channels are transmitted in non-linear fiber, then it is resulting in more damaged channels.



(a) 100 Ghz



(b) 50 Ghz



(c) 25 Ghz

Fig. 5. Q-factor of 80 channel at different channel spacing

For more accurate, Fig.(5) describes the phenomenon that occurs on 80 channels. From Fig.(5), it can be seen that all the channels have BER value equal to 1 or Q factor equal to zero. This phenomenon proves the Kerr-effect on the non-linear fiber that severely limit the number of transmitted channel. Changes of n_2 coupled with the increasing number of soliton pulses cause a shift in refractive index optical fiber. The changes are in accordance with equation (1)

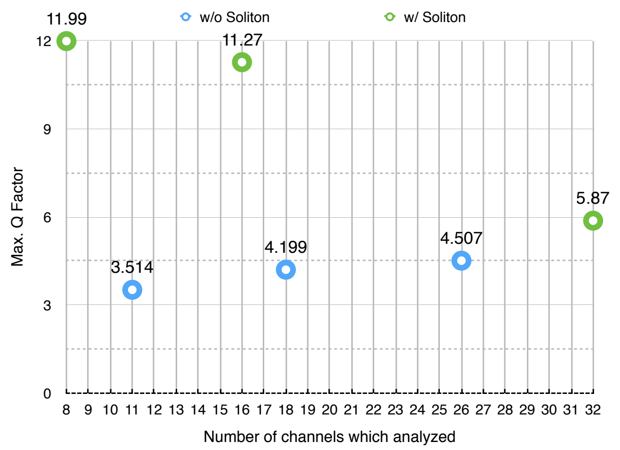


Fig. 6. Comparison performance with and without soliton

Fig. (6) shows about the comparison DWDM technology using Soliton pulse and without it. The green circle is our research with soliton pulse. It has increases value of Q factor about 46% in the maximum of number channel. In addition, soliton pulse can be one of solution to reduce Kerr-effecs.

IV. Conclusion

We have conducted DWDM channel 10 Gbps soliton transmission with non-linear effects over a distance of 200 km. It is shown that the changes in the value of the refractive index of non-linear n_2 greatly affect the performance of the soliton transmission. The increasing value of refractive index of non-linear n_2 influences on reducing the number of input channels that have BER under 10^{-9}. But the results showed that solitons can improve the quality of performance by Q factor more than 6. Therefore, it can be concluded that the non-linear effects limit the number of channels in DWDM optical transmission systems for refractive index shift produces a wavelength shift operation, but soliton could be one compensation for non-linear effects.

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