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Four-wave mixing in amplified WDM system with anomalous dispersion fibers

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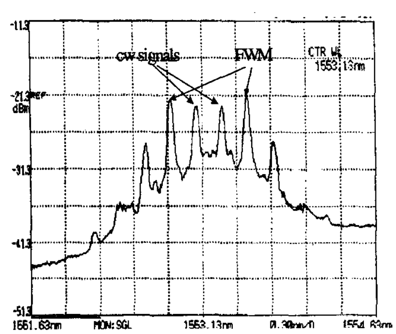
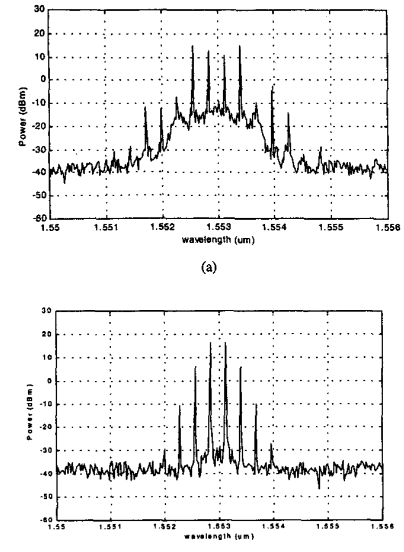
The effect of four wave mixing (FWM) on wavelength-division multiplexing (WDM) optical fiber systems has long been studied, as it causes crosstalk and degrades system performance.[1] It is known that FWM efficiency depends on the optical signal powers and the phase matching condition between different signal channels traveling along the fiber.[2] In this paper, we report that FWM efficiency can be significantly enhanced by modulation instability (MI)[3] in amplified optical systems with anomalous dispersions. The experimental result is verified by a numerical simulation. This effect has to be taken into account in WDM system designs.

Consider a simple system with only two signal channels. FWM causes energy transfer from the signals into newly generated sidebands. It has been predicted previously that FWM efficiency can be close to unity if the fiber dispersion is sufficiently small.[1] However, it was generally accepted that the power in the FWM components could never be higher than the signals power level, otherwise, a reverse energy transfer from FWM sidebands back to the signals would happen. MI, on the other hand, is a parametric amplification process that originates from the same nonlinear Kerr effect and it happens only in fiber systems with anomalous dispersions.

In order to study the interaction between FWM and MI in amplified WDM optical systems, an experiment was carried out. Light from two tunable lasers were polarization aligned, combined and launched into a two-span fiber system. The total output optical powers of both EDFAs were 16 dBm and the two fiber spans were both 22 km non-zero-dispersion-shifted fibers (NZDSF) with the dispersion parameter of 2.75 ps/nm-km at the signal wavelength. Figure 1 shows an optical spectrum at the output of the system. The two peaks at the center are signals and they are separated by 35 GHz. It can be seen from Fig. 1



CThK58 **Fig. 1.** Optical power spectra measured at the output of a NZDSF system with anomalous dispersion (D = 2.75 ps/nm-km).



CThK58 **Fig. 2.** Simulation optical power spectra from the two-span 22 km length of NDSF system, (a) for anomalous dispersion D = 2.75 ps/nm-km, (b) for normal dispersion D = −2.75 ps/nm-km.

that the power of FWM components at each side of the signals are higher than the power of the signals. This cannot be explained by a simple FWM theory.[2] In fact, we believe that the FWM sidebands were effectively amplified by MI gain.

To verify the experimental results a Split-Step Fourier simulation was carried out which solves the nonlinear Schrodinger equation numerically. The parameters used in the simulation were chosen to be the same as those in the experiment. The result is shown in Fig. 2(a), where the MI gain profile around the center wavelength is clearly demonstrated and the amplified FWM sidebands are indeed higher than the signals. We also simulated the output optical spectrum in the same system but with normal dispersion fibers (D = −2.75 ps/nm-km) and the anomalous amplification of FWM sidebands does not exist in this case as shown in Fig. 3(b).

1. R.W. Tkach, *et al.*, J. Lightwave Technol. Vol. **13,** p. 841–849, 1995.
2. N. Shibata, *et al.*, IEEE, J. Quantum Electron., vol. **QE-23,** p. 1205–1210, 1987.
3. R. Hui, *et al.*, J. Lightwave Technol. Vol. **15,** p. 1071–1082, 1997.

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Demonstration of a prototype bandwidth-on-demand broadband access network using monolithically integrated coherent transceivers

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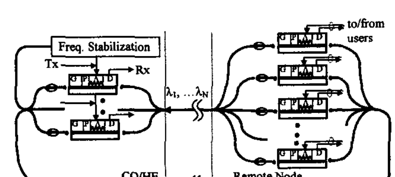
Among the few potential broadband access schemes, the coherent dense WDM technology[1,2] is advantageous to provide a system with very small channel spacing, easy channel selection, and massive-user support due to its superior receiving sensitivity and electronic tuning and filtering capability.

Recently, we proposed a coherent access network with the features of bandwidth-on-demand (BOD) and privacy.[3] The BOD services are realized by using tunable coherent transceiver arrays at remote nodes and the privacy is achieved by deploying dedicated coaxial cable to each subscriber. We also proposed and demonstrated a novel concept of dynamically partitioning users' bandwidth between their up- and down-stream signals.[4] In this paper, we report the demonstration of a prototype access network with multiple wavelength channels and users using tunable coherent transceivers (TCTs)[5] operated under a counter-receiving heterodyne detection (CRHD) scheme.[6]

The experimental set-up is illustrated in Fig. 1. The output signals from the TCT array at the central office or head-end (CO/HE) were combined first and then delivered to the user TCT arrays at remote nodes via a standard single mode fiber. The up-stream signals from the user units were transmitted to the CO/HE via a second fiber. The TCT is composed of a three-section DBR laser and an integrated waveguide detector.[5] The optical frequencies of the TCTs at the CO/HE were fixed with a frequency stabilization circuit and the TCTs at user ends were tuned and locked to the desired wavelength channels set by the CO/HE according to application needs.

To facilitate BOD services, one of the optical channels should be TDM-shared among all users for signaling, low bit rate operation, and network maintenance purposes. In our experiment, two TCTs were used to simulate the CO/HE and another two were used to represent the user units. To demonstrate the signal-



CThK59 **Fig. 1.** Schematic of the bandwidth-on-demand broadband access network. CO/HE: central office or head-end. G: gain section, P: phase section, Λ: grating section, D: detector section, Tx: transmitted data, Rx: received data.