Conference materials
UDC 535.015
DOI: https://doi.org/10.18721/JPM.183.243

Experimental study of the FWM-effect in the fiber-optic system with wavelength division multiplexing

E.I. Andreeva, V.R. Kassihin✉

Bonch-Bruevich Saint Petersburg State University of Telecommunications, St. Petersburg, Russia

✉ e-andreeva-spb@yandex.ru

Abstract. Four-wave mixing (FWM) is the intermodulation phenomenon in the optical signal, as a result of which several linearly polarized optical waves interact. An experimental study of the Four-Wave Mixing effect in standard single-mode fiber (SSMF) and nonzero dispersion-shifted fiber (NZDSF) was carried out, with two and three wavelengths. An experimental investigation was carried out with the typical DWDM equipment. It was shown that FWM-effect has the significant influence on the propagation of the symbol pulses in dispersion - shifted optical fiber.

Keywords: fiber-optic communication system, Wavelength Division Multiplexing, optical fiber, dispersion-shifted fiber, nonlinear effects, Four-Photon Mixing

Citation: Andreeva E.I., Kassihin V.R., Experimental study of the FWM-effect in the fiber-optic system with wavelength division multiplexing, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 18 (3.2) (2025) 214–217. DOI: https://doi.org/10.18721/JPM.183.243

Материалы конференции
УДК 535.015
DOI: https://doi.org/10.18721/JPM.183.243

Экспериментальное исследование FWM-эффекта в волоконно-оптической системе с мультиплексированием с разделением длин волн

Е. И. Андреева, В. Р. Кассихин✉

Санкт-Петербургский государственный университет телекоммуникаций им. проф. М.А. Бонч-Бруевича, Санкт-Петербург, Россия

✉ e-andreeva-spb@yandex.ru

Аннотация. Четырехволновое смешение (FWM) – это явление интермодуляции в оптическом сигнале, в результате которого взаимодействуют несколько линейно поляризованных оптических волн. Было проведено экспериментальное исследование эффекта четырехволнового смешивания в стандартном одномодовом волокне (SSMF) и волокне с ненулевым сдвигом дисперсии (NZDSF), с двумя и тремя рабочими длинами волн. Экспериментальное исследование проводилось на обычном оборудовании DWDM. Было показано, что FWM - эффект оказывает существенное влияние на распространение символьных импульсов в оптическом волокне со смещением дисперсии.

Ключевые слова: волоконно-оптическая система связи, мультиплексирование с разделением длин волн, оптическое волокно, волокно со смещенной дисперсией, нелинейные эффекты, четырехфотонное смешение

Ссылка при цитировании: Андреева Е.И., Кассихин В.Р. Экспериментальное исследование FWM-эффекта в волоконно-оптической системе с мультиплексированием с разделением длин волн // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2025. Т. 18. № 3.2. С. 214–217. DOI: https://doi.org/10.18721/JPM.183.243

Introduction

Fiber-optic communication lines serve as the backbone of contemporary data networks, enabling high-bandwidth and robust long-distance data transfer. In wavelength division multiplexing (DWDM) systems, the quality of data transmission is affected by linear (loss, dispersion) effects and nonlinear effects, such as Four-Wave Mixing (FWM), Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBR), Carrier-lnduced Phase modulation (ClP), and others [1–5]. In the processes of SRS and SBR, the optical fiber is a nonlinear medium and plays an active role, since vibrations of its molecules are involved. In parametric processes, one of which is four-wave mixing, the optical fiber acts as the passive medium in which optical waves interact through the nonlinear response of the electrons of the outer shells excited by them.

FWM is characterized by the low threshold of manifestation, therefore it requires an assessment of the impact on the Bit Error Rate (BER).

The essence of the effect is that when four linearly polarized optical waves with frequencies ω_1, ω_2, ω_3 and ω_4 interact, photons of one frequency can be destroyed and rotons of other frequencies can be created while maintaining the pulse energy. There are two types of four-wave mixing [1–2]:

the energy of two photons is transferred to two new ones, generated at the frequencies:

$$\omega_3 + \omega_4 = \omega_1 + \omega_2;$$

the energy of three photons is transferred to the fourth, generated at the frequency:

$$\omega_4 = \omega_1 + \omega_2 + \omega_3.$$

The first case was investigated with two DWDM-channels.

Experimental Results and Discussion

The experimental study was conducted with the typical telecommunication DWDM equipment (Fig. 1.).

The experimental setup included: the laser sources: *1* is the laser source (λ_1=1536,6nm), *2* is the laser source (λ_2=1537.4nm), *3* is the laser source (λ_3=1538.2nm); *4* is the multiplexor; *5* is the optical Er-doped amplifier; 6 is the optical fiber; *7* is the attenuator; *8* is the optical spectrum analyzer. A multiplexer receives the 1 dBm signal from laser sources and transmits multiplexed signal to the amplifier. The erbium amplifier provided up to 24 dBm of optical power in the optical fiber.

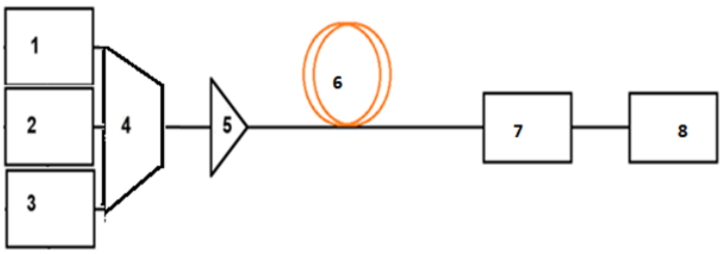

Fig. 1. Optical block diagram of the experimental setup: laser sources *1*–*3* (laser source with wavelength λ_1 = 1536.6 nm, laser source with wavelength λ_2=1537.4 nm, and laser source with wavelength λ_3 = 1538.2nm), multiplexor *4*, optical Er-doped amplifier *5*, optical fiber *6*, attenuator *7*, optical spectrum analyzer *8*

The dispersion-shifted optical fiber (NZDSF) parameters: Kerr nonlinearity coefficient $\gamma = 2.5\ W^{-1}km^{-1}$, dispersion 2 ps/nm/km ($\beta_2 = -2.5\ ps^2/km$), loss 0.2 dB/km.

The standard single-mode optical fiber (SSMF) parameters: Kerr nonlinearity coefficient $\gamma = 1.2\ W^{-1}km^{-1}$, dispersion $D = 16.67$ ps/nm/km ($\beta_2 = -20\ ps^2/km$), loss 0.2 dB/km.

The experimental investigation was carried out with telecommunication DWDM equipment. Optical signals at λ_3 and λ_4 are the result of FWM- effect (Fig. 2). There is the optical signal spectrum at the end of optical cable of 22.5 km length as the example of the experimental study.

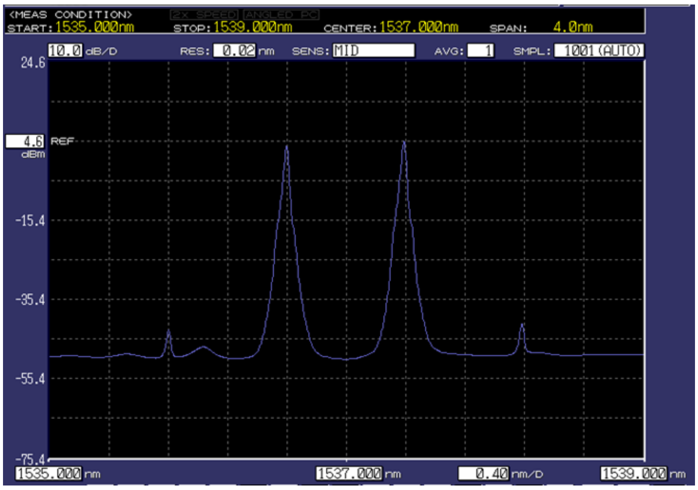

Fig. 2. Optical pulse spectrum with 2 laser sources at the end of optical cable of 22.5 km length

The experimental investigation was telecommunication DWDM equipment. Optical signals at λ_4, λ_5, λ_6 and λ_7 are the result of FWM-effect (Fig. 3).

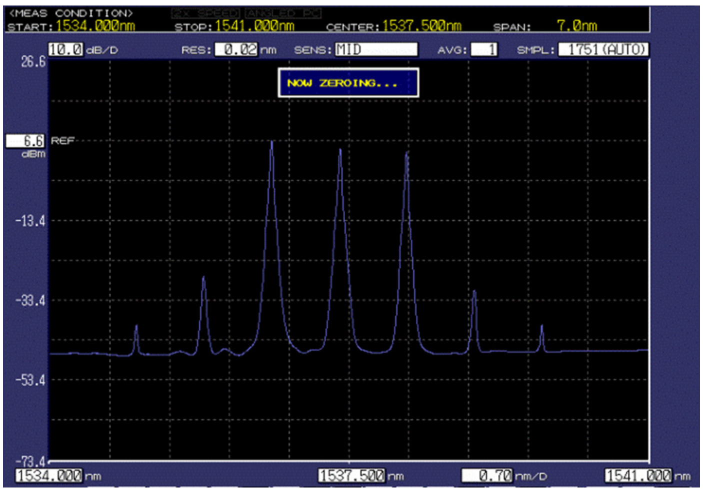

Fig. 3. Optical pulse spectrum with 3 laser sources at the end of optical cable of 22.5 km length

Experimental investigation has shown that FWM effect imposes limitations on the initial optical pulse power in DWDM telecommunication system. As the number of working channels increases, the number and power of interference located at the wavelengths of the working channels of the DWDM-system increase too.

Conclusion

Thus, the experimental study of FWM effect in SSMF and NZDSF was carried out. It was shown that FWM - effect has significant influence on the propagation of the symbol pulses in dispersion - shifted optical fiber in DWDM communication systems.

REFERENCES

1. **Agrawal G. G.,** Fiber-Optics Communication Systems. 5th Edition. New York. 2021.
2. **Agrawal G.,** Nonlinear Fiber Optics. 6th Edition. Elsevier. 2019.
3. **Yakovlev N.V., Bykov A.V., Andreeva E.I.,** Effect of the FWM and SRS on the fiber optics wavelength multiplexing system parameters. "Saint Petersburg OPEN 2021" 8th International School and Conference on Optoelectronics, Photonics, Engineering and Nanostructures St. Petersburg, Russia, May 25 – 28. 2021.
4. **Ferreira M.,** Nonlinear Effects in Optical Fibers. John Wiley & Sons, Inc., Hoboken, New Jersey, USA. 2011.
5. **Andreeva E.I.,** Feature of optical soliton sequence propagation in single-mode fiber. Journal of Physics: Conference Series. (2020) 012125.

THE AUTHORS

ANDREEVA Elena I.
e-andreeva-spb@yandex.ru
ORCID: 0000-0002-1945-1050

KASSIHIN Vladimir R.
e-andreeva-spb@yandex.ru
ORCID: 0009-0006-7950-7104

Received 26.08.2025. Approved after reviewing 10.09.2025. Accepted 01.10.2025.