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Ultra-wideband signal generator based on cross gain modulation effect in a distributed feedback laser

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ABSTRACT

In this paper, a novel scheme to generate ultra-wideband (UWB) signals based on cross-gain modulation (XGM) effect in a DFB laser is proposed and experimentally demonstrated, and the modulation and transmission of the UWB signals are also experimentally investigated. In the proposed system, a gain-switched laser (GSL) is used as master laser (ML) and the optical pulses from the ML are optically injected into a DFB laser, which is used as slave laser (SL). By proper system configuration, UWB monocycle, doublet or triplet UWB signals can be generated after the balanced photodiode (BPD) detection. Besides, other modulation formats can also be realized, such as on-off keying (OOK) and pulse amplitude modulation (PAM) by properly modulating the ML optical pulses. Finally, fiber transmission of the modulated UWB signals is experimentally investigated, and it is shown that the UWB signals can be well maintained after 40 km optical fiber transmission.

1. Introduction

Ultra-wide band (UWB) technologies are of interest in the fields of short-range, high-capacity wireless communications and broadband sensor networks [1]. The wideband but extremely power limited bandwidth, which is determined by U.S. Federal Communications Commission (FCC) for unlicensed use between 3.1 and 10.6 GHz frequency bands, allows high data rate communications but short range applications of this technology. In order to extend the coverage of UWB signals, UWB over fiber (UWBoF) technology is proposed, where UWB signals can be delivered using low loss optical fibers. In an UWBoF system, it is highly desirable that the UWB signals can be generated, modulated and transmitted in the optical domain. In recent years, the issue of photonic generation of UWB signals has attracted a lot of research interests. Interested readers can refer to recent review articles [2,3].

UWB signals can be generated through optical spectrum shaping and frequency to time mapping (FTTM) technique, which can be realized either using a spatial modulator [4,5], or all-fiber components [6]. However, the schemes are usually complicated and suffer from system stability issues, or limited tunability. Another technique to generate UWB signals is electro-optic phase modulation (PM) to intensity modulation (IM) conversion [7]. In this scheme, an FBG can be used as the differential device to convert the gauss pulses to UWB signals by switching the wavelength of the optical carrier at different regions of the FBG. However, the modulation speed of the generated UWB signals can be limited by the tuning speed of the tunable laser source (TLS). UWB signals can also be generated based on microwave photonic filter (MPF) [8–10]. These approaches have demonstrated a high reconfigurability of the generated UWB waveforms, but the structures of these MPFs are usually complicated and bulky. In recent years, optical nonlinear effects are also explored to generate UWB signals. For example, UWB signals were generated based on cross gain modulation (XGM) effect in semiconductor optical amplifier (SOA) [11–13], cross phase modulation (XPM) effect in nonlinear optical loop mirror (NolM) [14,15], and in fiber optical parametric amplifier (OPA) [16]. With the development of integrated optics, an integrated UWB signal generator based on the XPM effect has been proposed in [17]. A high reconfigurability of the generated UWB has been demonstrated by those schemes. However, these systems are usually complicated and expensive.

In this paper, we propose a novel scheme to generate UWB

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signals, the UWB signal generator is based on the XGM effect in a distribute feedback (DFB) laser cavity, which is realized by optical pulses injection of a DFB laser. Compared with most of the works proposed before, this scheme is reconfigurable, by properly setting the proposed system, UWB monocycle, doublet and triplet signals can be generated. Moreover, OOK modulation and PAM of the generated UWB signals can also be realized. The generation and modulation of UWB signals by the proposed generator are experimentally demonstrated, and the fiber transmission of the generated UWB signals is also experimentally investigated.

2. Principle

The principle of the UWB doublet signal generator is shown in Fig. 1. The optical pulses generated by a GSL are injected to a DFB laser, which is used as the SL. Then, the XGM effect will arise in the laser cavity and the SL can be gain switched operated, when the modulation depth induced by the XGM effect is high enough, and optical pulses with trailers can be generated, whose waveforms match well with the desired UWB monocycle signals. Therefore, if an optical bandpass filter (OBPF) is employed in the system to completely filter out optical pulses emitted by the ML, then UWB monocycle signal can be acquired. If the OBPF is not used and optical pulses from the ML remains, then UWB doublet signals can be acquired as a result of the combination of the optical pulses emitted by the ML and SL [18]. Meanwhile, if part of the optical power from the ML remains, the amplitude of the optical pulses from the ML can be depressed and UWB triplet signals are generated. With the help of detection by the BPD, the Bi-phased UWB signals can be acquired at the output of the BPD.

In this scheme, the XGM effect in the DFB laser cavity is the key to generate the UWB signals. The analysis of XGM effect in the cavity of a distributed-feedback (DFB) semiconductor laser has been detailed in [19]. If optical pulses are injected into the SL, the laser cavity, which is driven by a direct current, will provide gain to the injected optical pulses, and thus the cavity mode of the SL can also be modulated through gain suppression, this kind of modulation induced by the XGM effect is equivalent to direct microwave signal modulation, and the SL can be gain switched, when the modulation depth is high enough.

According to [20,21], when the laser is gain switched operated, the modulation dynamics of the laser can be modeled by coupled rate equations which describe the relation between the carrier density $N(t)$, photon density $S(t)$, and optical phase $\phi(t)$.

$$\frac{dN(t)}{dt} = \frac{I(t)}{eV} + g_0\frac{N(t) - N_0}{1 + \varepsilon S(t)} - \frac{N(t)}{\tau_n} \tag{1}$$

Table 1
Parameters for simulation.

Parameter	Value
Γ	0.3
λ	1550 nm
V	2.5e−11 cm^3
g_0	1.87e−6 cm^3/s
ε	1.72e−17/cm^3
τ_p	0.91 ps
τ_n	0.83 ns
N_0	1.46e18/cm^3
c	2.99792457778e8 m/s
α	4
H	0.5

$$\frac{dS(t)}{dt} = \Gamma g_0\frac{N(t) - N_0}{1 + \varepsilon S(t)}S(t) - \frac{S(t)}{\tau_p} + \frac{\Gamma\beta N(t)}{\tau_n} \tag{2}$$

$$\frac{d\varphi(t)}{dt} = \frac{1}{2}\alpha\left\{\Gamma g_0[N(t) - N_0] - \frac{1}{\tau_p}\right\} \tag{3}$$

where Γ is the mode confinement factor, e is the electron charge, V is the active layer volume, N_0 is the carrier density at transparency for which the net gain is zero, $I(t)$ is the injected current, τ_p is the photon lifetime, β is the fraction of spontaneous emission coupled into the lasing mode, τ_n is the electron lifetime, g_0 is the gain slope constant, α is the linewidth enhancement factor and ε is the gain compression factor. Assume the signal that used to directly modulate the DFB laser is a cosine signal, at this time, the current injected to the DFB laser and the signal output from the GSL can be expressed by

$$I(t) = I_{bM} + I_m\cos(2\pi f_m t) \tag{4}$$

$$U(t) = \sqrt{P(t)}\exp\{j[2\pi\nu + \varphi(t)]\} \tag{5}$$

In the equations above, I_{bM} and I_m are the amplitude of the bias current and the signal injected to the DFB laser, respectively. Here, the modulation depth is defined as $R_b = I_m/I_b$. A Runge–Kutta algorithm is used to numerically obtain the calculated waveform of the optical pulses output from the GSL. The parameters of the DFB laser provided for the calculation are given in Table 1.

The frequency of the I_m is assumed to be 2.5 GHz, the bias current of the ML and SL are set to be 40 mA, and the R_b of the ML is assumed to be 1.0. The optical pulses can be calculated as the simulation result shown in Fig. 2(a). Compared with the GSL, the SL is driven by a direct current, which is expressed as I_{bS}. However, when the optical pulses with enough power are directly injected to the SL, the SL is modulated by the injected pulses due to the XGM effect, as it is shown in Fig. 2(b), at each period, the I_{bS} can

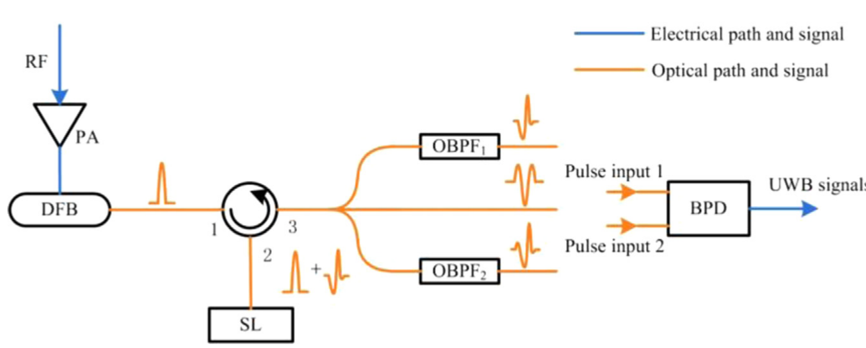

Fig. 1. The principle of this scheme.