# WDM Transmitter Based on Spectral Slicing of Similariton Spectrum

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***Abstract*—In this paper, we take advantage of the characteristics of similariton pulse, and the properties of normal dispersion highly nonlinear PCF for generating a spectrally flat and power continuum source. This continuum covering the C-band of optical communication window is capable of providing all the necessary channels for the efficiency of the WDM transmitter system after spectral slicing of this one by an optical demultiplexer. The generated channels are pulses trains have the same repetition rate than the initial source, where each channel is suitable to modulating by user data and then to multiplexing into a single fiber.**

***Index Terms*—similariton pulse, continuum source, photonic crystal fiber (PCF), wavelength division multiplexing (WDM).**

## I. Introduction

Similariton pulse generated in normal dispersion fibers has become a topic of growing interest owing to its characteristics, such as parabolic waveform, resistance to optical wave breaking, self similarity in shape, chirp linearity, and a flat and broad spectrum which could lead to continuum generation [1]-[4].

One of the most important applications of continuum in the field of optical telecommunications is the design of multi-wavelength sources for wavelength division multiplexing (WDM) transmission systems based on spectral slicing of this one by an optical demulteplexing.

There have been numerous theoretical and experimental investigation of continuum generation based on similariton spectrum. Takushima et all [5] used picoseconds pulse source launched into kilometer length of normal dispersion flattened fiber (DFF) without gain and a broad continuum was generated, however the spectrum has ripples and the flatness did not maintain. To avoid this problem Ozeki [6], [7] used the same pulse source and replaced the DFF by a low normal dispersion erbium-doped fiber amplifier (EDF) and a broadband continuum of the similariton pulse was shown with high spectral flatness. However, the continuum bandwidth generated was not covering the hall C-band of optical communication window (bandwidth~18 *nm*). Moreover, it needs several kilometers length of conventional fibers.

Nowadays, recent research efforts have focused on the development of continuum sources generated by photonic crystal fiber (PCF) owing to its high nonlinearity and flexible design of the dispersion profile.

Continuum sources generated in normal dispersion PCF leads to flat broadband spectrum and needs a fiber of few meters length [8], [9]. However during the propagation in the PCF, the output pick power of the pulse decreased because the highly nonlinearity of the PCF and the continuum was not suitable for WDM application, in which one required a high power continuum over a narrow bandwidth with good spectral flatness (<1 dB power variation). To keep the high peak power of the pulses, the value of normal dispersion should be small; also, the higher nonlinearity of the normal dispersion fiber can make the required power lower and required fiber length shorter for effective continuum generation [10].

In this paper, we proposed to combine between the similariton characteristics and the PCF properties for obtaining spectrally flat and power continuum source covering the hall C- band of optical communication window. This source can be spectrally sliced into many channels with deferent wavelengths used as a WDM transmitter.

## II. Continuum Source Based on Similariton Spectrum

Similariton pulse is result of interaction between normal dispersion, nonlinearity and gain. The numerical model of the similariton propagation in optical fiber is the well-known nonlinear Schrödinger equation (NLSE) with gain expressed in the following (dimensional) form [3]:

$$i\frac{\partial A}{\partial z} = \frac{\beta_2}{2}\frac{\partial^2 A}{\partial T^2} - \gamma |A|^2 A + i\frac{g}{2}A \tag{1}$$

Where A is the slowly varying amplitude of the pulse, α is the attenuation of the fiber, $\beta_2$ is the second order dispersion of the fiber and γ is the nonlinear coefficient, and *g* is the distributed gain coefficient.

It is possible to solve equation (1) numerically by using the split step Fourier method (SSF) [11], the split

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step Fourier method is used extensively to solve the pulse propagation problems in nonlinear dispersive media.

Using the real cross-section of the PCF used in [12], 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 [13]. The fiber shows ultra flattened chromatic dispersion of *D* ± 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 $\beta_3$, and high nonlinearity, it would be perfectly suitable for required continuum spectrum for a WDM application, when the flat and power spectrum are interesting because it can have channels of the same power level. Now we investigate it through the following numerical simulation: The simulation is done by an advanced optical communication system simulation package called COMSIS.

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 the 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: $P_0$ = 2 W, $T_{FWHM}$ = 2.4 *ps*, the central wavelength $\lambda_0$=1550 *nm*, and the coefficient of amplification g=1.9 $m^{-1}$ [1].

In our numerical analysis, we neglect third-order dispersion, and consider a small propagation distance where attenuation can be also neglected.

Figure1 shows the evolution of the spectrum of the picosecond pulse for propagation distances z=3 *m*.

During the propagation through the PCF and under the amplification, the pulse waveform becomes parabolic (similariton) due to the interaction of the linear frequency chirp induced by the self phase modulation (SPM), the normal dispersion, and the gain [3].

The frequency chirp induced by a parabolic waveform pulse is linear, and the accumulation of such chirp results in flat spectral broadening, however the spectrum consists of many small oscillations (Figure 1), this features show a typical pattern of SPM which is assumed to be the dominant nonlinear effects responsible for the spectral broadening. These oscillations are the results of the interference between the same optical frequencies in the pulse.

One of the important advantages of this method is that the output power level of the continuum spectrum can be tuned by varying the input pulse power or the coefficient of amplification, without degrading the spectral flatness. This gives a dynamic range of power levels available for the WDM source.

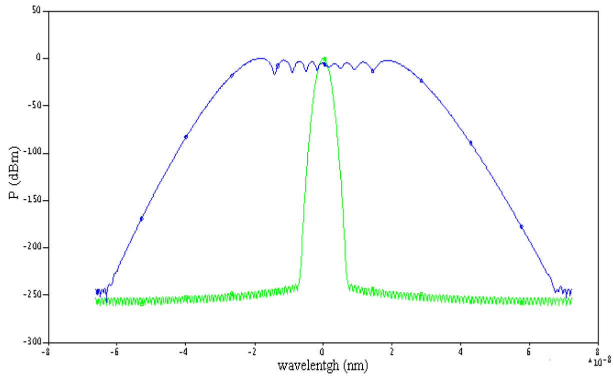



Figure 1. Input spectrum (green trace), similariton spectrum (bleu trace)

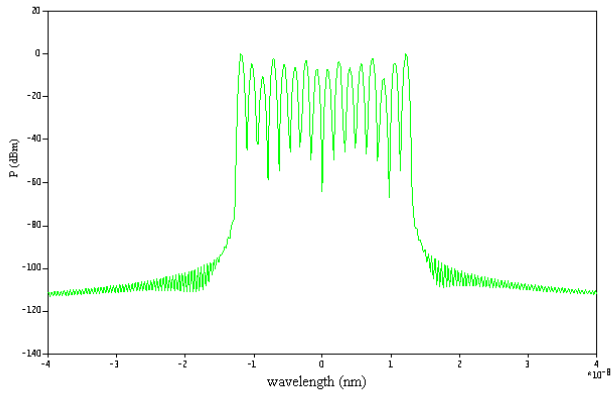
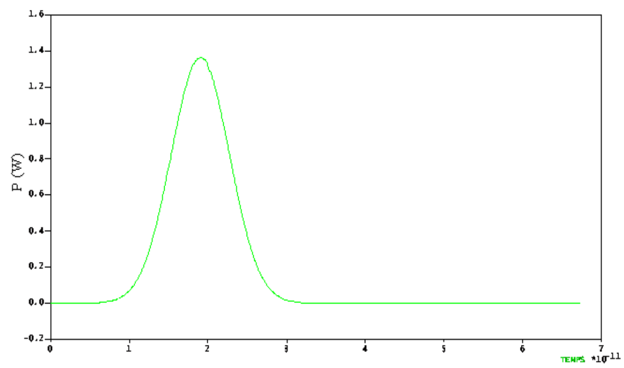
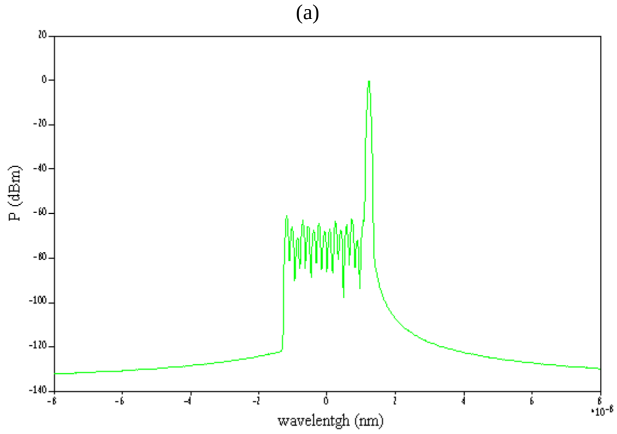



Figure 2. Spectrum obtained after spectral slicing by WDM demultiplexer




(a)




(b)

Figure 3. Temporal waveform (a), and spectrum (b) of first channel obtained after slicing by WDM demultiplexer

The output spectrum (Figure 1) shows a widening (from 5 nm to 100 nm) with good spectral flatness in the center of the pulse spectrum (< 1 dB ripple over a range of 40 nm). The continuum is centered on the wavelength λ = 1550 *nm* and have spectral width of 40 *nm* and can cover the C -band. So it will be used as WDM transmitter systems.

Figure 2 shows spectrum obtained after its slicing by a WDM demultiplexer. The total bandwidth of the WDM 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 WDM demultiplexer. The channels are generated in the 1528- 1558*nm* wavelength range.

The pulse widths product are almost constant at ~6 *ps* (Figure 3. a) across all channels, as determined mainly by the WDM demultiplexer characteristics. The spectral width of the channels is taken less than or equal to that of the filter of the WDM demultiplexer. We obtained sub-band spectral of 0.7*nm* (Figure 3 .b).

## III. WDM Transmitter Simulation

The obtained continuum allow to generate more than 200 channels spaced 100 *GHz* (0.8 *nm*) all centered at 1550 *nm*, witch 32 channels in the C-band.

Increasing the number of channels leads to the increase in the capacity of transmission. So, if the source is delivered at repetition rate of 10 *GHz* we can achieve a rate of 2 *Tbit / s*.

In the following, the 32-optical channel WDM transmitter at 32.10 Gb/s is demonstrated (Figure 4) in order to well understand the proposed method.

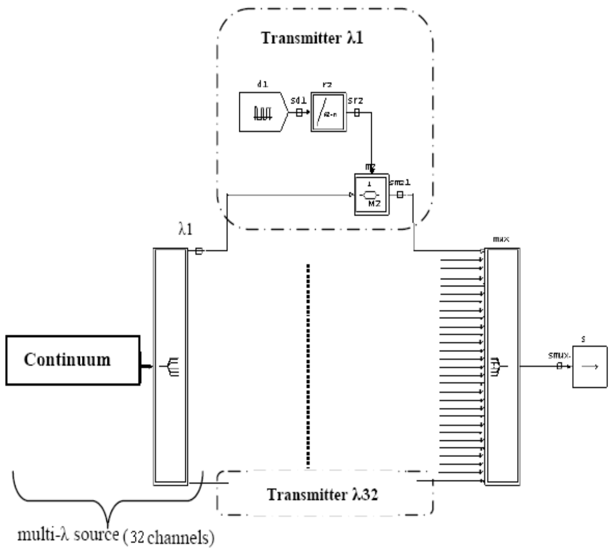



Figure 4. WDM transmitter based on spectral slicing

The pulse trains of first 4- optical sliced channels centered in the 1550 *nm* region are plotted in Figure 5.a. This region was chosen to minimize influence of fiber loss and to have a potential opportunity to use EDFAs (Erbium Doped Fiber Amplifiers) for spans longer than 10 *km*. Each channel modulated through Mach-Zehnder modulator with modulation rate of 10 *GHz* to achieve data transfer rate of 10 *Gb/s*. the RZ (Return to Zero) code format (Figure 5.b) was used for signal coding. The temporal waveform of modulated sliced signal is shown in Figure 5.c.

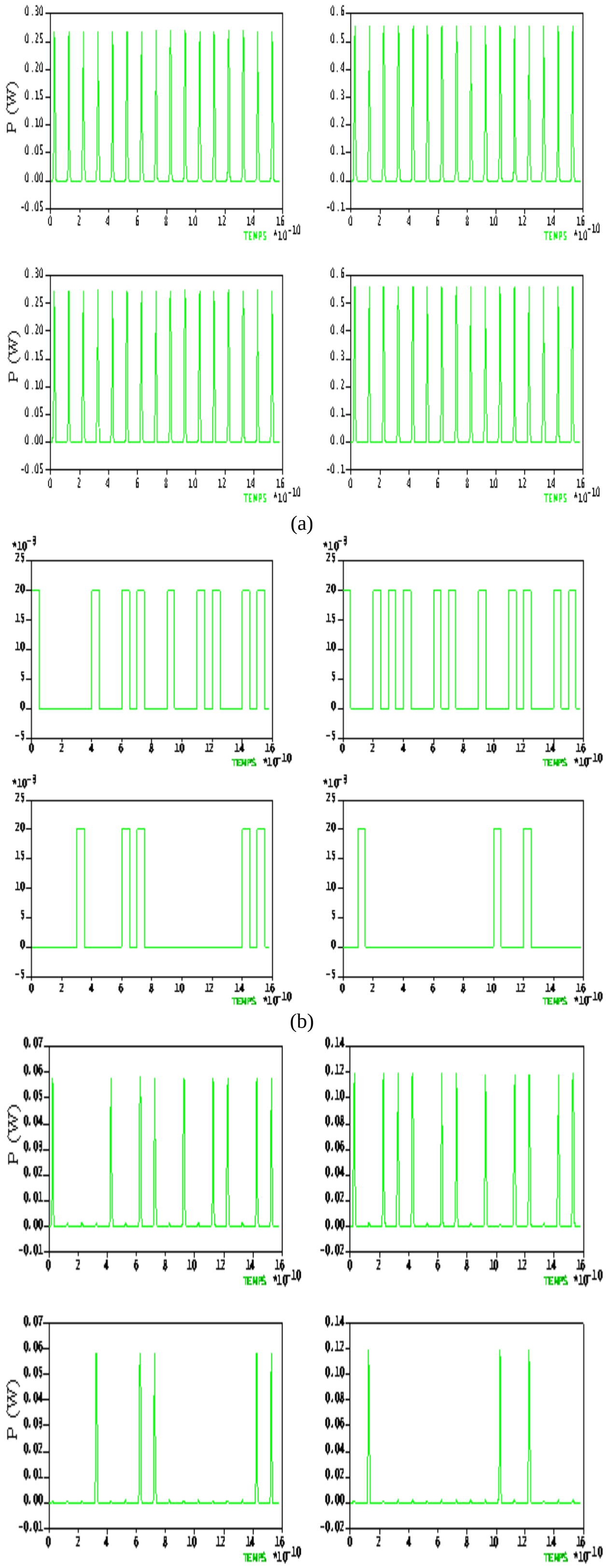
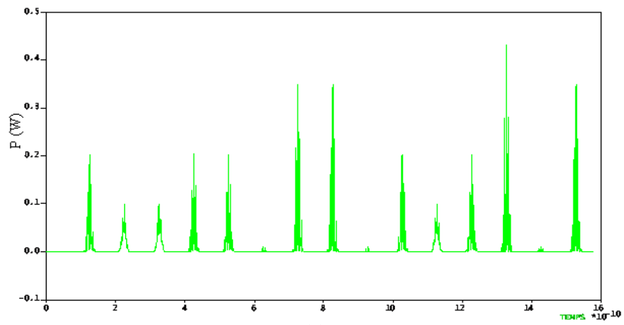
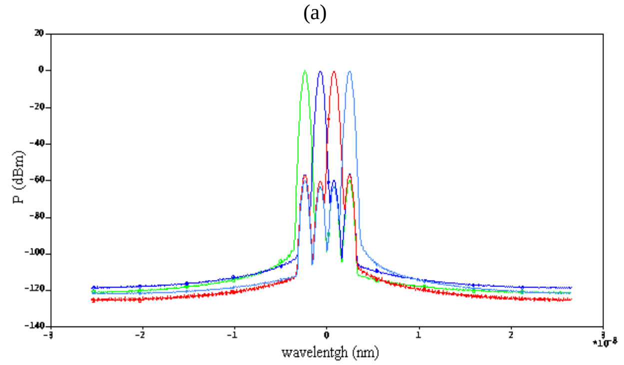



Figure 5. Pulse trains of 4- optical sliced channels (a), the RZ code format (b), and temporal waveform of modulated 4- optical sliced channels (c)

For multiplexing the 4-modulated channels into a single fiber, the optical multiplexer has the same parameters as the demultiplexer in terms of channel bandwidth and channel spacing is used to reduce the crosstalk between adjacent channels. The system was designed so that to minimize noise from the adjacent channels. The spectrum and waveform of the 4- optical channel multiplexed signal at output of multiplexer is shown in Figure 6. The spectrum of the optical signal from the multiplexer used to illustrate the superposition 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. In the time domain, this signal did not contain any interpretation information because of interference that occurs between the different wavelengths. Now, the multiplexed signal of 4-modulated channels is available to transmit over the transmission fiber.




(a)




(b)

Figure 6. Temporal waveform (a), and spectrum (b) of multiplexed 4-modulated channels

## IV. Conclusion

In this paper, we have developed an optical continuum source to achieve WDM transmitter system by exploiting the characteristics of similariton pulse and the PCF properties. The proposed solution is a power and flat continuum source covering the whole C-band of optical communication window. This continuum source is capable of providing all the necessary channels for the efficiency of the WDM transmitter system after spectral slicing of this one by a WDM demultiplexer of 50 *GHz* bandwidth with 100 *GHz* (0.8 *nm*) frequency space in term to reduce the crosstalk between adjacent channels. The 32- channel WDM transmitter system at 32.10 *Gb/s* is demonstrated to well understand the proposed method. The generated channels are pulse trains and have the same repetition rate than the initial source. The pulse widths products are almost constant at ~6 *ps* across all channels, as determined mainly by the WDM demultiplexer characteristics. Each channel modulated with modulation rate of 10 *GHz* to achieve data transfer rate of 10 *Gbit/s*, and then multiplexed in order to transmit the signal over a transmission fiber.

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