Generation of UWB pulses using direct modulation of semiconductor laser and optical filtering

Q.T. Le, D. Brigghmann and F. Kueppers

A new method to generate ultra-wideband (UWB) pulses based on direct modulation of laser and optical filtering is demonstrated. The intensity modulation and the frequency modulation of the directly modulated laser are combined by the optical filter, which performs a photonic electro-optical derivative operation. Gaussian driving pulses are used in order to generate monocycles for ultra-wideband systems. In association with laser power oscillation, doublet waveforms could also be obtained. Monocyte and doublet pulses are experimentally generated with fractional bandwidths of 139 and 105%, respectively.

Introduction: Ultra-wideband (UWB) technology has attracted great interest for wireless communications, sensor networks, radar, imaging and positioning systems due to different benefits, including low power consumption, immunity to multipath fading, interference mitigation, carrier free, high data rate and capability to penetrate through obstacles [1]. However, this technique is limited in coverage, up to 10 m, because of its low radiation power. Meanwhile, optical access technology such as fibre-to-the-premises (FTTP), which has currently been deployed world-wide, has the well-known advantages of low loss and long reach. Therefore, UWB-over-fibre (UWBoF) is a promising solution to extend the reach of UWB systems [2]. In this scenario, all-optical UWB signal generation is highly desired.

The UWBoF radio-frequency (RF) spectrum was regulated by the US Federal Communications Commission (FCC) between the 3.1 and 10.6 GHz band with a maximum power spectral density (PSD) of $-41.3 \text{ dBm/MHz}$ [3]. To meet this requirement, the desired pulse shapes are based on derivatives of the Gaussian Function. The first derivative of the Gaussian pulse is referred to as a monocycle, and the second derivative is known as a doublet. In the past few years, various techniques for UWB pulse generation were reported; a good summary can be found in [4]. Most of the techniques proposed so far in the literature are complex and costly with the use of external modulators. Simpler techniques were also proposed exploiting the transient chirp [5] or power oscillation [6] of directly modulated lasers.

In this Letter, we propose a simple technique to generate UWB pulses using direct modulation of laser and optical filtering. The proposed device performs an electro-optical derivative operation which generates monocyclic pulses when a Gaussian driving signal is applied. In addition, our solution could also be associated with laser power oscillation in order to generate the doublet waveforms.

Principle of operation: The considered UWBoF signal generator consists of a directly modulated 1550 nm distributed feedback (DFB) laser and a narrow optical bandpass filter (OBF).

When the laser is modulated by a driving current, both the optical intensity (proportional to photon density inside the cavity) and optical frequency are modulated. At a modulation rate higher than 10 MHz, the frequency modulation (FM) is mainly due to the carrier density change which modifies the refractive index of the laser cavity [7]. Owing to the carrier effect, the optical FM and the intensity modulation (IM) are out of phase. More precisely, the FM induced by carrier density change is advanced in phase compared with the IM induced by photon density change. At high optical power level (bias current far from the laser threshold), the phase difference was experimentally proved in [8]. This delay is inversely proportional to the laser damping factor which increases with the optical power level. Using this property, the DFB laser is modulated by an electrical pulse, the modulated output intensity is proportional to the driving signal waveform $I(t) = p(t)$. When the laser bias is far from the threshold, the transient chirp could be neglected, the modulated output frequency can be written as: $f(t) = k \cdot p(t)+c(t)$, which is advanced in phase compared with $f(t)$, $k$ is the adiabatic chirp coefficient (Fig. 1a). The laser output is then sent into an optical filter. The laser spectrum is positioned at the negative slope ($-S$) of the filter which allows negative FM-to-IM conversion (Fig. 1b). At the filter output, the IM becomes: $IM(t) = p(t) - S \cdot q(t)$. If the filter slope is chosen to be $S = 1/\tau$, the laser output is thus a negative first derivative of the driving signal waveform: $IM(t) = -p'(t)$. The device performs an electro-optical derivative operation which generates monocyclic pulses when a Gaussian driving signal is applied (Fig. 1c).

Experimental results: Our experimental setup is schematically depicted in Fig. 2. A commercial 10 Gbit/s direct modulated laser with an integrated optical filter was used. The central wavelength, input impedance and threshold current of the laser module were 1538 nm, 50 $\Omega$ and 25 mA, respectively. The integrated OBF is a multiple cavity filter with a 3 dB bandwidth of 0.06 mm and a 10 dB bandwidth of 0.12 mm. The centre wavelength of the filter is tuned by temperature regulation. The laser bias current was set at 60 mA, and the average output power was 2.5 dBm. The electrical 625 MHz driving signal was generated by a pulse pattern generator at 10 Gbit/s with a pattern of ‘1000 0000 0000 0000’ (1 bit ‘1’ every 16 bits). An electrical lowpass filter of 7.46 GHz bandwidth was used to carve the pulse shape, resulting in Gaussian-like pulses with a full width at half maximum (FWHM) of 93 ps. The modulation peak-to-peak voltage was 1.2 V. The formed pulses are received and analysed by 20 GHz optoelectronic converters. The resolution bandwidth of the electrical spectrum analyser was set at 1 MHz.

![Image](image-url)
of about 139%. The undesired low frequency components which surpass the FCC mask could be removed by an RF highpass filtering.

The doublet waveform can also be generated in this configuration by increasing the laser power oscillation. At a lower laser bias current, the average output power is reduced, and hence the laser damping factor decreases. As a consequence, the laser power oscillation becomes stronger at the end of the pulse. Fig. 4 shows the temporal waveform (Fig. 4a) and RF spectrum (Fig. 4b) of the generated UWB doublet pulse. The laser bias current was 45 mA. The output doublet pulse has a FWHM of 46 ps. The spectral components below 4 GHz are considerably reduced compared with the case of monocyclic pulses. The RF spectrum has a 10 dB bandwidth of about 6.6 GHz (from 3.1 to 10 GHz), corresponding to a fractional bandwidth of 105%.

Conclusion: We have demonstrated for the first time an all-optical UWB signal generator which consists of a directly modulated DFB laser and an optical filter. The adiabatic chirp and IM of the directly modulated laser are out of phase due to the carrier effect; therefore, a photonic derivative operator could be performed with FM-to-IM conversion. Monocyclic pulses could be generated when a Gaussian driving signal is applied. A Gaussian doublet could also be obtained when associated with laser power oscillation. On the one hand, the device is simple, compact and cost-efficient. On the other hand, it is also worth mentioning that it can also generate a conventional on-off keying format as well as more advanced digital modulation formats (such as differential phase-shift keying and duobinary) using the chirp-managed approach [9]. Therefore, it could be used as a universal transmitter for both UWB and FTTP systems.

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Q.T. Le, D. Briggmann and F. Kueppers (Institute for Microwave Engineering and Photonics, TU Darmstadt, Merckstr. 25, 64283 Darmstadt, Germany)
E-mail: le@imp.tu-darmstadt.de

References

Fig. 4 Generated UWB Gaussian doublet

a Intensity waveform
b RF spectrum

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