

# Simulation and Performance Analysis of FWM Wavelength Converter

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**Abstract:** *Optical Wavelength Conversion is a necessary function for Optical-Time-Division Multiplexing/ Wavelength-Division-Multiplexing (OTDM/WDM) networks. These Wavelength Converters can be realized by using fibre non-linearities, Semiconductor Optical Amplifier (SOA) non-linearities etc. A FWM (Four Wave Mixing) Wavelength Converter using different types of fibers is analyzed here. The power of the converted signals for different fiber lengths and relation between pump and probe power are evaluated. The Wavelength Converter is simulated using a commercial optical system simulator named OptiSystem 12.0 by Optiwave.*

**Keywords:** Wavelength Conversion, Non-linearities, Four Wave Mixing (FWM), Pump signal, Probe signal.

## 1. Introduction

Fibre optic communication has revolutionised the telecommunications industry. It has also made its presence widely felt within the data networking community as well. Using fibre optic cable, optical communications have enabled telecommunications links to be made over much greater distances and with much lower levels of loss in the transmission medium and possibly most important of all, fiber optical communications has enabled much higher data rates to be accommodated. As a result of these advantages, fibre optic communications systems are widely employed for applications ranging from major telecommunications backbone infrastructure to Ethernet systems, broadband distribution, and general data networking. When signals are transmitted over fibers, there exist various kinds of nonlinear effects such as Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS), Cross-Phase Modulation (XPM), Cross-Gain Modulation (XGM) and Four-Wave Mixing (FWM). This is a serious disadvantage in optical communications especially in wavelength-division multiplexing (WDM) systems. On the other hand, this optical non-linearities can be very useful for a number of applications such as wavelength conversion, pulse regeneration, optical monitoring, pulse compression, solitons, optical tunable delays, optical switching, pulse retiming etc.

Optical wavelength conversion is an essential function for the high-speed wavelength division multiplexing optical networks. In optical network, wavelength conversion reduce wavelength blocking, provide wavelength routing and switching, increase flexibility and the capacity of the networks.

## 2. Theoretical Analysis

### 2.1 Wavelength Converters

Wavelength converter changes the input wavelength to a new wavelength without modifying the data contents of the signal. Their most important use will be for avoidance of wavelength

blocking in optical cross connects in WDM networks. Thereby the converters increase the flexibility and the capacity of the network for a fixed set of wavelengths. They are useful components in WDM networks for three major reasons [7]. Convert the input wavelength to a wavelength that is suitable for use within the network.

- Improve utilization of the available wavelengths on the network links.
- Used at the boundaries between different networks.

The features of the converters [8] are

- Bit-rate transparency (up to at least 10 Gb/s).
- No extinction ratio degradation.
- High signal-to-noise ratio at the output.
- Moderate input power levels( 0 dBm).
- Large wavelength span for both input and output signals.
- Possibility for same input and output wavelengths.
- Low chirp.
- Fast setup time of output wavelength.
- Insensitivity to input signal polarization.
- Simple implementation.

### 2.2 Four-Wave Mixing

Four-wave mixing is a type of nonlinear effect, which originates from third order nonlinear susceptibility  $\chi^{(3)}$ . The FWM effect occurs when light of two or more wavelengths is launched into an optical fiber. The newly generated signals can be called as up converted signal or down converted signal. The FWM causes generation of additional noise and degrades system performance and power is lost from wanted signals into unwanted spurious signals [2]. Increasing of the effective area of the optical fiber can reduce the FWM effect. [3]. The Figure 1 shows a simple principle of mixing of two waves at frequency  $\omega_1$  and  $\omega_2$  such that  $\omega_2 > \omega_1$

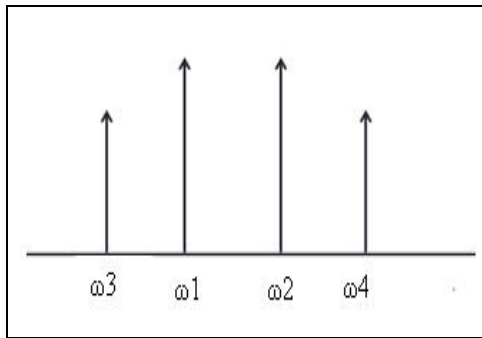


Figure 1: FWM of two wave  $\omega_1$  and  $\omega_2$

In effect, two new frequency components are generated:  
 $\omega_3 = \omega_1 - (\omega_2 - \omega_1) = 2\omega_1 - \omega_2$  and  
 $\omega_4 = \omega_2 + (\omega_2 - \omega_1) = 2\omega_2 - \omega_1$  (2.1)  
 also  $\omega_1 + \omega_2 = \omega_3 + \omega_4$  (2.2)

Similarly, three co-propagating waves will create nine new optical sideband waves at frequencies given by equation (2.3). In general for N wavelengths launched into fiber, the number of generated mixed products M is,  
 $M = N^2(N-1)/2$  (2.3)

### 3. System Design

FWM wavelength converter is based on the impact of the generation of sidebands at new frequencies. The converter is based on four different commercial optical fibers which are: SMF-28 single mode fiber, negative dispersion non-zero dispersion shifted fiber (METRO), dispersion compensating fiber and positive dispersion non-zero dispersion-shifted fiber (LEAF). For the purpose of wavelength conversion, two input signals namely the pump (data) signal ( $\lambda_1$ ) and the probe signal ( $\lambda_2$ ) at different wavelengths are applied to the optical fiber. The launch of different wavelengths produce signals at new wavelengths at the output of the fiber. And the newly generated which is the converted signal ( $\lambda_3$ ) can be filtered out by optical filter at the receiver side. In order to see the impact of link length in the wavelength conversion process, different fiber link lengths is applied for all type of fibers. The FWM wavelength converter is shown in Figure 2.

The transmitter section consist of a Pseudo Random Bit Sequence (PRBS) generator, Non Return to Zero (NRZ) encoder, Continuous Wave (CW) lasers and a Mach-Zehnder Modulator (MZM). Optical fiber is used as communication channel that is the nonlinear medium. The receiver section consist optical filter. FWM wavelength converter using different fibers is simulated in optisystem software. The simulation layout of FWM wavelength converter using different fibers is shown in Figure 2. Pseudo random bit sequence generator, shown in figure generate data signals at a bit rate of 10 Gbps which are encoded using a non return zero pulse generator. Two continuous-wave lasers, tuned inside the C-band, is used as the pump and signal sources. The wavelength of pump is 1563 nm and probe is 1547 nm. The pump is modulated using a LiNbO<sub>3</sub> Mach-Zehnder modulator. The modulated pump and the CW signal beams are combined through an WDM multiplexer. The nonlinear refractive index ( $n_2$ ) is  $2.6 \times 10^{-20} \text{ m}^2/\text{W}$  for all types of fibers. The peak power of the pump into the fiber was 0 dBm

,while the power of the signal was -2 dBm and it's varied from -20 to -2 dBm to compare the converted signal power at different value of probe signal power.

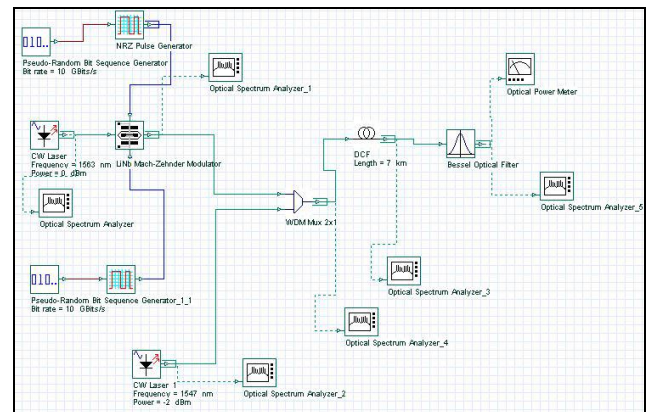


Figure 2: Simulation layout of FWM wavelength converter using different fibers

In order to see the impact of link length in the wavelength conversion process, different fiber link lengths is applied for all type of fibers. The used fiber lengths are 1 km and 7 km. A tunable optical filter is utilized at the output port to filter out the converted signal from the newly generated wavelengths.

### 4. Results and Discussions

The pump power of 0 dBm with wavelength 1563 nm and probe power of -2 dBm with wavelength 1547 nm are applied into the fiber. The Figure 3(a) shows spectral analysis of pump signal at 1563 nm and the probe signal at 1547 nm is shown in Figure 3(b). These two signals combined through a WDM multiplexer and the multiplexed output is shown in Figure 4. When this multiplexed signal passed through the optical fiber FWM process occurs and as a result of this, two converted signals are generated which are upconverted

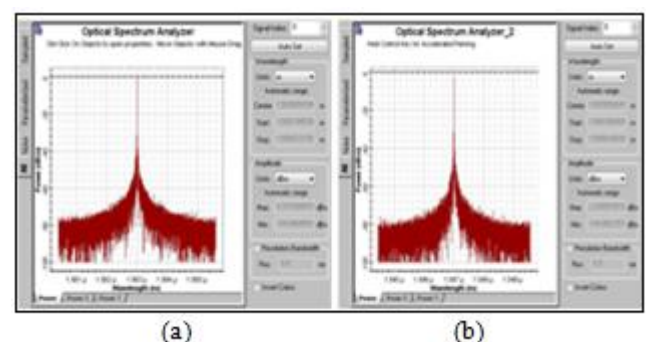
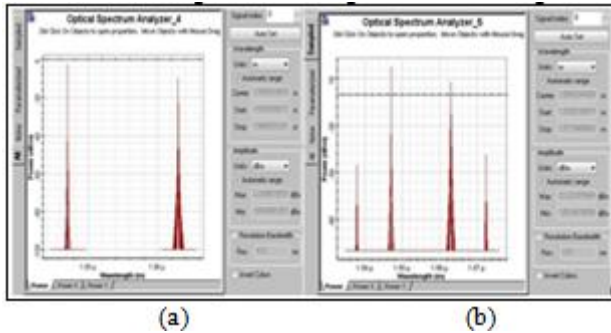


Figure 3: Spectrum of (a)pump with 1563nm (b)probe with 1547nm.

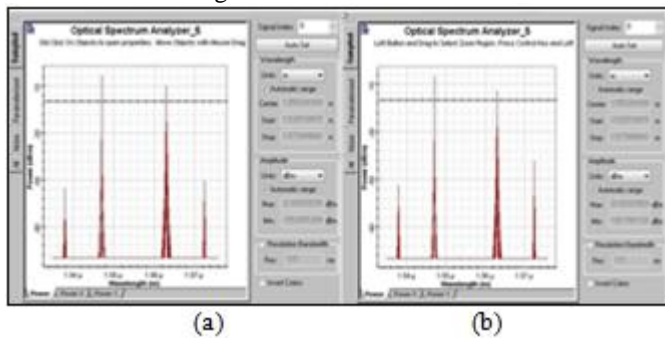
(1572 nm) and downconverted (1538 nm) signals. The spectrum of FWM output with converted signals at 1572 nm and 1538 nm is shown in Figure 4. Among the converted signals, 1572 nm has the peak power of -41.8 dBm.



**Figure 4:** Spectrum of (a) multiplexed signal (b) fiber output with converted wavelengths

#### 4.1 Influence of Fiber Length

In FWM-based wavelength converter, the selected optical fiber is very important for achieving FWM effectively. In order to see the impact of link length in the wavelength conversion process, different fiber link lengths is applied for all type of fibers. The used fiber lengths are 1 km and 7 km and the power of the pump into the fiber was 0 dBm, while the power of the signal was -2 dBm. The output spectrum of the FWM phenomena when utilizing DCF fiber of 1 km and 7 km is shown in Figure 5.



**Figure 5:** Spectrum of DCF fiber output for (a) 1km (b) 7km

As a result of FWM, two converted signals, down converted and up converted signals are generated at 1538 nm and 1572 nm respectively. The peak power of the converted signal 1572 nm, for 1 km and 7 km fiber length is -51 dBm and -40.4 dBm respectively. Similarly, the same procedure is done for SMF-28, LEAF and METRO fibers. The obtained results are summarized and compared in Table 1.

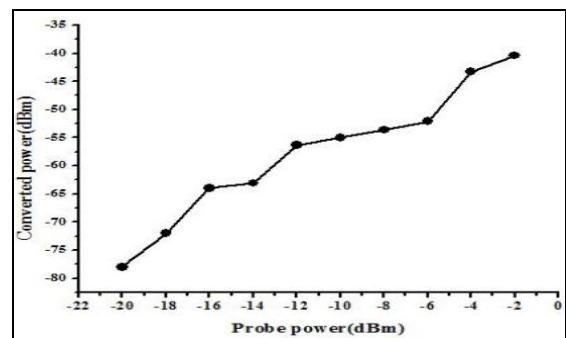
The results obtained indicate that, the peak optical powers of the two newly generated sidebands are higher when changing the fiber link length from 1 km to 7 km. That is, the nonlinear effects depend on the transmission length of the optical fiber. This is because the longer the optical fiber, the more the light interacts with the fiber material and more the nonlinear effects. On the other hand, it is obtained that the DCF fiber has the highest received peak power compared to the other three types of fibers even when changing the fiber length. This is due to the smallest effective area of the DCF fiber compared to the other optical fibers.

**Table 1:** Comparison between the different applied fibers and the effect of fiber length

Type of Optical Fiber	Optical power at 1572 nm in dBm	
	1 km fiber length	7 km fiber length
Dispersion compensating fiber (DCF)	-51	-40.4
Single mode fiber (SMF-28)	-54	-41.8
Positive dispersion non-zero dispersion-shifted fiber (LEAF)	-52.32	-45
Negative dispersion non-zero dispersion-shifted fiber (METRO)	-67.4	-53

#### 4.2 Influence of probe power

In FWM wavelength converter, the probe power is varied from -20 dBm to -2 dBm in order to find the influence of probe power on the converted signal power. The Figure 6 shows the obtained relation of probe power with the converted signal (1572 nm) power for DCF fiber of 7 km. The converted signal varies when changes the input signal power. From the figure its clear that the converted signal power increases with increase in input signal power and the highest value of power for converted signal is obtained at -2 dBm with -40.4 dBm.



**Figure 6:** Probe power Vs Converted signal power

### 5. Conclusion

The FWM wavelength converters using different fibers has been simulated and the results obtained indicate that DCF is the best applied fiber among the four different fibers. This is because of the smaller cross sectional area of DCF. In FWM wavelength converters, it is obtained that the longest interaction length of optical fiber (7 km) lead to highest peak power at the converted wavelength. Also in FWM based wavelength conversion, wavelength conversion covering the entire C-band, can be achieved with different fiber types.

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