Incoherent broadband optical pulse generation using an optical gate

Biao Chen (陈 彪) and Qiong Jiang (江 琼)

Centre for Optical and Electromagnetic Research, Zhejiang University, Hangzhou 310058

Received February 18, 2008

In two-dimensional (2D) time-spreading/wavelength-hopping optical code division multiple access (OCDMA) systems, employing less coherent broadband optical pulse sources allows lower electrical operating rate and better system performance. An optical gate based scheme for generating weakly coherent (approximately incoherent) broadband optical pulses was proposed and experimentally demonstrated. In this scheme, the terahertz optical asymmetric demultiplexer, together with a coherent narrowband control pulse source, turns an incoherent broadband continuous-wave (CW) light source into the required pulse source.

OCIS codes: 060.0060, 060.2330, 060.1810.

doi: 10.3788/COL20080609.0638.

Optical code division multiple access (OCDMA) is one of the most promising technologies for future all-optical communication applications, especially in access realm. Time-spreading/wavelength-hopping OCDMA, which utilizes both time and wavelength domain (two-dimensional (2D)) encoding, can provide a greater number of codes, namely, it can accommodate a larger number of users than one-dimensional (1D) OCDMA schemes using only time or wavelength domain encoding[1−5]. Broadband optical pulse sources are always required in such 2D OCDMA systems. Till now, light emitting diodes (LEDs), superluminescent diodes (SLEDs), and amplified spontaneous emission (ASE) light sources, which are weakly coherent (approximately incoherent), have been employed as broadband continuous-wave (CW) light sources. The electrical data signal driving the modulator should be in return-to-zero (RZ) coding format and the electrical pulse should be narrower than the chip duration. Thus, using CW sources requires that the electrical layer should operate at chip rates rather than bit rates, which greatly limits the operating data rates. The data driving modulator can be in non-return-to-zero (NRZ) format, if optical pulse sources are employed. Super-continuum pulse sources have also been employed as broadband light sources for 2D encoding systems, and modulators can be driven with the data in NRZ format, thus these modulators may operate at bit rates rather than chip rates. However, existing pulse sources employed in 2D encoding systems are usually coherent. OCDMA systems using coherent light sources will incur strong beat noise, which impairs the system performance greatly[4−6]. In addition, existing pulse sources are usually too expensive to be used in access realm. To solve this problem, we propose an optical gate based scheme for generating incoherent (weakly coherent) broadband optical pulses. The optical gate is implemented with a terahertz optical asymmetric demultiplexer (TOAD)[7]. The TOAD has been used for clock recovery and frame synchronization in optical time division multiplexing systems[8,9], here it is used for turning a CW light source into pulse source.

Our design for generating incoherent broadband optical pulses is shown in Fig. 1. It is made up of an incoherent broadband CW light source, specific TOAD, and control pulse source. When it is used in a 2D time-spreading /wavelength-hopping OCDMA encoder, the control pulse is generated by a mode locked short pulse source which can be modulated with data in NRZ format. In an all-optical network, the transmitted data usually appear as a sequence of light pulses, which may be used as the control pulse directly.

A loop mirror consists of a 2 × 2 3-dB coupler with two joined ports. The TOAD here consists of a loop mirror with an additional, intra-loop 2 × 2 coupler, and a semiconductor optical amplifier (SOA) that is offset from the loop's midpoint by a distance of Δx. The CW light enters the loop through the main coupler and produces two lights propagating in the opposite directions in the loop. Since lights of both directions experience the equal amplification of the SOA as they traverse the loop, then they interfere as in an ordinary loop mirror and do not emerge from the output port. The SOA is placed in such a way that the clockwise propagating light arrives at SOA before counterclockwise propagating light with arrival time interval τ_{x}, and

$$\tau_{\mathrm{x}} = 2\Delta x / v, \tag{1}$$

where v is the speed of light in the loop. A polarization controller (PC) is added into the loop to make better interference between the clockwise and the counterclockwise propagating CW light.

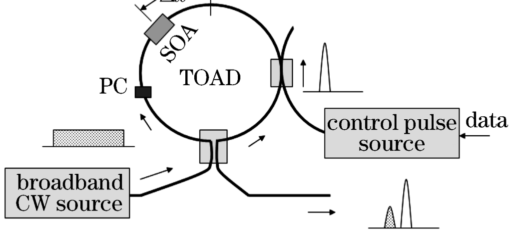

Fig. 1. Design for generating incoherent broadband optical pulse.

When a control pulse, whose duration is assumed as τ_c, arrives at SOA and may saturate SOA, the gain and the phase shift of SOA change and then recover. The recovery time is assumed as τ. If $\tau_c \ll \tau < \tau_x$, there exists a period with the length of τ, the clockwise propagating CW light experiences the normal amplification but the counterclockwise propagating CW light experiences the saturated amplification. In other words, lights of both directions experience different amplifications (different gains and phase shifts) of the SOA as they traverse the loop during this period, and they no longer interfere as in an ordinary loop mirror. An incoherent broadband pulse with duration of τ plus saturation time will emerge from the output port, following the residue control pulse, which can be used for synchronization in an OCDMA link. If $\tau \ll \tau_c < \tau_x$, the saturated amplification lasts for near τ_c, during which lights of both directions experience different amplifications of the SOA as they traverse the loop, therefore, an incoherent broadband pulse with width of a little less than τ_c will emerge from the output port. τ_c should be smaller than the data bit period T_b.

In our experiment setup, a cost-effective mode locked fiber laser, made on the basis of a simple fiber laser[10], with ~ 4-dBm peak power, ~ 60-ps pulse duration, and 1-GHz repetition rate, was employed as the control pulse source, and an ASE source was employed as the broadband CW light source. The gain of SOA used in this experiment is 14.2 dB at 1550 nm, the polarization dependence is 1 dB, and the drive current was set to maximum of 500 mA to minimize the gain recovery time τ. The SOA was arranged in the loop so that $\tau_c < \tau_x$. The PC was adjusted to maximize the peak of generated broadband pulse. The output was connected to an oscilloscope to view the temporal wave and then connected to a spectrum analyzer.

Figure 2 shows the oscilloscope trace of transient output light power and Fig. 3 shows the output spectrum. From Fig. 2, one can see that lower pulses emerge from the output port, going after the higher residue control pulses. And duration of the broadband pulse is a little less than that of the control pulse. These phenomena roughly support the results of theoretical analysis described above. From Fig. 3, one can see that the broadband pulse peak is ~ 20 dB above the noise level and ~ 20 dB below control pulse peak. The full-width at half-maximum (FWHM) of the broadband pulse is ~ 42 nm, which is 67 times larger than that of control pulse and 26 times larger than that of the super-continuum pulse source used in Ref. [2]. Thus, the coherent ratio[6] is now much better than either using the control pulse directly or using the expensive super-continuum pulse source for OCDMA coding. With increasing coherent ratio, the effect of beat noise decreases in such 2D OCDMA systems.

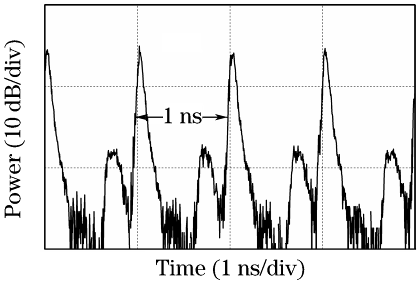

Fig. 2. Oscilloscope trace of transient output light power.

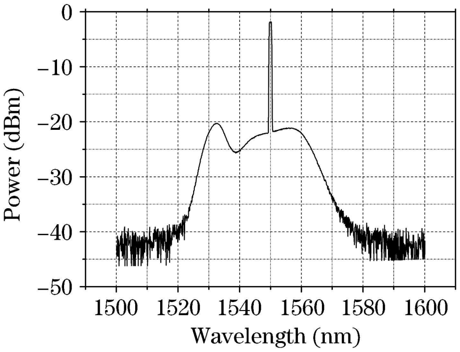

Fig. 3. Output light spectrum.

The peaks of generated pulses demonstrated in Fig. 2 are not maximized. It was found that the peak could be raised by increasing the peak power of control pulses. Theoretically, the peak can reach the input CW light power minus 3 dB and plus gain of SOA, if the control pulses are strong enough to saturate the SOA fully. The peak can also be raised by employing stronger CW light sources, such as SLEDs. On the other hand, the duration of generated pulses could be shortened by applying the control pulses of smaller duration.

The proposed incoherent (weakly coherent) broadband optical pulse generation scheme helps to reduce both the beat noise and the required electrical bandwidth for time-spreading/wavelength-hopping OCDMA systems, and it is proved to be feasible by experiments. The proposed light pulse source generates two pulses per period, of which the narrowband and stronger one can be used for bit or chip synchronization in an OCDMA transmission link, and the broadband one is used for OCDMA coding.

B. Chen's e-mail address is biaochen@coer.zju.edu.cn.

References

1. W. Wang, J. Yu, X. Fu, and E. Yang, Acta Opt. Sin. (in Chinese) **26,** 1303 (2006).
2. V. Baby, I. Glesk, R. J. Runser, R. Fischer, Y.-K. Huang, C.-S. Brès, W. C. Kwong, T. H. Curtis, and P. R. Prucnal, IEEE Photon. Technol. Lett. **17,** 253 (2005).
3. K. Takiguchi, T. Shibata, and H. Takahashi, Electron. Lett. **42,** 301 (2006).
4. C.-S. Brès, Y.-K. Huang, D. Rand, I. Glesk, P. R. Prucnal, T. Bazan, C. Michie, D. Harle, and I. Andonovic, IEEE Photon. Technol. Lett. **18,** 2314 (2006).
5. L. Tancevski and L. A. Rusch, IEEE Commun. Lett. **4,** 264 (2000).
6. X. Wang and K.-I. Kitayama, J. Lightwave Technol. **22,** 2226 (2004).
7. J. P. Sokoloff, P. R. Prucnal, I. Glesk, and M. Kane, IEEE Photon. Technol. Lett. **5,** 787 (1993).
8. L. J. Wang, H. X. Shi, J. T. Lin, K. J. Guan, and P. Ye, IEEE Photon. Technol. Lett. **10,** 881 (1998).
9. H. J. Lee, H. G. Kim, J. Y. Choi, K. Kim, and J. Lee, IEEE Photon. Technol. Lett. **11,** 1310 (1999).
10. D. Chen and S. Qin, Chin. Opt. Lett. **5,** 96 (2007).