Research Article

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8×10 Gbps optical system with DCF and EDFA for different channel spacing

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Abstract
An optical system with specification of eight channels, 10 Gbps as bit rate, differential phase shift keying (DPSK) as a modulation format and 300 Km optical fiber length that consist of five spans each with 60 Km containing dispersion compensating fiber (DCF) and Erbium doped fiber amplifier (EDFA) have been studied. It is in the form of bit error rate (BER) Vs Signal-to-noise ratio (SNR) and quality (Q)-Factor Vs input power (P) for different channel spacing (200, 100, 50 and 25 GHz). The result pointed that the spacing between channels of 200 GHz was the best because the BER has been improved by (2 orders) if it compared with the 100 GHz channel spacing system at 10 dB SNR, the BER in the case of channel spacing 100 GHz also improved by (1.9 orders) if it compared with the 50 GHz channel spacing system at 10 dB SNR and the BER also improved by (0.7 orders) in the case of optical systems with 50 GHz as if we compared it with system of 25 GHz channel spacing at 10 dB SNR. The Q-Factor has been improved as the channel spacing increased, so generally the performance of an optical fiber system has been improved with the presence of DCF and EDFA in the optical link because the effect of these two elements in the linear and nonlinear fiber impairments.

Keywords
Dispersion compensating fiber (DCF), Erbium doped fiber amplifier (EDFA), Wavelength division multiplexed (WDM), Channel spacing.

1.Introduction
Dispersion of the transmitted optical signal causes distortion for both digital and analogue transmissions along optical fibers. When considering the major implementation of optical fiber transmission, which involves some form of digital modulation, then dispersion mechanisms within the fiber cause broadening of the transmitted light pulses as they travel along the channel [1].

A pulse can be broadened or compressed in a dispersive medium depending on the sign of the chirp and the dispersion. Dispersion compensation plays a key role in generating, amplification and propagation of femtosecond pulses. To obtain the ultra-short pulses, the pulse group delay (GD) should have about frequency independence after the dispersion compensation. Especially to compress a pulse to near the transform limit one should not only compensate the GD but also eliminate the high order dispersion term. [2]. Pulse distortion reduces maximum spacing between optical transmitters and receivers if the same BER performance of the system is to be maintained.

When commercial single-mode optical fiber links were first introduced and installed, they were designed to offer zero dispersion at 13µm, since that was the wavelength of commercially available light sources. Operated nowadays at 155µm, these fibers exhibit substantial positive dispersion that may be cancelled out by using dispersion compensating fibers which provide large negative dispersion at that wavelength [3] [4].

Because of the relatively low transmission loss at wavelengths near 1550 NM and the erbium-doped fiber amplifier (EDFA) working in this wavelength region, the preferred transmission window is around 1550 NM. A large number of the optical fiber cable transmission systems are installed based on standard single-mode fibers (SSMF), i.e., fibers with zero dispersion at 1310 NM and a dispersion coefficient of about 17 ps/NM/km at1550 NM [5]. Dispersion is one of the four basic limitations in the modern optical transmission systems. Pulse broadening occurs because of the nonzero bandwidth of an optical signal. Dispersion compensating optical fibers (DCF) with minus dispersion value and minus dispersion slope (-50 ~ -500 ps/nm2 /km) are used to compensate or optimize the dispersion characteristics of long distance transmission systems [6]. The high

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negative dispersion coefficient is provided by the DCF, which will be opposite in sign, but larger than the positive chromatic dispersion of conventional single mode fibers at 1550 NM. The technique based on DCF is widely developed in this connection to combat the chromatic dispersion of the fibers [7] [8].
Nonlinearity effects have to be considered when the optical communication systems operated at higher bit rates such as 10 Gbps and above and/or at higher transmitter powers. In the case of WDM systems, nonlinear effects can become important, even at moderate powers and bitrates. The nonlinear effects that we consider in this section arise owing to the dependence of the refractive index of the intensity of the applied electric field, which in turn is proportional to the square of the field amplitude. At sufficiently high optical intensities, nonlinear refraction occurs in the core (Kerr effect), which is the variation of the index of refraction in light intensity. This makes nonlinear impairments a critical concern in optical networks for long-haul transmission commonly relies on high power lasers to transmit optical pulses over long spans to overcome attenuation. Nonlinear Impairments depend mainly on the fiber type and length and can be placed into two categories. The first includes the nonlinear effects that affect the energy of an optical pulse and includes:

- Stimulated Brillouin Scattering (SBS)
- Stimulated Raman Scattering (SRS)
- Four-wave mixing (FWM)

Nonlinear effects that affect the shape of an optical pulse include:

- Self-Phase Modulation (SPM)
- Cross-Phase Modulation (XPM) [9] [10]

As the optical fiber transmission systems evolved to longer distances and higher bit rates, the linear effect of fibers, which is the attenuation and dispersion, becomes the important limiting factor. As for WDM (Wavelength Division Multiplexed) systems that transmit multiple wavelengths simultaneously at even higher bit rates and distances, the nonlinear effects in the fiber begin to present a serious limitation. The success of high bit rate long haul point-to-point optical transmission networks depend upon how best the linear and nonlinear effects are managed. Several methods are reported for dispersion and nonlinearity management.

The EDFA (Erbium-doped fiber amplifiers) are the by far most important fiber amplifiers in the context of long-range optical fiber communications; they can efficiently amplify light in the 1.5-µm wavelength region, where telecom fibers have their loss minimum. Since EDFA works in 1550 NM wave band, the average single mode fiber (SMF) dispersion value in this wave band is very big, about 15-20ps / (NM. km-1) [11] [12].

2.8×10 Gbps optical system design

In this paper, we will discuss eight channel optical systems with different channel spacing, as shown in *Figure 2*, the optical transmitter has a DPSK (Differential phase shift keying) as a modulation format. An ITU-T G.652 optical fiber is used in the simulation to be the optimal fiber channel type against the fiber impairments as compared to other types of optical fibers. A dispersion compensating fiber (DCF) can be used to compensate the accumulated dispersion in the fiber which leads to decreasing the pulse broadening resulting from the chromatic dispersion (CD) effects. The DCF is one of the prime appliances to compensate chromatic dispersion for a large bandwidth of wavelengths. DCF is designed to reach large negative waveguide dispersion up to -85 ps/nm.km, which enables to balance the amount of CD in the fiber.

As shown in *Figure 1*, the optical fiber channel consists of a DCF fiber with a length of 5 km, its attenuation constant is 0.5 dB/km, the dispersion coefficient value is -85 ps/NM/km and the dispersion slope coefficient is -0.3 ps/nm2. km. The effective area of the DCF is 22 µm2. The DCF is followed by an Erbium-Doped Fiber Amplifier EDFA with noise figure of 4dB and Gain of 2.5 dB followed by a single mode fiber (SMF) with an attenuation value of 0.2 dB/km, a dispersion coefficient value of 17 ps/NM/km and dispersion slope coefficient of 0.075 ps/nm2/km. The length of the SMF is 25 km with an effective area of 80 µm2. The SMF is followed by an EDFA with Noise figure of 4 dB and a gain of 5dB. A second SMF, EDFA, DCF and EDFA with the same parameters of the first part are used again. This configuration forms the symmetrical dispersion-compensating scheme. The simulation value of the DGD parameter for all fiber types is 0.1 ps/km. The span length is taken as 60 km. Simulation parameters of the SMF and DCF are summarized in *Table 1*.

Then the signal is fed into the DPSK receiver to detect it and convert it into an electrical signal. A balanced receiver is used for the detection to convert the phase change into an intensity change. In order to analyze the received signal a set of eye diagrams was used.

3.Simulation results and discussion

The system bit rate is 10 Gbps with DPSK as modulation format and with the use of DCF and EDFA we can observe that the system performance was improved in the case when the channel spacing was 200 GHz if we compared it with the other cases gradually (100, 50 and 25 GHz) as shown through the bit error rate (BER) versus signal to noise ratio (SNR) curves and Q-factor versus input power (P) curves that are shown in *Figures (3)* and *Figure (4).* In the figure (*Figure3*), it is clear that the bit error rate (BER) is getting better with the increase of the SNR, so for example in the case of the channel spacing is 200GHz we can observe that if the signal to noise ratio (SNR) is 10 dB, the BER is $10^{-8.2}$. While in the case of channel spacing is 100 GHz the BER is $10^{-6.105}$. So the system performance was improved by $10^{2.095}$ orders. Again in SNR 10 dB, The BER is $10^{-4.2}$ in case of channel spacing 50 GHz, also the system has been improved by $10^{1.905}$ order if we compare between the 100 and 50 GHz and so on with the other cases, shown in *Table 2*. It is well shown that the optical system with channel spacing of 200 GHz is the best, because the dispersion is reduced, also Stimulated Raman Scattering (SRS), Cross-Phase Modulation (XPM) and Four-Wave Mixing (FWM) are also reduced. In *Figure (4)* there is the relation between the Q-factor and the input Power for each system. The highest channel spacing and the highest Q-factor which is the most improved.

Figures (5, 6) illustrate the spectrum of the optical signal before optical link and after it. So we can observe the nonlinear effects before and after the threshold point, so we take 0 dBm and 9 dBm as an example of two points one of them before the threshold point and the other after it.

4.Conclusion

DCF and EDFA are powerful elements that used in the fiber link and that's clear from their effects in reducing the optical impairments and improving the system performance and that is what we notice from *Figure (3)* and *Figure (4)*. The BER of the system in case of channel spacing 200 GHz is most improved compared to the other channel spacing. Also the quality factor (Q-factor) of the optical system was improved in the case of 200 GHz channel spacing if we compared it with the other cases with increasing the input power to the threshold point reached the system performance begin to reduce as shown in *Table 3*. All this happens because the optical fiber link was almost dispersionless and almost clear from fiber nonlinearities and that is the effect of the DCF and EDFA. Even the other cases of channel spacing (100, 50 and 25 GHz) were considered better if we compared it with an optical system that has no DCF and EDFA.

Acknowledgment

None.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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Table 1 SMF and DCF parameters

Parameter	Value
SMF	
Attenuation (α)	0.2 dB/km
Dispersion parameter (D)	17 ps/nm.km
Dispersion slope (S)	0.075 ps/nm^2.km
Effective area	80 µm^2
DGD parameter	0.1 ps/km
DCF	
Attenuation (α)	0.5 dB/km
Dispersion parameter (D)	-85 ps/nm.km
Dispersion slope (S)	-0.3 ps/nm^2.km
Effective area	22 µm^2
DGD parameter	0.1 ps/km

Table 2 The improvement of $\log_{10}$ BER for the channel spacing.

Channel Spacing (Ghz)	Improvement In Log_{10} Ber At Snr 10 Db
200-100	2.095
100-50	1.905
50-25	1.031

Table 3 The improvement of Q-factor for the channel spacing.

Chanel Spacing (Ghz)	Improvement In Q-Factor At Input Power (P) 5 Dbm
200-100	19.502
100-50	18.998
50-25	9.3

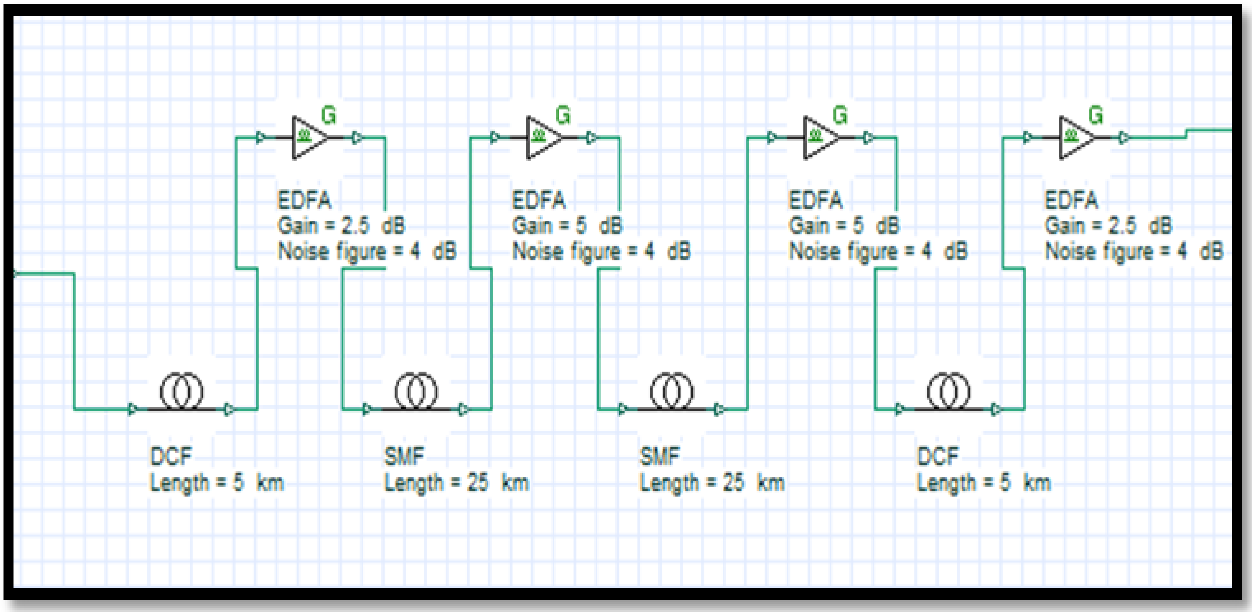

Figure 1 Optical fiber link

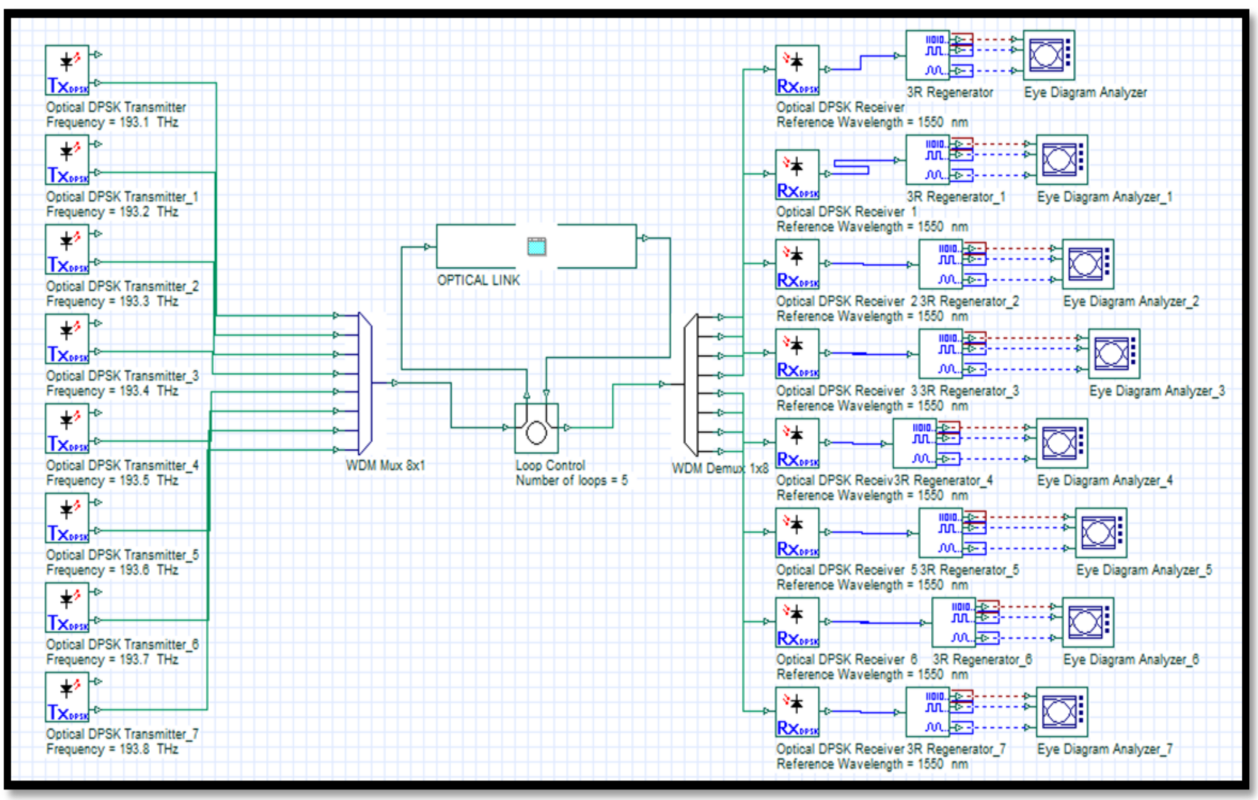

Figure 2 8×10 Gbps optical fiber system

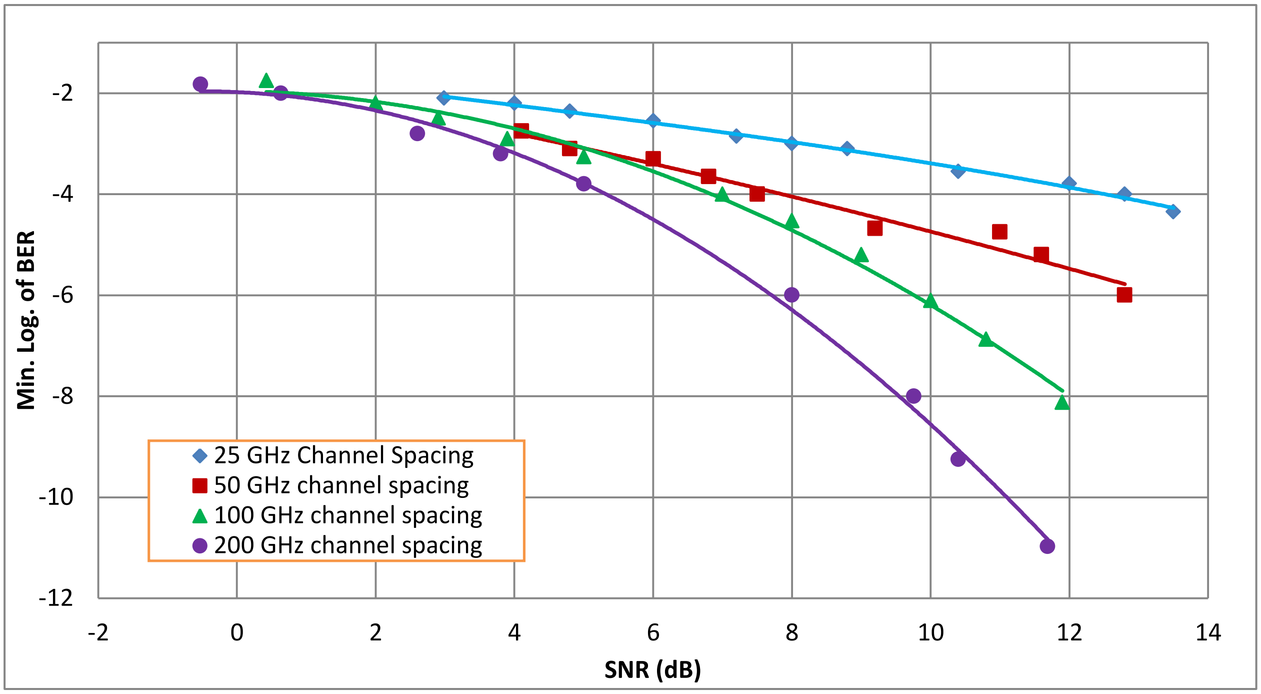

Figure 3 BER versus SNR

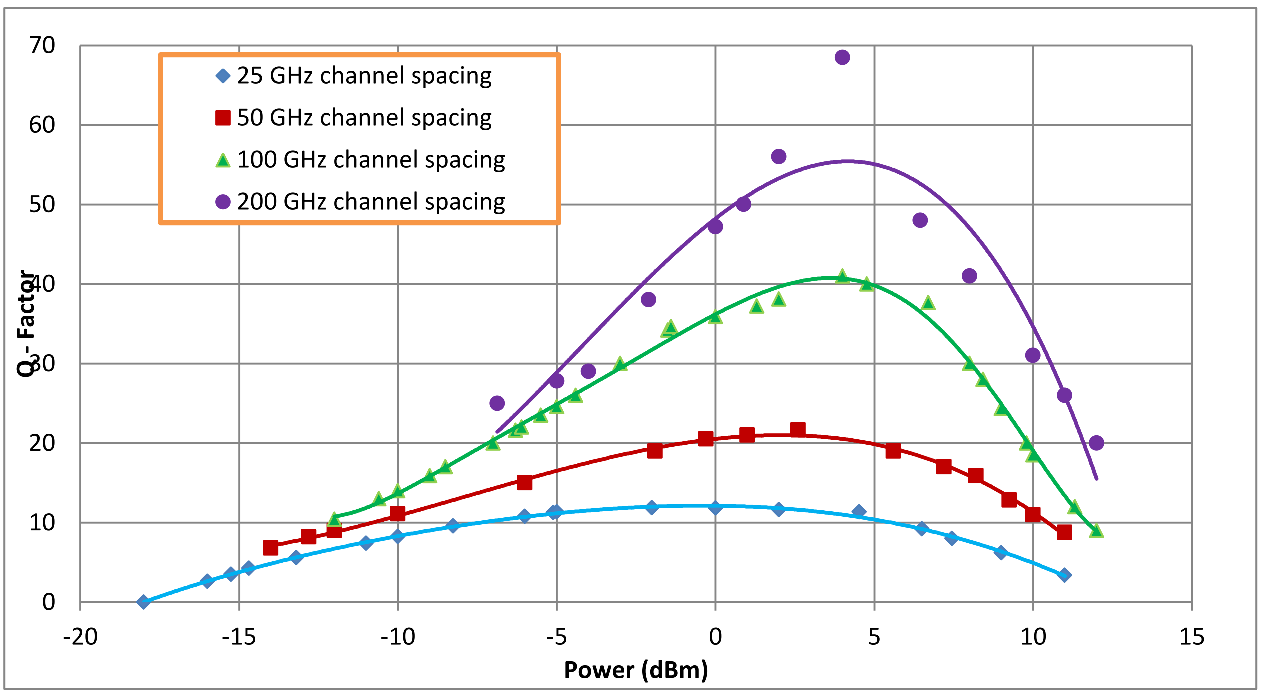

Figure 4 Q – Factor versus input power

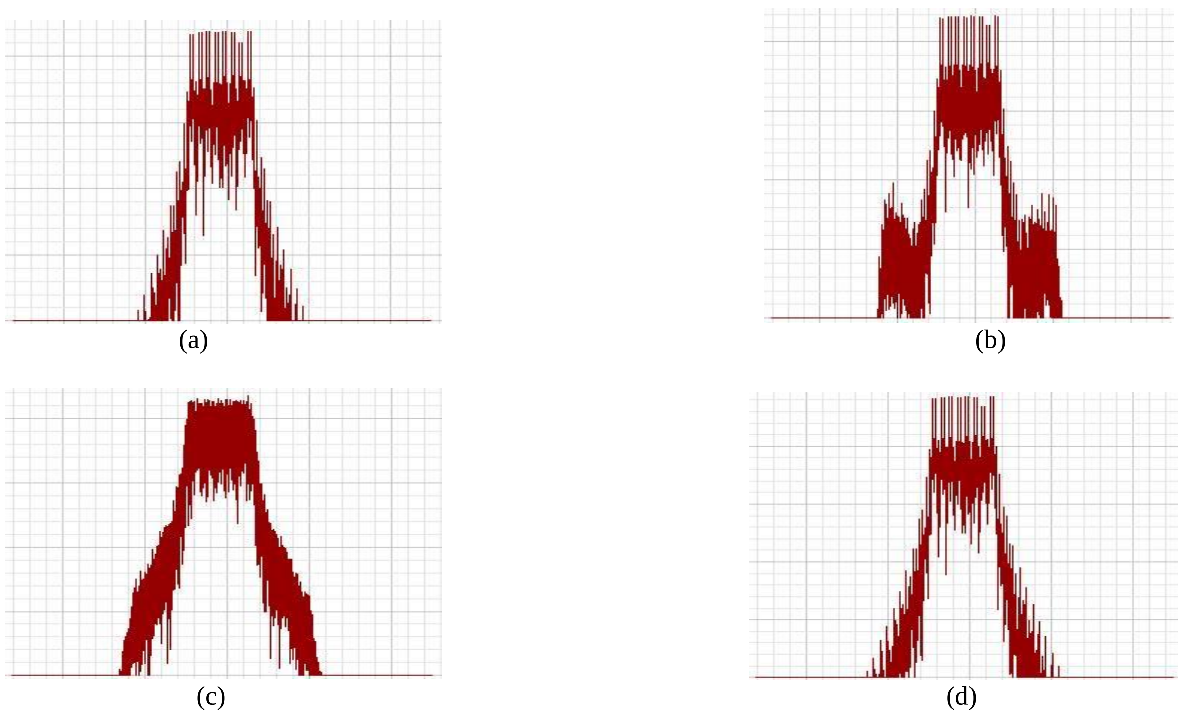

Figure 5 Spectrum for channel spacing 25 GHz
(a) at 0 dBm; (b) at 0 dBm after 300km; (c) at 9 dBm; (d) at 9 dBm after 300km.

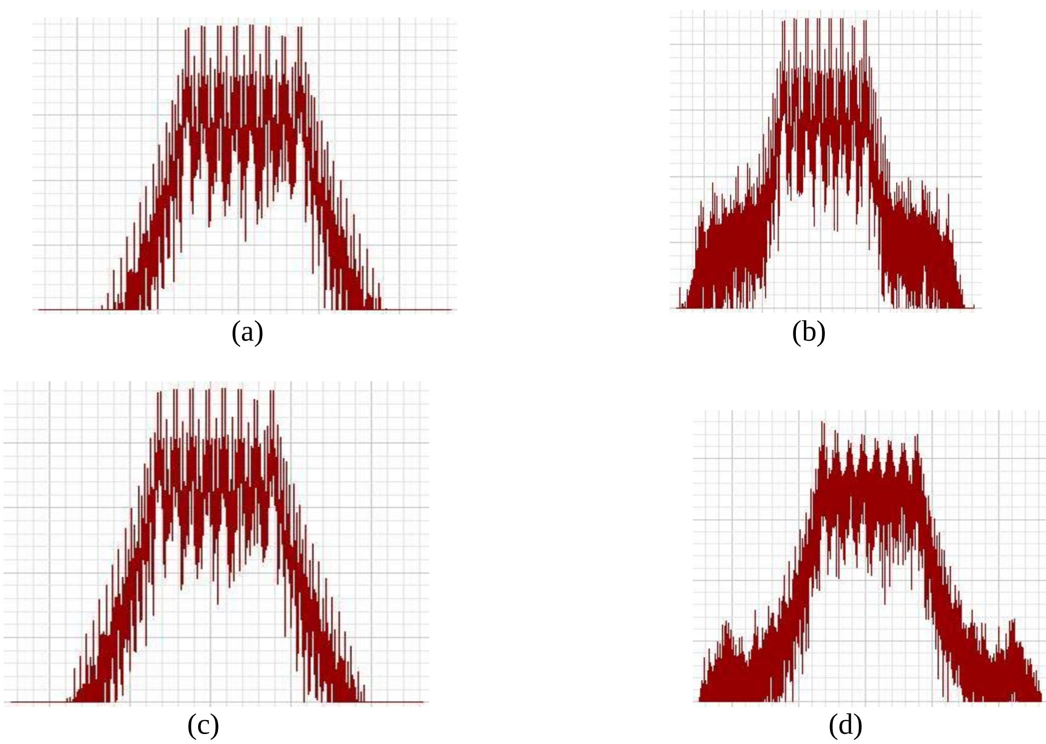

Figure 6 Spectrums for channel spacing 50 GHz
(a) at 0 dBm; (b) at 0 dBm after 300km; (c) at 9 dBm; (d) at 9 dBm after 300km.