SIMULATION OF DWDM COMMUNICATION SYSTEM AT 8.10 Gbit/s USING CONTINUUM SOURCE IN THE TRANSMITTER

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Abstract: In this paper, the 8-channel DWDM communication system at 8.10 Gbit/s is demonstrated. Laser diodes used in conventional DWDM link have been replaced by continuum covering C-band of optical communication window. If the initial source is delivered at repetition rate of 10 *GHz*, The spectral slicing of this continuum allows obtaining the 8- channel at different wavelengths where each channel is a pulses train has the same repetition rate. Then, they were modulated, in order to achieve data transfer rate of 10 Gbit/s. The modulation format RZ-OOK was used for channels coding. The proposed system components were simulated using COMSIS software.

Keywords: *DWDM system, nonlinear optics, continuum, multiplexing, demultiplexing.*

I. INTRODUCTION

Dense Wave Division Multiplexing (DWDM) technology is widely used in today's telecommunication networks. However, the economical factor makes DWDM systems available only for applications in long-haul systems with demand for high capacity. The particularity of DWDM is that it involved sending a large number of closely spaced optical channels over a single fiber. However, the disadvantage of this technology is that it used in laser cooling. The emission wavelength is very close (in the vicinity of wavelength of 1550 *nm*), so, it is necessary to cooling temperature tuning of laser between pulses because the length of the central wavelength emission of laser diode varies as the temperature changes. Realization of temperature tuning is very difficult, and cost is also very high. Another drawback is the noise laser. These fluctuations impose an ultimate limit to the performance of any optical system communications. This noise is caused especially by spontaneous emission in the laser diode. In addition, laser chirp is the major disadvantage in the DWDM directly modulated system performance, and it increases when the bit rate increased, which limits the transmission at bit rate less than 5 Gbit/s [1, 2].

To avoid these disadvantages, the continuum technique replaces laser diodes to generate many optical transmitter sources, because it is insensitive to temperature variation, and, the advantage of the pulsed mode is that the source is insensitive to reflections of light in the source. In this aim, we propose to generate a single continuum source capable of providing all the necessary channels for the efficiency of the DWDM system. The continuum source we used, is based on the generation of continuum in special highly nonlinear and normal dispersion fiber or microstructured (PCF: Photonic Crystal Fiber) [3].

In order to well understand the proposed method, the 8-channel DWDM telecommunication system at 8.10 Gbit/s is demonstrated. We interest especially to the transmitter.

II. CONTINUUM FOR DWDM APPLICATION

The continuum source we used, is defined on the C-band (1530 *nm* - 1565 *nm*) compatible with the spectral band of optical amplifiers currently used, with power spectral density as flat as possible.

Continuum sources generated by pulse propagation in normal dispersion PCF leads to flat broadband spectrum and needs a few meters length of fiber [4, 5].

The numerical model of the pulse propagation in PCF is the well-known generalized nonlinear Schrödinger equation (GNLSE) that is suitable for studying the evolution of ultrashort pulse in nonlinear media [6]:

$$\frac{\partial A}{\partial z}+\frac{\alpha}{2}A+i\frac{\beta_2}{2}\frac{\partial^2 A}{\partial t^2}-\frac{\beta_3}{6}\frac{\partial^3 A}{\partial t^3}=i\gamma(|A|^2 A+\frac{i}{\omega_0}\frac{\partial}{\partial t}(|A|^2 A)-T_R A\frac{\partial|A|^2}{\partial t}) \quad (1)$$

Equation. 1 given for pulse shorter than 5*ps.* Where A is the slowly varying amplitude of the pulse, α is the attenuation of the PCF, β_2 and β_3 are the coefficients of second and third-order dispersion respectively, γ is the nonlinear coefficient, and T_R=3fs at wavelength λ=1550 *nm.*

It is possible to solve equation (1) numerically by using the split step Fourier method (SSF) [6], the split step Fourier method used extensively to solve the pulse propagation problems in nonlinear dispersive media.

Using the real cross-section of the PCF used in ref [3], the chromatic dispersion has been computed for a wavelength range extending from 1060 to 1680 *nm*. The calculations were performed by means of a full vectorial finite element method [7]. The fiber shows ultra flattened chromatic dispersion of $D \pm 0.4$ *ps/(nm.Km)* from 1060 to 1680 *nm* wavelength range (*D*=0.8 *ps/(nm.Km)* at 1550 *nm*), has a high nonlinear coefficient $\gamma=51\,[W.Km]^{-1}$ at 1550 *nm*, and a third order dispersion $\beta_3=-0.01\ ps^3/Km$.

For the PCF mentioned above, with low normal group velocity dispersion, small β_3, and high nonlinearity, it would be perfectly suit for required continuum spectrum for DWDM application, when the flat spectrum are interesting because it can generate channels with the same power level.

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Now we investigate it through the following numerical simulation:

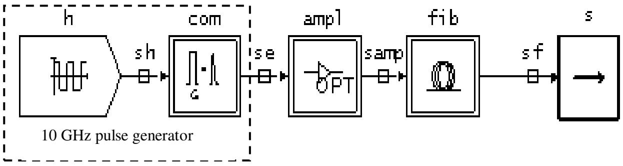


Figure 1. Bloc diagram of continuum generation

Figure 1 is the bloc diagram of continuum generation that we are going to simulate. It is an optical short pulse generator of Super-Gaussian type. The input signal is formed of clock representing binary states (0 or 1) of the message to be transmitted. For each binary state 1, one pulse is generated. The maximum of the pulse is located at the centre of bit time. The optical amplifier of 30 dBm allows achieving levels of high peak power required for the non-linear effects to continuum generation. We obtained after optical amplification a pulses train at a repetition rate of 10 *GHz*, which allows us to obtain after propagation in the non-linear fiber, a pulses train of 10 *GHz* having for each spectrum our continuum.

We assume the incident pulse, to be of Gaussian shape, the electric field *A (0, t)* corresponding to such a pulse can be expressed in form:

$$A(0,t) = \sqrt{P_0}\,\exp(-\frac{t^2}{2T_0^2}) \qquad (2)$$

Where P_0 is the power of the pulse and T_0 is the input pulse width, and it is related to the full wide at half maximum (FWHM) of the input pulse by $T_{FWHM} \approx 1.665T_0$.

The specific values of parameters used in simulation are given as follows: P_0 = 150 *mW*, T_{FWHM} = 2.4 *ps*, and the central wavelength λ_0=1550 *nm*.

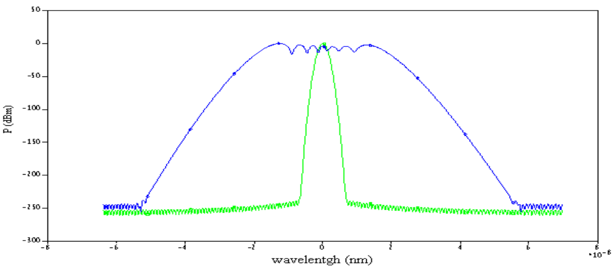


Figure 2. Input spectrum (green), continuum spectrum (bleu)

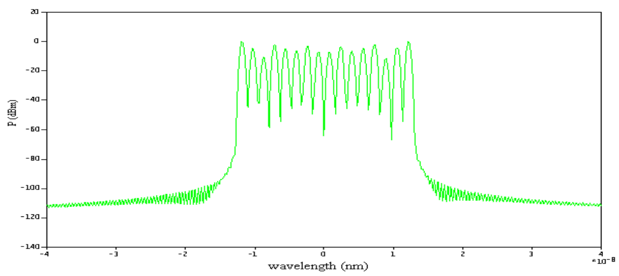


Figure 3. Spectrum obtained after spectral slicing by optical demultiplexer

From Figure 2, we can see that the input pulse changes its spectrum to a broadband continuum (for propagation distance z=20 *m*) from 1530 to 1570 *nm* (source covering C-band of optical communication window) with good spectral flatness (variation power <1dB) due to linearity of the spectral chirp induced by the interaction of the self phase modulation (SPM) and the normal dispersion [7].

For generating multi-wavelength Sources, we use optical demultiplexer for slicing the continuum spectrum (wide of 40 *nm*) in many channels at different wavelength. This source generate more than 60 channels spaced of 100 *GHz* (0.8 *nm*), all centered on 1550 *nm*, whose 32 channels in the band 1530-1565 *nm*. Increasing the number of channels leads to the increase of the bit rate, and thus increasing the capacity of transmission by optical fiber. If the initial source is delivered with repetition rate of 10 *GHz*, a bit rate of 600 *Gbit/s* can be achieved.

Figure 3 shows spectrum obtained after slicing by optical demultiplexer. The total bandwidth of the demultiplexer is 50 *GHz* with 200 *GHz* (1.6 *nm*) channel spacing in order to limit interference at best. We show a superposition of the spectra of 16 channels in the output of the demultiplexer. The channels are generated in the 1528- 1558*nm* wavelength range. The pulse widths products are almost constant at ~7*ps* across all channels, as determined mainly by the demultiplexer characteristics. The spectral width of the channels is taken less than or equal to that of the filter of the demultiplexer. We obtained sub-band spectral of 2 *nm*.

III. SIMULATION OF THE TRANSMISSION CHAIN

The simulated transmission chain is based on the block diagram of Figure 4. The Chain comprises a transmitting module which aims to register electrical information on optical signal. Data modulation to 10 Gbit/s is done through Mach-Zehnder modulator; its parameters were fired bibliographical reference [8]. The transmission medium considered in this study is a standard single-mode fiber (SMF), followed by dispersion compensating fiber (DCF) and an optical Erbium-Doped Fiber Amplifiers (EDFA). The receiving block is designed to convert the optical signal that carries the information into electrical pulses. It is composed of demultiplexer of 50 *GHz* bandwidth used to separate different channels, PIN photodiodes, and decision circuits [8].

Once the link is built, and according to the result of simulations, we visualized the signals at various points of the link. This allows to visualizing the successive transformations of the signal during his career as well as the behavior and influence of each block.

In the following, 8-channel DWDM telecommunication system at 8.10 Gbit/s is demonstrated in order to well understand the proposed method.

On the transmission side of the system, the pulse train of the first optical channel centered in the 1550 *nm* region is plotted in Figure 5.a. This region was chosen to minimize influence of fiber loss and to have a potential opportunity to use EDFAs for spans longer than 10 *km*. Each channel modulated with modulation rate to achieve data transfer rate of 10 Gbit/s. the Return to Zero – On –Off Keying (RZ-OOK) code format was used for signal coding (figure 5.b). The temporal waveform of modulated sliced signal is shown in Figure 5.c.

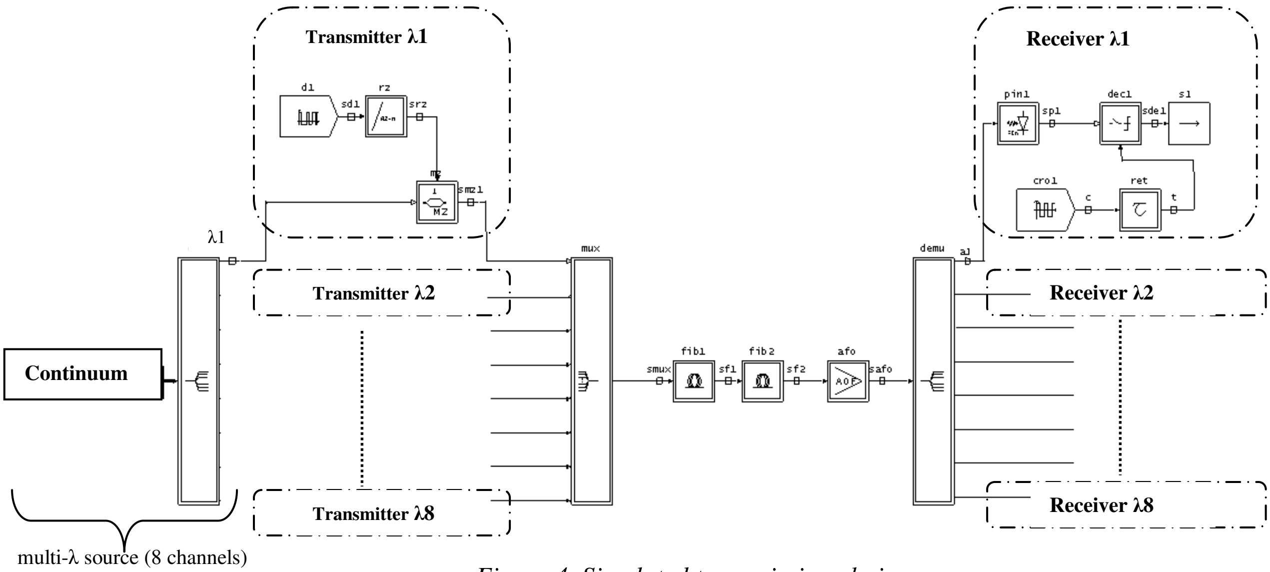


Figure 4. Simulated transmission chain

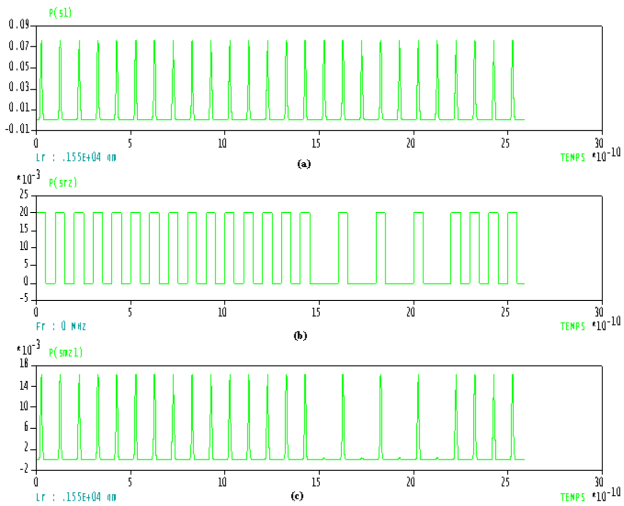


Figure 5. Pulse trains of first optical sliced channel (a) RZ code format (b), and temporal waveform of first modulated channel (c)

For multiplexing the modulated 8-channels into a single fiber, the optical multiplexer has the same parameters as the demultiplexer used for slicing the continuum in terms of spectral bandwidth and channel spacing is used to reduce cross-talk between adjacent channels. The system was designed so that to minimize noise from the adjacent channels. The spectrum and waveform of the 8-optical channels multiplexed signal at output of multiplexer is shown in Figure 6. The optical spectrum of the signal from the multiplexer allows to illustrating the superposition of channels, which is operated by wavelength multiplexing (power spectral density of the optical signal at the output of multiplexer). The spectral width of the optical signals is visible in the spectrum of the multiplexed signal. Temporally, this signal did not contain any easy interpretation information due to beats occurring between the different wavelengths (Figure 6.a).

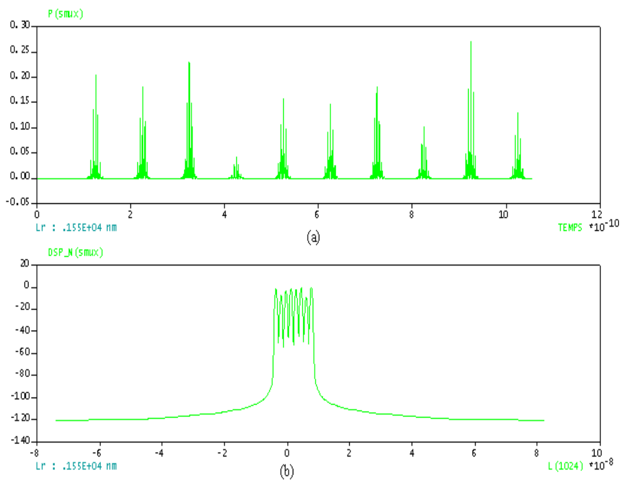
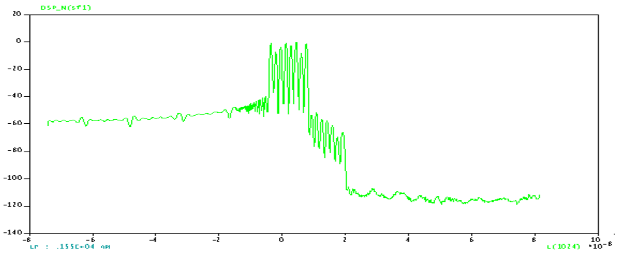
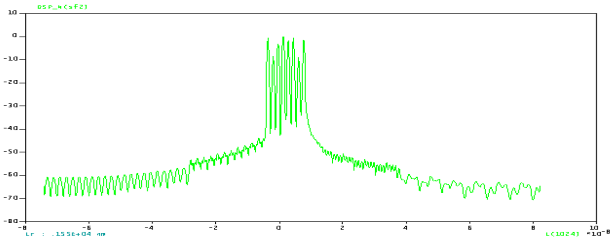


Figure 6. Temporal waveform (a), and spectrum (b) of multiplexed 8- modulated channels

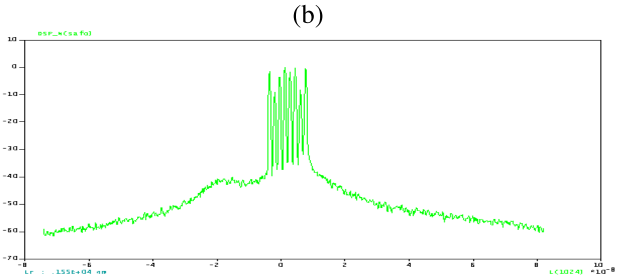
The multiplexed signal of 8- modulated channel is tested by transmitting the signal over 20 *km* of SMF. The spectrum of multiplexed signal at output of the fiber is shown in figure (7. a). Single mode fiber has been chosen to minimize the influence of the dispersion and the main limitation of the system as seen from the simulation. At output of optical fiber SMF, the spectrum shape of the multiplexed signal is modified by the properties of chromatic dispersion of the fiber. The DCF is a tool to compensate the nonlinear losses (Figure 7.b) which comprises introducing into the link a section of fiber producing negative dispersion (about -100 *ps / nm.km*) compensation. For a length of 100 *km*, it takes about section of 10 *km*. Because DWDM systems handle information optically rather than electrically, it is imperative that long-haul applications do not suffer the effects of dispersion and attenuation. Optical amplifiers such as EDFA counteract these problems. EDFA works without having to convert optical signal into electrical. When a weak signal at 1550 *nm* enters the fiber, the light stimulates the rare earth atoms to release their stored energy as additional 1550 *nm* light. This process continues as the signal passes down the fiber, continually growing stronger. They do not support only a single wavelength, as repeaters do, but the whole range of wavelengths. The EDFA used gain is 30dB. The multiplexed channels spectrum after EDFA is shown in figure (7.c). It can be see that the power level of amplified channels is between 0 dBm and -10dBm due to the small variation of the continuum flatness.



(a)

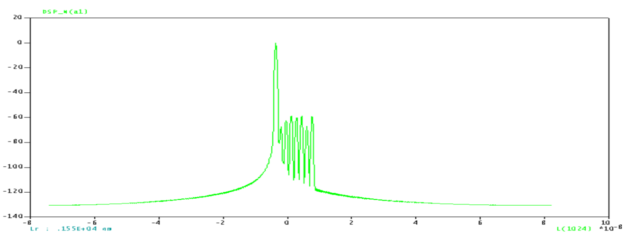


(b)

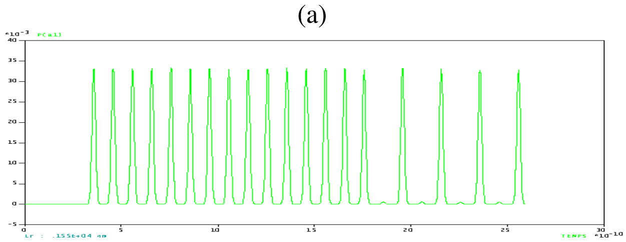


(c)

Figure 7. Multiplexed signal spectrum after: SMF (a), DCF (b), and EDFA (c)



(a)



(b)

Figure 8. Spectrum (a) and temporal waveform of first detected channel (b)

After demultiplexing, we obtained the spectrum of each received channels. It is observed in figure (8.a) curve of first channel detected imperfect rejection of adjacent DWDM channels. The same output in the time domain is shown in Figure (8.b). We Observed by comparing the output and input signal that the information is generally conserved after multiplexing, propagation, demultiplexing, and detection.

IV. CONCLUSION

We are represented the simulation results of 8-channel DWDM telecommunication system in high bit rate optical transmission system. Laser diodes used in a conventional DWDM link has been replaced by continuum covering the C-band of optical communication window compatible with the spectral band of optical amplifiers currently used, with power spectral density as flat as possible because it can generate channels with the same power level. The source we used is based on the generation of continuum in special highly nonlinear and normal dispersion microstructured fiber. This source can be spectrally sliced into many channels with deferent wavelengths used as a DWDM transmitter, each channel is a pulses train having the same repetition rate as the initial source suitable to modulate by user data. The resulting signal is RZ-OOK type format and whose pulse duration is 0.33 % of the bit time. The multiplexed signal of 8-modulated channel is tested by transmitting the signal over 20 km of SMF followed by DCF fiber and an optical Erbium-Doped Fiber amplifier EDFA, we found that the information is generally conserved after multiplexing, propagation, demultiplexing, and detection.

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