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WAVELENGTH CONVERSION BASED ON FOUR WAVE MIXING USING DIFFERENT TYPES OF FIBERS

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***Abstract*— The wavelength conversion based on FWM nonlinear effect is investigated using different types of fibers. The analysis is done at 10 Gbps data rate in terms of wavelength conversion efficiency, Q-factor for up conversion and down conversion. In the simulation setup, one data source (probe signal) and two pump sources are used. The power of probe signal is varied for the investigation purposes and its effect is studied in terms of conversion efficiency and Q factor. The SMF has more conversion efficiency than NZDSF and DCF. It is also observed that the down conversion is better than up conversion.**

***Index Terms*— FWM, WC, SMF, NZDSF, DCF, Q-factor, Conversion efficiency.**

I. INTRODUCTION

Optical wavelength converters have become the key components of future broadcast optical networks. Wavelength convertors (translators) change the carrying wavelength while keeping transmitted data unchanged. These devices fall into two categories: electro- optical and all optical. Electro-optical converters works as repeaters (regenerators) [2]. They convert an optical input signal into electrical form, generate a logical copy of the input signal and then use this signal to drive a transmitter to generate an optical signal at new wavelength. All optical-converters use nonlinear effects to reproduce the information signal at new wavelength.

II. NONLINEAR PHENOMENON IN OPTICS

When a light signal of high power (intensity) impinges on an optical fiber, the refractive index changes in according with the power of signal. The refractive index may be expressed as:

$$n = n_o + n_2 I \quad \text{......................(1)}$$

n_o is the linear refractive index

n_2 is the nonlinear refractive index

I is the power density of the signal

Because of this optical Kerr-effect, Varity of nonlinear phenomenon occur in the optical fibers, including SPM, XPM, FWM, SBS and SRS [6]. The nonlinear effects which are created due to high optical power are also affected by the optical fiber characteristics such that it's effective transmission length and its effective cross section area.

III. FOUR WAVE MIXING (FWM)

The most troublesome nonlinear phenomenon today in optical system is Four Wave Mixing (FWM). The origin of FWM lies in the nonlinear response of bound electrons of a material to an applied optical field [6]. In fact, the polarization induced in the medium contains not only linear terms but also the nonlinear terms. The magnitudes of these terms are governed by the nonlinear susceptibilities of different orders. The FWM process originates from third order nonlinear susceptibility $(\chi^{(3)})$ FWM in optical fiber has been studied extensively because it can be quite efficient for generating new waves.

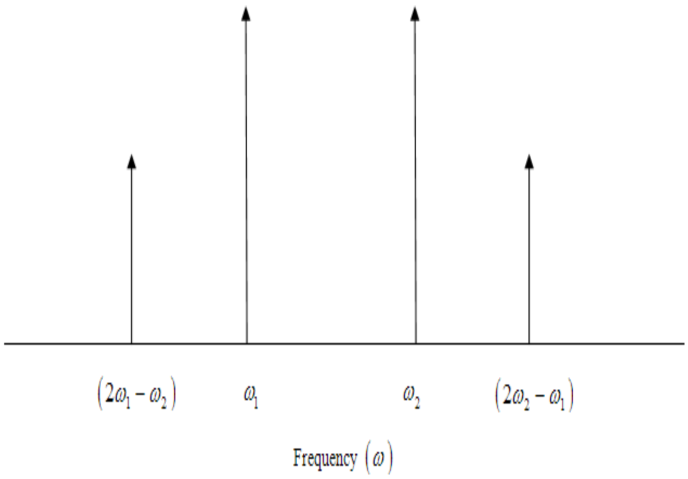

Figure 1 Mixing of two waves

Figure 1 shows a simple example of mixing of two waves at frequencies ω_1 and ω_2. When these waves mixed up they generate sidebands at $2\omega_1 - \omega_2$ and $2\omega_2 - \omega_1$ frequencies. In general for N wavelengths launched into fiber, the number of generated mixed products M is:

$$M = \frac{N^2(N-1)}{2} \quad \text{.........................(2)}$$

IV. WAVELENGTH CONVERSION

The function of wavelength conversion is to transform information from one wavelength to another. The wavelength conversion is an important component in all optical networks, since the wavelength of incoming signal may already being used by another information channel residing on the destined outgoing path [1].

For the wavelength conversion, FWM phenomenon is effectively used. A simple method of wavelength conversion is shown in figure 2

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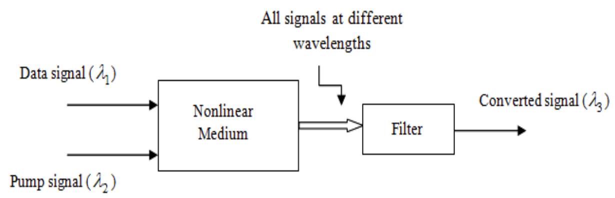

Figure 2 Phenomenological description of wavelength conversion through FWM process

As shown in figure 2, data input and pump signal are injected into a nonlinear medium, new signals are generated at different wavelengths and the particular desired signal is selected using the filter (Bessel optical filter).

Conversion efficiency (η) of FWM wavelength converter is expressed as:

$$\eta = 10\log\frac{P_{out}(\lambda_{converted})}{P_{in}(\lambda_{probe})} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

V. SIMULATION SETUP

All the simulations are performed over the OptiSystem v7.0 software by Optiwave. In the simulation, the data rate is kept constant at 10 Gbps and lengths of used fibers are also kept constant at 25 km. The data signal as well as two pump signals having frequencies 193.3 THz and 193.5 THz respectively are multiplexed using WDM MUX. Then the multiplexed signal is launched into the different types of fibers. The optical spectrum of signal after travelling through the different fibers is obtained by using Optical Spectrum Analyzer. At receiver side optical filter is used to detect the up converted and down converted signals. The power of both the pump signals is kept fixed and power of probe signal is varied for analysis purposes.

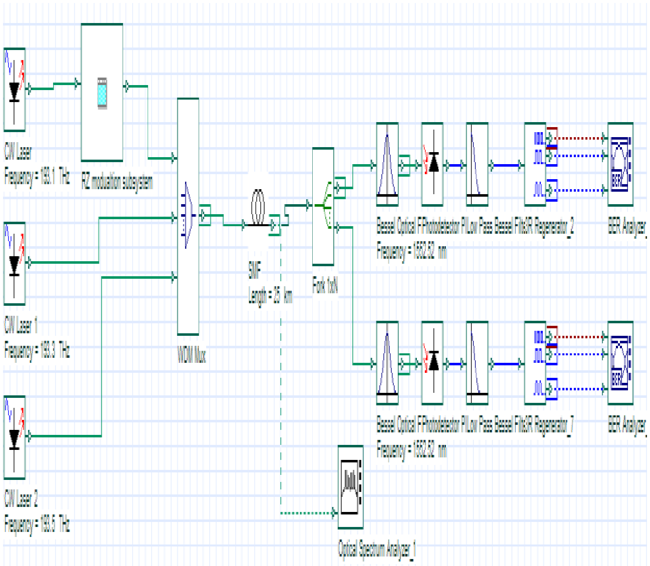

Figure 3 Simulation setup for FWM wavelength conversion

Three types of optical fibers are used for analysis purposes. The important specifications of these fibers are listed in table number 1

Table 1 Specification of fibers used for simulation

Parameters	SMF	DCF	NZ-DSF
Reference wavelength (nm)	1550	1550	1550
Attenuation (dB/km)	0.2	0.5	0.207
Dispersion (ps/nm/km)	17	-85	5.7
Dispersion slope (ps/nm^2/km)	0.075	-0.3	0.029
Effective area (μm^2)	75	22	48

VI. RESULTS AND DISCUSSIONS

The simulation has been carried out for the setup as shown in figure 3. At receiver end the wavelength of received signal varies between 1552.54 nm to 1552.04 nm for down conversion and this variation in wavelength is between 1552.60 nm to 1553.09 nm for up conversion. The power of probe signal is varied and its effect on different types of fiber is investigated in terms of conversion efficiency and Q-factor.

A. Influence of SMF

In case of single mode fiber, the wavelength of Bessel optical filter at receiving side is varied according to up and down conversion wavelengths (checked from the output of optical spectrum analyzer). The power of probe signal is varied from -5 dBm to 10 dBm by keeping the power of both pump signals constant at 0 dBm. The output of Optical Spectrum Analyzer is shown in figure 4.

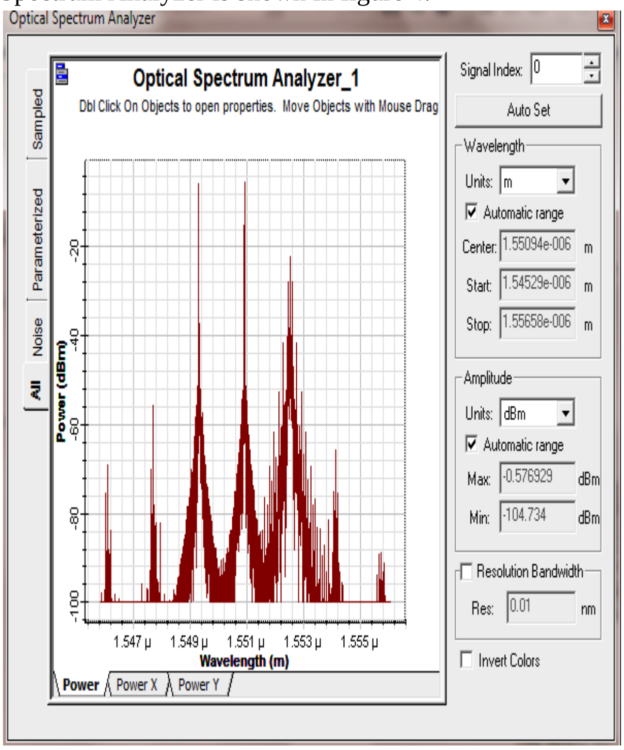

Figure 4 Optical Spectrum Analyzer output using SMF when power is -5 dBm

The effect of power variation of probe signal on Q-factor and conversion efficiency is listed in table number 2 and table number 3 respectively.

Table 2 Variation of Q-factor for different wavelengths in SMF

S. No.	λ_{probe} (nm)	Q- factor (down conversion)			
		Probe signal power (dBm)			
		-5	0	5	10
1	1552.44	19.5886	44.8704	62.2562	70.2463
2	1552.28	8.27416	18.2086	23.8524	25.5449
3	1552.20	7.21987	16.5972	22.3386	23.4738
4	1552.12	4.76441	12.6857	21.9702	24.631
S. No.	λ_{probe} (nm)	Q- factor (up conversion)			
		Probe signal power (dBm)			
		-5	0	5	10
1	1552.60	17.0197	38.129	47.9139	55.2998
2	1552.69	14.3256	28.2016	32.5799	33.1226
3	1552.77	9.08407	20.5987	26.431	27.3472
4	1552.93	4.99326	13.6353	23.7491	26.7598

Table 3 Conversion efficiency for SMF

Conversion type	Conversion efficiency (dB)			
	Probe signal power (dBm)			
	-5	0	5	10
Down conversion	-11.031	-11.896	-12.213	-12.315
Up conversion	-11.23	-11.975	-12.243	-12.328

The Q- factor for both up and down conversion increases as the input power of probe signal increases. But the conversion efficiency decreases as the input power of probe signal increases.

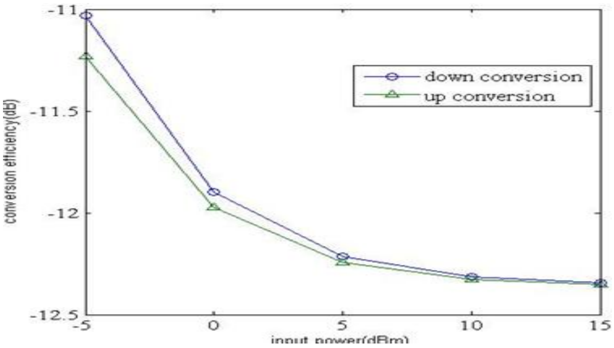

Figure 5 Variation of conversion efficiency for different input power in SMF

B. Influence of NZDSF

In case of Non Zero Dispersion Shifted Fiber, the wavelength of Bessel optical filter at receiving side is varied according to up and down conversion wavelengths (checked from the output of optical spectrum analyzer). The power of probe signal is varied from -5 dBm to 10 dBm by keeping the power of both pump signals constant at 0 dBm. The output of Optical Spectrum Analyzer is shown in figure 6.

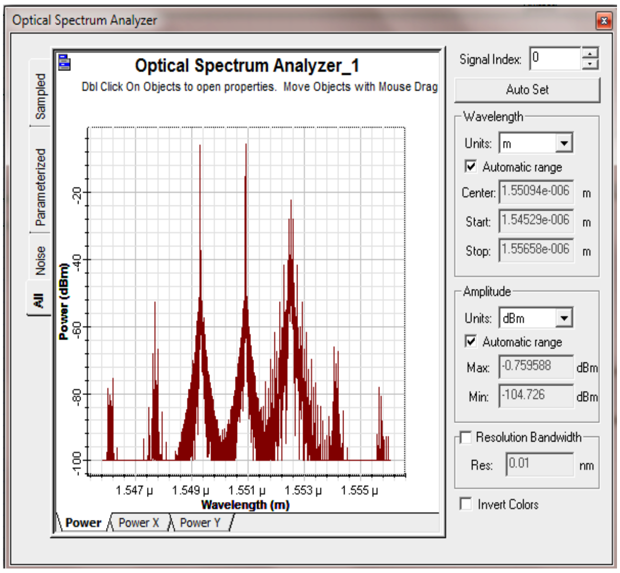

Figure 6 Optical Spectrum Analyzer output using NZ DSF when power is -5 dBm

The effect of power variation of probe signal on Q-factor and conversion efficiency is listed in table number 4 and table number 5 respectively.

Table 4 Variation of Q-factor for different wavelengths in NZ DSF

S. No.	λ_{probe} (nm)	Q- factor (down conversion)			
		Probe signal power (dBm)			
		-5	0	5	10
1	1552.44	21.9099	63.4169	148.683	269.494
2	1552.28	10.818	32.7467	78.1996	134.685
3	1552.20	9.00124	26.6413	67.1373	122.247
4	1552.12	6.22003	18.9896	52.2102	106.956
S. No.	λ_{probe} (nm)	Q- factor (up conversion)			
		Probe signal power (dBm)			
		-5	0	5	10
1	1552.60	24.1631	66.4273	111.611	129.794
2	1552.69	16.116	43.9299	99.1708	138.254
3	1552.77	10.4745	32.4557	85.4913	154.311
4	1552.93	6.34434	19.3228	53.3657	116.652

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Table 5 Conversion efficiency for NZ DSF

Conversion type	Conversion efficiency (dB)			
	Probe signal power (dBm)			
	-5	0	5	10
Down conversion	-11.213	-12.069	-12.389	-12.499
Up conversion	-11.411	-12.148	-12.419	-12.514

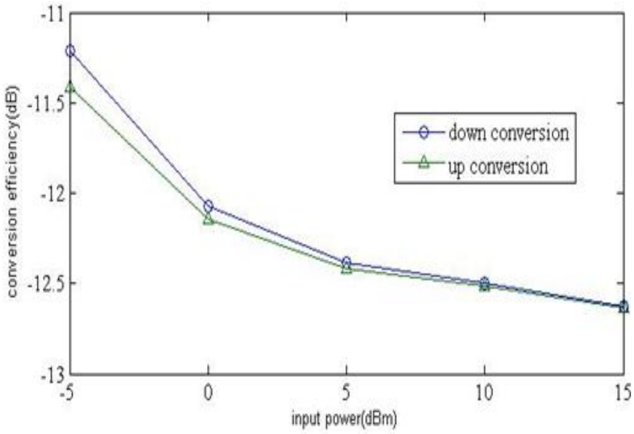

Figure 7 Variation of conversion efficiency for different input power in NZDSF

The Q- factor for both up and down conversion increases as the input power of probe signal increases. But the conversion efficiency decreases as the input power of probe signal increases.

C. Influence of DCF

In case of dispersion compensating fiber, the wavelength of Bessel optical filter at receiving side is varied according to up and down conversion wavelengths (checked from the output of optical spectrum analyzer). The power of probe signal is varied from -5 dBm to 10 dBm by keeping the power of both pump signals constant at 0 dBm. The output of Optical Spectrum Analyzer is shown in figure 8.

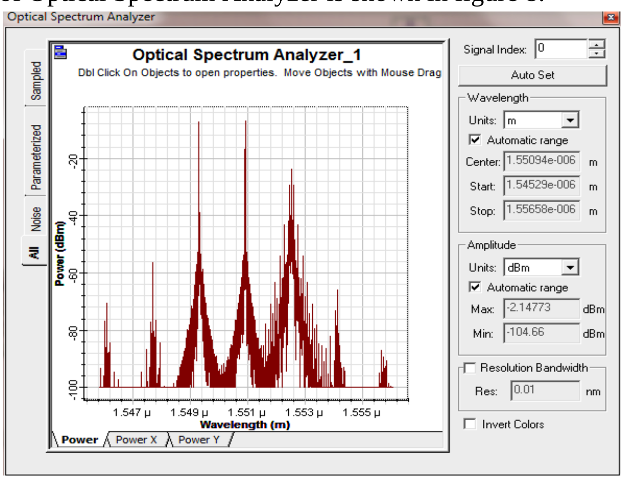

Figure 8 Optical Spectrum Analyzer output using DCF when power is -5 dBm

The effect of power variation of probe signal on Q-factor and conversion efficiency is listed in table number 6 and table number 7 respectively.

Table 6 Variation of Q-factor for different wavelengths in DCF

S. No.	λ_{probe} (nm)	Q- factor (down conversion)			
		Probe signal power (dBm)			
		-5	0	5	10
1	1552.44	17.4771	45.3105	106.235	117.254
2	1552.28	9.37117	27.8746	67.523	102.364
3	1552.20	6.72601	20.6835	55.1309	98.9101
4	1552.12	5.26541	16.0075	45.4776	92.5709
S. No.	λ_{probe} (nm)	Q- factor (up conversion)			
		Probe signal power (dBm)			
		-5	0	5	10
1	1552.60	16.1516	44.7619	101.805	124.274
2	1552.69	13.1338	35.8829	75.3294	113.543
3	1552.77	9.2636	27.355	62.783	100.335
4	1552.93	4.81218	15.248	43.0898	90.5644

Table 7 Conversion efficiency for DCF

Conversion type	Conversion efficiency (dB)			
	Probe signal power (dBm)			
	-5	0	5	10
Down conversion	-12.26	-12.968	-14.7854	-14.954
Up conversion	-13.8069	-14.6880	-15.0220	-15.1340

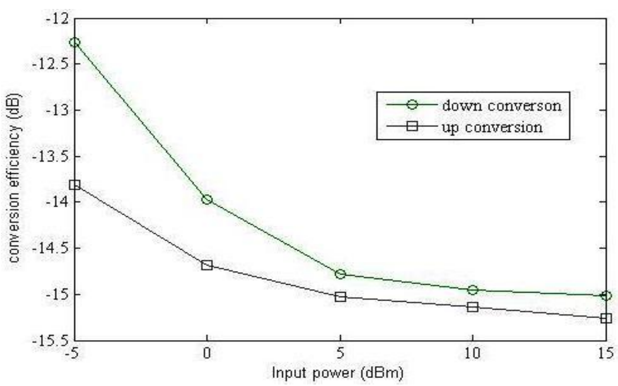

Figure 9 Variation of conversion efficiency for different input power in DCF

The Q- factor for both up and down conversion increases as the input power of probe signal increases. But the conversion efficiency decreases as the input power of probe signal increases.

As from the simulation it is observed that the Q-factor increases for all the fibers as the input probe signal power increases and their conversion efficiency decreases. The comparison is made among these three fibers in terms of their conversion efficiency; it is observed that the conversion efficiency of SMF is more as compare to NZDSF and DCF.

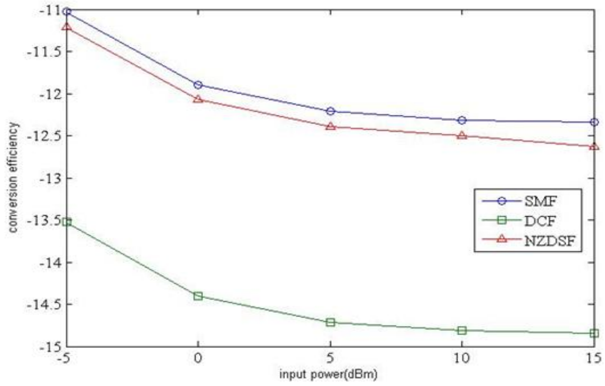

Figure 10 Variation of conversion efficiency w.r.t. input power of probe signal for different types of fibers

VII. CONCLUSION

The wavelength conversion process using FWM on three types of optical fibers has been studied. It is observed that conversion efficiency decreases as the input power increases in all three types of fibers. The SMF has more conversion efficiency than NZDSF and DCF. It is also observed that the down conversion is better than up conversion. It is beneficial to use the down conversion wavelength signals for wavelength conversion at wavelength converter node in an optical network. The conversion efficiency of SMF at -5 dBm power is -11.031 dB for down conversion while -11.32 dB for up conversion.

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