Multiwavelength 40 GHz pulse source based on saturated optical parametric amplifier

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Abstract: We present a novel multiwavelength 40 GHz pulse source employing high order FWM products of a saturated OPA. We demonstrate pulse width reduction with FWM order.

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The increasing demand on information capacity has initiated intense research efforts on the development of new optical sources with the capability of providing narrow optical pulses at high repetition rates. An efficient method to produce pulse sources is based on optical parametric amplifier (OPA). A multiwavelength tunable pulse source has been demonstrated at 10 GHz using a pulsed pump [1]. However, by taking advantage of the nonlinear (exponential) dependence of the OPA gain on the pump power, it is possible replace the pulsed pump by a simpler, sinusoidally modulated pump [2]. Other techniques to generate multi-wavelength pulse sources are based on spectral slicing of a super continuum generated spectrum [3].

This paper describes a novel technique to produce multiwavelength narrow pulse sources using a single pumped saturated OPA. An intensity modulated pump is launched with a single CW signal to a highly nonlinear fiber (HNLF). For sufficiently high input signal power, several orders of four wave mixing (FWM) products are generated, each using a spectrally adjacent signal as its pump. Under optimized conditions, the generated pulses should shorten with increasing FWM order.

Generation of multi-wavelength pulses was demonstrated using the system shown schematically in Fig. 1. The tunable pump is set at 1543 nm and modulated at 40 GHz using a Mach-Zehnder modulator biased at V_{π} and driven by a 20 GHz RF source. An Erbium doped fiber amplifier (EDFA₁) acts as a preamplifier to a booster (EDFA₂) which enables a launch power of +21 dBm into a 4 km long HLNF with an average λ_0 of 1536.3 nm, a dispersion slope of 0.018 ps/nm² and a nonlinear coefficient γ =10.6 W⁻¹/km. To avoid stimulated Brillouin scattering, the CW pump is phase modulated with NRZ data at 2.5 Gbit/s. The CW signal is set at 1551.5 nm and amplified (EDFA₃) before being coupled to the HLNF through an array waveguide grating. A variable optical attenuator placed after EDFA₃ allows to vary the signal input power. At the OPA output, in order to selected one of the FWM products while reducing the adjacent channel crosstalks, we employed two cascaded tunable band pass filters (BPF₂ and BPF₃) whose 3dB bandwidth are 3.45 and 2.8 nm, respectively. An amplifier (EDFA₄) is inserted between the two filters to compensate for their losses as well to provide sufficient power to the 50 GHz photodetector and the autocorrelator.



Fig. 1. Experimental set up. TL ; Tunable laser, PM: Phase modulator, IM : Intensity modulator; VOA ; variable optical attenuator, BPF : Band pass filter, PC: Polarization controller, OSA : Optical spectrum analyser, OSC : Oscilloscope, Auto : Autocorrelator

Figure 2 shows the optical spectrum at the output of the OPA. The OPA exhibits a gain bandwidth larger than 20 nm. The input signal wavelength is located at the peak gain and its spectrum as well as the spectrum of 1^{st} order FWM product (called idler₁) occupy the entire sideband bandwidth. Several FWM products were generated, even at low input signal power, as indicated in figure 2. Indeed, the used of a long HLNF allows to reduce the launched pump power while enhancing the saturation effects. Since the tuning range of our filters was limited to ~ 40 nm we placed the pump 8 nm away from λ_0 so that we could make use of several FWM products.



Fig. 2. optical fiber output spectrum for increasing input signal power (from -20 to 10 dBm) and without signal (dash curve)

Figure 3a shows 40 GHz pulse trains detected by a 50 GHz photo-detector for the signal, the 2^{nd} and the 4^{th} idlers at an input signal power of +5 dBm. The pulses remain stable over time with an RMS timing jitter smaller than 1 ps. The pulse widths, shown by the autocorrelation traces narrow with increasing FWM product order. At the signal wavelength the pulses are 7.1 ps wide, at the 2^{nd} idler wavelength they are 5 ps wide. The 4^{th} idler exhibits the narrowest pulse (4 ps). In spite of the long fiber length, there is no walk off between the pump and the different signals since they are synchronized to the pump through XPM effect [4] which enables the good compression quality.

Figure 4 shows the optical spectra of the 40 GHz pulse at the signal, idler₂, and idler₄ wavelengths measured with a resolution of 0.01 nm for an input signal power of 5 dBm. The spectral width is 0.92 nm, 1 nm and 0.89 nm respectively, resulting in a time bandwidth product (TBP) of 0.81, 0.63 and 0.48 respectively. Clearly, only idler₄ is transform limited with a TBP close to the Gaussian TBP of 0.44. The spectral lines are 40 GHz apart but residual sub-lines at 20 GHz are also present with more than 15 dB attenuation. They result from the non perfect pump modulation at V_{π} .

By changing the input signal power while keeping the pump power constant, the pulse width and the spectrum shape change at each wavelength. Figure 5 (a) and (b) show the pulse width variation and the TBP, respectively for the pump, signal and the idlers 1, 2 and 4. When no signal is present the input sinusoidal pump build itself into soliton pulses whose pulse width is 8 ps. When the input signal increases, the complex interactions between the pump, signal and idler waves can make the pump pulses decrease up to 5.5 ps, However the TBP remains constant around 0.8. The signal and idler₁ have almost the same pulse width which increases with the input signal power but since idler₁ is closest to λ_0 , its spectral broadening is the largest. The pulses at idler₂ vary from 4.2 to 6 ps and the TBP varies from 0.7 to 1.1, indicating a chirped profile since it can also act as a pump. Only idler₄ has an almost a transform limited profile for large input signal powers and it width varies from 4 to 5.1 ps.

To conclude, we have demonstrated a novel technique to produce multiwavelength pulse sources at 40 GHz in a saturated OPA using a sinusoidally modulated pump controlled by a 20 GHz RF source. A single CW input signal can saturate the OPA by generating several orders of FWM products, each being a 40 GHz pulse source. Under optimized conditions, the width of the generated pulse reduces with increasing FWM order.

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Figure 5 : Pulse width (a) and time bandwidth product (b) as a function of the input signal power

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