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Analysis of Four-Wave-Mixing Effects in Up Stream Transmission Using SOA as Transmitter

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Abstract

We demonstrate four-wave-mixing (FWM) based wavelength modulation at 1.55 µm using SOA. For a pump peak power of -10 dBm, a numerical simulation is used to predict the performance of each ONU Transmitter for different experimental conditions and to address the potential of each SOA in wavelength modulation effects analysing four-wave-mixing. It is shown that wavelength conversion, covering the entire C-band, can be achieved with different performance for SMF-28 optical fiber at reasonable optical pump power and for different fiber lengths.

Keywords: Four-Wave-Mixing (FWM); optical fiber communication; nonlinear optics; wavelengthconversion.

Introduction

The field of nonlinear optics has continued to grow at a tremendous rate since its inception in 1961 and hasproven to be a nearly inexhaustible source of new phenomena and optical techniques [1]. In opticalcommunication systems the term nonlinearity refers to the dependence of the system on power of the opticalbeam/s being launched into the fiber cable. Nonlinear effects in optical fibers have become an area of academicresearch and of great importance in the optical fiber based systems. Several experiments in the past have shownthat the deployment of high-bit-rate multi-wavelength systems together with optical amplifiers creates majornonlinear effects such as stimulated Raman scattering (SRS), stimulated Brillion scattering (SBS), self-phasemodulation (SPM), cross-phase modulation (XPM) and four-wave-mixing (FWM) [2]. These effects haveproven to of utility in a great number of applications including pulse compression, solitons, optical tunabledelays, optical switching, pulse retiming and wavelength conversion [3].In a wavelength-routed optical network, wavelength conversion plays a major role to reduce wavelengthblocking, provide high flexibility and utilization of wavelength allocation in network management, which hasbeen investigated extensively in the past several years. An all-optical approach of wavelength conversion isfavorable to avoid bit-rate bottleneck and costly signal conversion between optical and electrical domains sincecurrent electronic processing speeds are approaching fundamental limits near 40Gb/s [4]. Ultra-high data rateall-optical wavelength conversion is an enabling technology for providing wavelength flexibility, increasing thecapacity of photonics networks and enhancing optimized all-optical routing and switching [4-5]. Several all- optical wavelength conversion approaches have been demonstrated, which are based on nonlinearities insemiconductor optical amplifiers [6], in optical fibers [7-8], in crystals [9] and so on. Among these approaches,wavelength conversion based on the nonlinearity of optical fibers is inherently featured of femtosecond responsetime, low insertion loss, non-degraded extinction radio of the signal and low-noise characteristics [10], whichshows the promising potential of achieving terabit-per-second performance. Nonlinear effects mainly applied infiber-based wavelength conversion are XPM, FWM and SPM, all of which originate from the Kerr effect [11].Among the various nonlinear phenomena exploited for fiber-based wavelength conversion, FWM is regarded asadvantageous due to its transparency both in terms of modulation format and bit rate [12]. However to make useof this nonlinear phenomenon in optical signal processing requires that a suitable fiber be available. So far, aFWM-based wavelength converter has been demonstrated by using a fabricated W-type soft glass fiber [13] orusing a highly nonlinear photonic crystal fiber [14] or using a highly nonlinear holey fiber [15].In this paper, we have embarked to the authors' knowledge for the first time four different commercialopticalfibers to achieve a wavelength conversion covering the entire C-band and make a comparison in theirperformance using a numerical simulation. The numerical simulating software is Optisystem 7.0 from OptiwaveInc.The remainder of this paper is organized as follows. The mathematical review is presented in Section 2.Based on the theory presented, a numerical analysis of the wavelength conversion process is carried out inSection 3.This is followed by the main conclusion in Section 4.

2.Mathematical Review

Nonlinear phenomena

When a light signal of high power impinges on an optical fiber, the refractive index changes in accordance withthe power of the signal. The refractive index *n* may be expressed as

$n=n_0+n_2$……………………………1

where:
nois the linear refractive index
$n_2$is the nonlinear refractive index, and
I is the power density of the signal
As a result of this, a variety of nonlinear phenomena occur in the optical fiber, including SPM, XPM, FWM,Brillouin

scattering, and so on [16].In a linear medium, the electric polarization P is assumed to be a linear function of the electric field E:

$$P = \varepsilon_0 \chi E \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.2$$

where for simplicity a scalar relation has been written. The quantity **χ** is termed as linear dielectric susceptibility.
At high optical intensities (which corresponds to high electric fields), all media behave in a nonlinear fashion.
Thus Eq. (2) gets modified to

$$P = \varepsilon_0(\chi E + \chi^{(2)}E^{(2)} + \chi^{(3)}E^{(3)} +) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.3$$

where**χ(2)**, **χ(3)**, … are higher order susceptibilities giving rise to the nonlinear terms. The second term on theright hand side is responsible for second harmonic generation, sum and difference frequency generation,parametric interactions etc. while the third term is responsible for third harmonic generation, intensity dependentrefractive index, self-phase modulation, four wave mixing etc. For media possessing inversion symmetry **χ (2)** iszero and there is no second order nonlinear effect. Thus silica optical fibers, which form the heart of today'scommunication networks, do not possess second order nonlinearity [17].

Theory of FWM

The origin of FWM process lies in the nonlinear response of bound electrons of a material to an applied opticalfield. In fact, in order to understand the FWM effect, consider a WDM signal, which is sum of n monochromaticplane waves. The electric field of such signal can be written as

$$E = \sum_{P=1}^{n} E_p \cos(w_p t - K_p z) \dots\dots\dots\dots\dots..4$$

Then the nonlinear polarization is given by

$$P_{nl} = \varepsilon_0 \chi^3 E^3 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.5$$

For this case P_{nl} takes the form as

$$P_{nl} = \varepsilon_0 \chi^3 \sum_{p=1}^{n}\sum_{q=1}^{n}\sum_{r=1}^{n} E_p \cos(w_p t - k_p t)\, E_p\, cos(w_p t - t_p z) E_r\, cos(w_r t - k_r z) \dots\dots\dots.6$$

The reason behind this phase mismatch is that, in real fibersk(3ω) ≠3k(ω) so any difference like (3ω −3k) is called as phase mismatch. The phase mismatch can also be understoodas the mismatch in phase between different signals traveling within the fiber at different group velocities. All these waves can be neglected because they contribute little. The last term represents phenomenon of four-wavemixing [3].

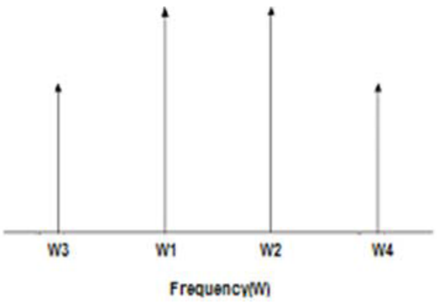
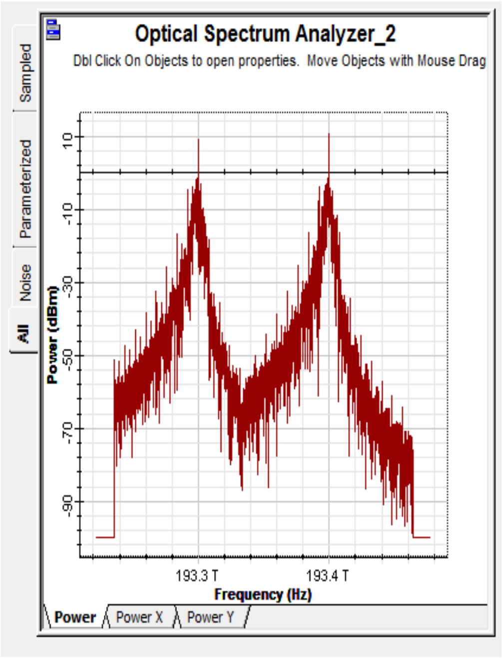


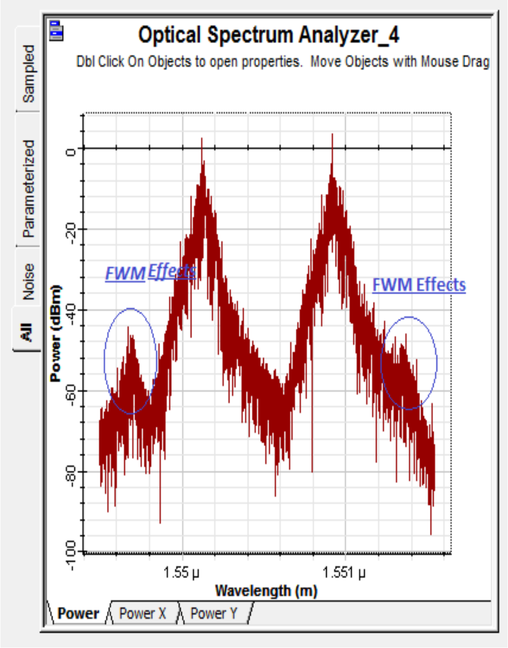
Fig.1. FWM of two wave ω1and ω2

Figure 1 shows a simple example of mixing of two waves at frequency ω1 and ω2. When these waves mixed up,they generate sidebands at ω3 and ω4 such that (ω1+ ω2=ω3+ω4) [18]. Similarly, three co-propagating waveswill create nine new optical sideband waves at frequencies given by Eq. (8). These sidebands travel along withoriginal waves and will grow at the expense of signal-strength depletion.In general for ***N*** wavelengths launched into fiber, the number of generated mixed products ***M*** is,
$M=(N^2/2)(N1)$……..………7

3.Results&Discussion

The modulation was based on SOA different commercial optical fibers which are: SMF-28 single mode fiber.We initially used the same parameters as in [12] forthe pump power, signal power and fiber length. Two continuous-wave (CW) lasers, tuned inside the C-band,were used as the pump and signal sources. In order to achieve peak pump powers of the order of a few dBmwith a moderate average-power fiber amplifier, the pump was modulated using a Mach-Zehndermodulator with rectangular pulses. The modulated pump and the CW signal beams were amplified by twoseparatefiber amplifiers and combined through an ideal multiplexer. This configuration allowed us to independently control the power of the two beams, and also ensured thatnonlinear interaction of the two signals occurred only in the applied fiber. The peak power of the pump into thefiber was -10 dBm, while the power of the signal was .In order to compare the performance of thewavelength conversion numerical experiment, we will apply the same parameters and conditions for the SMF-28fibers including the influence of the length of the induced fiber. At the output of the system, the FWMprocess between the pump and the signal in any specific optical fiber gave rise to a FWM effects which is highlighted by blue circle as shown in fig.2 (a) (b).





We have repeated the same procedure for the other three types of optical fibers and we have observed the samebehaviour but with different optical converted signal peak power. All results indicate that, 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 the greater thenonlinear effects. On the other hand, we have noticed that, the behavior of the SMF-28fiber has the highest peakpower compared to the other three types of fibers even when changing the fiber length. This was due to therelative advantage of the SMF-28fiber characteristics compared to the other optical fibers.

4.Conclusion

In this paper, the performance of different ONU's with SOA as a commercial transmitter in a high speed FWM-based wavelengthmodulation covering the entire C-band has been numerically analyzed. The results show that, the SMF-28opticalfiber has been shown to be a good candidate for wavelength conversion compared to the other commercialfibers. On the other hand, simulations revealed that, by increasing fiber length from 20 Km to 50 Km for all ONUsthe performance obtained from the system increase FWM effects in communication link.

References

i.]C. W. Thiel, "Four-wave mixing and itsapplications,"http://www.physics.montana.edu/students/thiel/docs/FWMixing.pdf, last access
ii. Aug. 2011
iii. .
iv. GurjitKaur, and Arvind Kumar Sharda, "Nonlinear Effects and Its Impact on Multichannel Systems," 2nd National Conference on
v. Challenges and opportunities in Information Technology at RIMT institute of Engineering and Technology, Punjab, pp. 1-6, Mar.2008.
vi. S. P. Singh, and N. Singh, "Nonlinear Effects in Optical Fibers: Origins, Management and Applications," Progress in ElectromagneticsResearch, PIER 73, pp. 249-275, 2007.
vii. C. H. Kwok, S. H. Lee, K. K. Chow, C. Shu, Chinlon Lin, and A. Bjarklev, "Widely Tunable Wavelength Conversion With ExtinctionRatio Enhancement Using PCF-Based NOLM," IEEE Photonics Technology Letters, vol. 17, no. 12, pp. 2655-2657, 2005.
viii. XinXiangjun, P.S. André, A.L.J. Teixeira, Ana Ferreira, Tiago Silveira, P.M. Monteiro, F. da Rocha, and J.L. Pinto, "Detailednumerical analysis of a four-wave mixing in dispersion-shifted fiber based all-optical wavelength converter of 10 Gb/s single sidebandoptical signal," Optical Fiber Technology, vol. 12, pp. 288–295 , 2006.
ix. D. Wolfson, A. Kloch, T. Fjelde, C. Janz, B. Dagens, and M. Renaud, "40-Gb/s all-optical wavelength conversion, regeneration, anddemultiplexing in an SOA-based all-active Mach-Zehnder interferometer," IEEE Photonics Technology Letters, vol. 12, no. 3, pp.332–334, 2000.
x. J. Yu, P. Jeppesen, and N.S.Knudsen,"80 Gbit/s pulsewidth-maintained wavelength conversion based on HNL DSF-NOLM includingtransmission over 80 km of conventional SMF," Electronics Letters, vol. 37, no. 9, pp. 577–579, 2001.
xi. J. Yu, and P. Jeppesen, "80-Gb/s wavelength conversion based on cross-phase modulation in high-nonlinearity dispersion-shifted fiberand optical filtering," IEEE Photonics Technology Letters, vol. 13, no. 8, pp. 833–835, 2001.
xii. J. Yamawaku, H. Takara, T. Ohara, K. Sato, A. Takada, T. Morioka, O. Tadanaga, H. Miyazawa, and M. Asobe, "Simultaneous 25GHz-spaced DWDM wavelength conversion of 1.03Tbit/s (103×10Gbit/s) signals in PPLN waveguide," Electronics Letters, vol. 39,pp. 1144–1145, 2003.
xiii. TakuoTanemura, Jun Suzuki, Kazuhiro Katoh, and Kazuro Kikuchi, "Polarization-Insensitive All-Optical Wavelength ConversionUsing Cross-Phase Modulation in Twisted Fiber and Optical Filtering," IEEE Photonics Technology Letters, vol. 17, no. 5, pp. 1052-1054, 2005.
xiv. Huangping Yan, Yuanqing Huang, ZhihuaWeng, Yiju Wang, Ruifang Ye, Zhaoxi Wu, and Jin Wan, "All-optical WavelengthConverter Based on Self-Phase Modulation in Highly Nonlinear Photonic Crystal Fiber," SPIE, vol. 6837, no. 683714, pp. 1-9, Jan.2008.
xv. S. Asimakis, P. Petropoulos, F. Poletti, J. Y. Y. Leong, R. C. Moore, K. E. Frampton, X. Feng, W. H. Loh, and D. J. Richardson,"Towards efficient and broadband four-wave-mixing using short-length dispersion tailored lead silicate holy fibers," Optics Express,vol. 15, no. 2, pp. 596-601, Jan. 2007.
xvi. Angela Camerlingo, Francesca Parmigiani, Xian Feng, Francesco Poletti, Peter Horak, Wei H. Loh, David J. Richardson, and PeriklisPetropoulos, "Wavelength Conversion in a Short Length of a Solid

Lead–Silicate Fiber," IEEE Photonics Technology Letters, vol. 22,no. 9, pp. 628-630, May 2010.

xvii. Peter A. Andersen, TorgerTokle, Yan Geng, Christophe Peucheret, and PalleJeppesen, "Wavelength Conversion of a 40-Gb/s RZDPSKSignal Using Four-Wave Mixing in a Dispersion-Flattened Highly Nonlinear Photonic Crystal Fiber," IEEE PhotonicsTechnology Letters, vol. 17, no. 9, pp. 1908-1910, Sep. 2005.

xviii. Ju Han Lee, Walter Belardi, KentaroFurusawa, Periklis Petropoulos, ZulfadzliYusoff, Tanya M. Monro, and David J. Richardson,"Four-Wave Mixing Based 10-Gb/s Tunable Wavelength Conversion Using a Holey Fiber With a High SBS Threshold," IEEEPhotonics Technology Letters, vol. 15, no. 3, pp. 440-442, Mar. 2003.

xix. JiroHiroishi, RyuichiSugizaki, Osamu Aso, MasateruTadakuma, and TaekoShibuta, "Development of Highly Nonlinear FibersforOptical Signal Processing," Furukawa Review, no. 23, 2003.

xx. K. Thyagarajan, and AjoyGhatak, "Some important nonlinear effects in optical fibers," Guided Wave Optical Components andDevices: Basics, Technology, and Applications, Bishnu P. Pal, Academic Press, pp. 91-121, 2006.

xxi. G. P. Agrawal, Nonlinear Fiber Optics, 4th edition, Academic Press, Oxford, pp. 391-392, 2007.