13C2-5

Equivalent Optical Circuit Synthesis using Polarimetric OTDR For Simulating Two-Pump Optical Fibre Parametric Amplifiers

Takeshi Ozeki , Takuro Kanou [10], Kazuki Hayashi and Teruhiko Kudou
Department of Electrical Engineering, Faculty of Science and Technology, Sophia University,
7-1, Kioi-cho, Chiyoda-ku, Tokyo, 102-8554, Japan
t-ozeki@gentei.ee.sophia.ac.jp

Abstract

Equivalent optical circuit synthsized by polarimetric OTDR mesurement is applied to simulate polarization gain spectrum of two-pump fiber optical parametric amplifier resulting better estimation of polarization gain spectrum but 5dB discrepancy in average gain.

Introduction

The orthogonal two-pump fibre optical parametric amplifier (FOPA) is expected as a useful polarization independent FOPA [1]. However, the polarization gain spectrum of FOPA with PMD=0.015 $ps/\sqrt{km}$ was analysed severely to show the relatively flat gain spectrum with 10dB gain reduction using the PMD operator $\mathrm{B}\cdot\sigma\cdot\delta\omega$ [2]. Further, the Raman scattering in the FOPA is analysed to show fairly large polarization dependant gain and gain-tilt [3].

The equivalent optical circuit sysnthsis using a polarimetric OTDR is successfully demonstrated to map polarization mode dispersion (PMD) distributed along fiber length [4,5]. However, it needs to be verified by demonstrations in various applications. Here, we demonstrate to regenerate the polarization gain spectrum of a two-pump FOPA by an equivalent optical circuit synthsized by polarimetric OTDR measurement , for the first time. Additionary, the behaviors of polarization states of constituent waves along the fiber are visualized.

Experiments

Figure 1 shows our experimental setup for an FOPA with orthogonally polarized pump waves. A 620m highly nonlinear fiber (HNF) is used in our FOPA. The zero dispersion wavelength of the fiber is 1548.5.nm and its dispersion slope is $0.048\,ps/nm^2km$. The measured nonlinear parameter γ is $9.8/W\cdot km$. The pump distributed feedback (DFB) laser diodes were modulated by current at 100 kHz (50%) for Stimulated Brillion Scattering (SBS) suppression. The

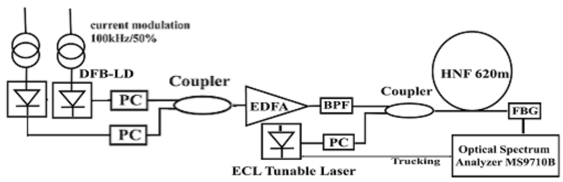

Fig.1 Experimental Set-Up:

The Polarimetric OTDR [4] is set at the output end of HNF preventing variation of polarization condition.The circuit is synthesed in revese way following the amplification direction.

pump power of 1531.5nm and 1567nm waves were adjusted to order of 500mW for each after an EDFA. Two-pump FOPA gain spectrum was measured for linearly polarized signal waves rotated by 0^o, 30^o, 60^o and 90^o at the input end, which are depicted by color coded lines of red, black, blue and magenda, respectively, in Fig.2. The gain variation depending on the input polarization states is about 3.5dB at shorter wavelength region. Two spikes in Fig.2 correspond to attenuated two pumps.

Numerical Simulation

The numerical simulation based on measured parameters without PMD considering six optical vector waves in the non-linear coupled equations of the two-pump FOPA, is depicted in Fig.2 comparing the measured polarization gain spectrum. The gain and bandwidth simulated almost fit well with the measured values. The polarization dependences are reduced to negligible level by considering six vector waves [3].

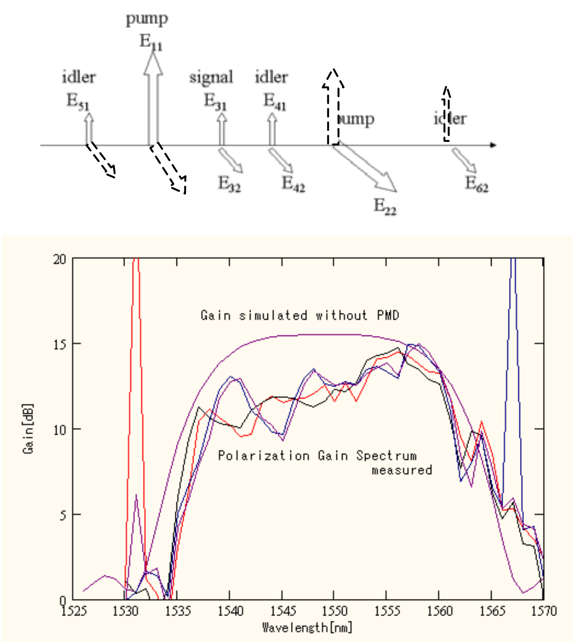

Fig.2 Simulation of Polarization Gain Spectrum by using measured parameters without PMD. In the upper panel, six vector waves in the nonlinear parametric process involuved in two-pump FOPA are illustrated. The colour codes are in text.

Simulation of FOPA using Equivalent optical Circuit determined by Polarimetric OTDR

Here, the transfer matrix j_m of m[th] fibre segment with 0.5m length determined by the polarimetric OTDR measurement [4] is used for simulation based on coupled six vector wave non-linear equations. The phase shifts $\phi_m^k, \theta_m, \psi_m^k$ of j_m at the optical frequency of k for the signal, idler, and two pump waves are described in the following way for the 1[st] order PMD, for an example,

$\phi_m^k = \phi_m \cdot \omega_k / \omega_o$,

where ϕ_m is the phase shift determined by the polarimetric OTDR measurement, ω_o and ω_k are the optical frequencies of the OTDR using $\lambda_0 = 1550nm$ and *k wave,* respectively. θ_m is the rotation angle of the fibre segment. Fig.3 shows the evolutions of the x-component of the pump, and the signal wave intensity of both polarizations and y-component, along the HNF. The PMD of the NHF is 0.064ps with almost linear accumulation proportional to fibre length as shown in Fig.3. It is clear that the signal wave polarization varies almost corresponding to the polarization state variations of the pump wave. The polarization gain spectrums simulated using the Jones matrix synthesized by the polarimetric OTDR measurement are shown in Fig.4. The average gain reduction by introducing PMD is about 10dB, which agrees with the discussion of ref. [2]. The polarization dependence of the gain spectrum simulated is about 0.8dB, which is smaller than the 3.5dB PDG measured.

Discussion

The polarization gain spectrum is simulated by the six pairs of nonlinear vector coupled equations using all measured parameters including the fiber Jones matrix, for the first time. It is said that the quantitative fitting of the polarization gain spectrum is not sufficient in details yet.

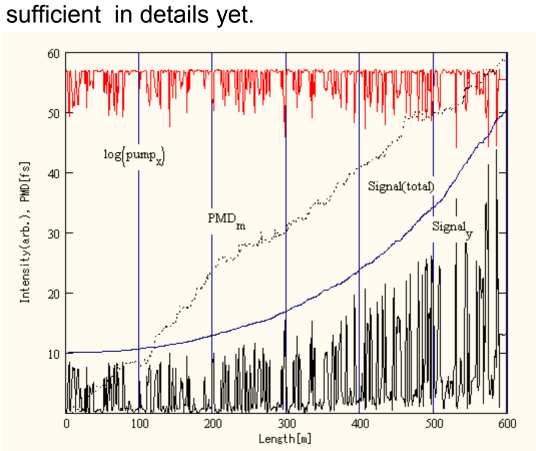

Fig.3 Evolution of Pump, signal polarization along the HNF. The red line denotes the x-component pump power in log, which correlated with the y-component signal depicted by black line. The total signal power is depicted by blue line. PMD is depicted by black dotted line.

It suggests the simultaneous consideration of Raman scattering [3,6,7,8], zero dispersion wavelength mapping [9] and PMD mapping for better fitting accuracy. The gain tilts observed could be attributed also to the Raman scattering contribution in FWM process [3].

Conclusions

Equivalent optical circuit synthsized using polarimetric OTDR mesurement is applied to simulate polarization gain spectrum of two-pump optical fiber parametric amplifier, resulting better estimation in polarization gain variation but 5dB discrepancy in average gain.

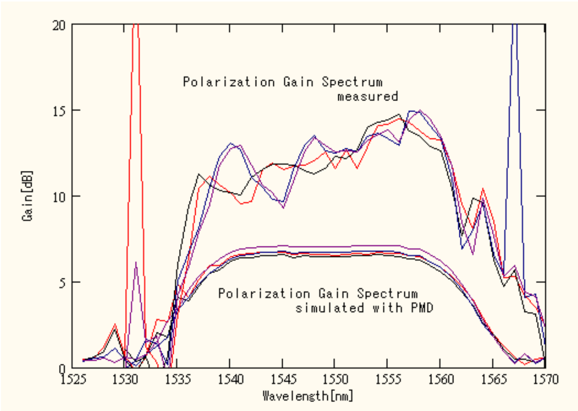

Fig.4 Gain Spectrum Simulated considering PMD. The colour codes of polarization Gain Spectrums are same for the measured and simulated spectrums.

References

1. K. Y. Wong, and et. al.; IEEE Photon. Tech. Lett. vol. 14, No.7, 911 (2002)
2. F. Yaman, Q. Lin and G.P.Agrawal, IEEE Photon. Tech. Lett.Vol.16, no.2, 431 (2004)
3. Q. Lin, F. Yaman, G.P.Agrawal, I., IEEE Photon. Tech. Lett. Vol.18, no.2, 397(2006)
4. T.Ozeki, and et.al., J. Lightwave Tech. vol.24, no.7, 3882 (2006)
5. T. Kudou, M. Iguchi, M. Musuda, and T. Ozeki; J. Lightwave Technol.vol.18, 614 (2000)
6. G. P. Agrawal," Nonlinear Fiber Optics", Third Edition, Academic Press, San Diego (2001)
7. R.H.Stolen,J.P.Gordon,W.J.Tomlinson,H.A.Haus, J.Opt.Soc.Am.B,vol.6,no.6,1159 (1989)
8. D. J. Dougherty, F. X. Kartner, H. A. Haus and E. P. Ippen, Opt.Lett.vol.20,no.1, 31(1995)
9. A. Mossot and et.al., IEEE Photon. Tech. Lett. Vol.18, no.1, 22, (2006)
10. Presently, at Sumitomo Electric Industries, Ltd.