Optics Communications 373 (2016) 59–64

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Integrated wideband optical frequency combs with high stability and their application in microwave photonic filters

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ARTICLE INFO

Article history:
Received 15 March 2015
Received in revised form
21 August 2015
Accepted 30 September 2015
Available online 8 October 2015

Keywords:
Microwave photonic filter
Mode-locked laser
Optoelectronics
Optical frequency combs

ABSTRACT

An integrated wideband optical frequency comb (OFC) based on a semiconductor quantum dot laser is realized with high stability. The OFC module is packaged in our lab. A circuit which is designed to provide a low-ripple current and control the temperature regards as a servo system to enhance the stability of the OFC. The frequency stability of the OFC is 2.7×10^{-9} (Allan Variance). The free spectral range (FSR) of the OFC is 40 GHz and the number of comb lines is up to 55. The flatness of the OFC over span of 4 nm can be limited to 0.5 dB. Negative coefficients microwave photonic filters with multiple taps are generated based on the proposed OFC. For the 10 taps microwave photonic filter, the pass-band at 8.74 GHz has a 3 dB bandwidth of 630 MHz with 16.58 dB side-lobe suppression. Compared with the published microwave photonic filters, the proposed system is more stable, of more compact structures, and of less power consumption.

1. Introduction

Optical frequency comb (OFC) has become an indispensable tool in a variety of applications, ranging from metrology to spectroscopy [1–5]. The applications mainly include optical orthogonal frequency division multiplexing [3], arbitrary waveform generation and microwave signal processing. Many approaches have been proposed for the generation of OFC. The OFC can be generated by recirculating frequency shifting with an acoustic optical modulator in a loop [6], however, the comb spacing of OFC is unchangeable and the number of the comb lines is limited by the noise in the fiber loop. External modulation of a continuous-wave (CW) laser source using a phase modulator (PM) and Mach-Zehnder modulator (MZM) or cascading of multiple PMs and MZMs, has also been proposed to generate an OFC with high stability [7]. To generate a flat optical frequency comb using a single phase modulator [8] or polarization modulator (PolM) [9] driven by an RF reference signal is proposed. However, with these methods, a stable and high power microwave source is always needed to drive the modulators, and the complexity of the system is another limitation. OFC can also be generated by mode-locked lasers [10] with high flatness and wide span, quantum dot or quantum dash semiconductor mode-locked lasers have become a subject of many applications such as high bit rate transmission multiplexing [11–12], all-optical clock recovery at 40 Gbit/s [13]. However, the poor stability of the generated OFC with this method is a major disadvantage. In this paper, we packaged a new semiconductor mode-locked laser with 40 GHz repetition rate, and the full-width at half maximum (FWHM) of 40 GHz pulses generated by the mode-locked laser is less than 1.2 ps. To achieve an high stability OFC, a circuit is designed to control the driven current and temperature. And the whole OFC generator including the circuits is packaged as an entire small module.

In recent years, microwave photonic filters (MPFs) have attracted great attentions for their inherent advantages benefited from photonic signal processing, such as low loss, wide bandwidth, reconfigurability, and immunity to electromagnetic interference [14–16]. Various approaches have been proposed to design microwave photonic filters [17–19]. Unfortunately, only positive coefficient microwave filter can be achieved because the intensity is always positive, leading to a low-pass microwave filter. To obtain high-pass or band-pass responses, microwave photonic filters with negative coefficient are also implemented. Up to now, several structures have been demonstrated based on cross-gain modulation in a semiconductor optical amplifier (SOA) [20] and a pair of (MZM). In [15], microwave photonic filter with negative coefficient has been demonstrated using an electro-optic PM combined with a dispersive element to eliminate the baseband resonance of a conventional low-pass filter, this method is quite promising since

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http://dx.doi.org/10.1016/j.optcom.2015.09.110
0030-4018/

Fig. 1. The integrated ultra stable wideband OFC (left: the inside of OFC; right: the integrated OFC generator).

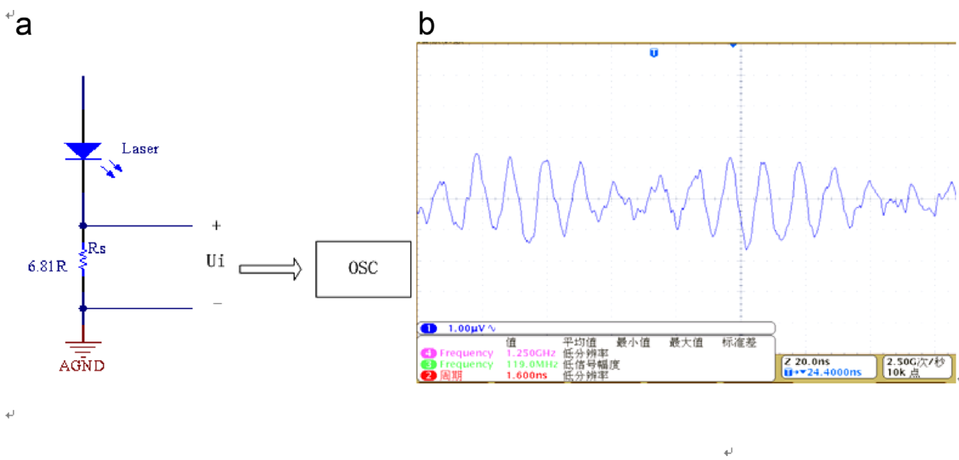

Fig. 2. (a) The OFC driver ripple testing circuit, (b) the signal ripple measured in the OSC.

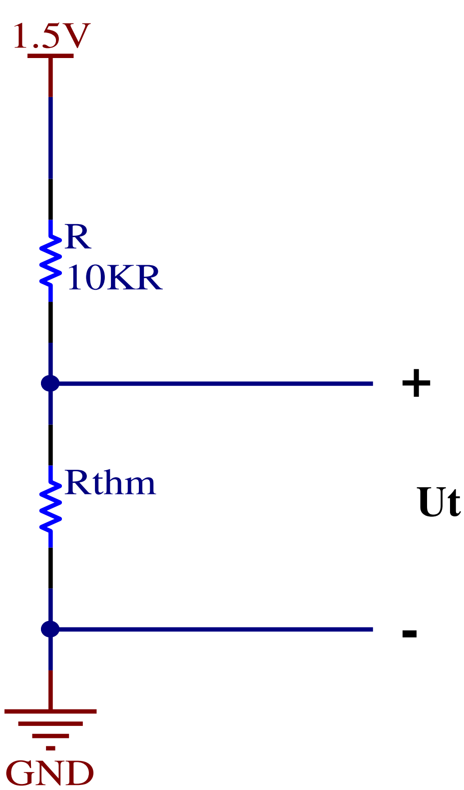

Fig. 3. The temperature measuring circuit.

it is easy to be expanded to realize multi-taps negative coefficient microwave filter. To do so, multi-wavelength laser source which consists of four independent laser diodes (LDs) have been used in [15] to realize four-taps band-pass microwave photonic filter. However, the multi-wavelength laser source with equally spaced frequency interval is costly. Microwave photonic filters based on OFC have been proposed with good properties [21]. However, the proposed structures are complex and the power consumption may be high due to cascading of multiple discrete components in a series format. In this paper, we first use an integrated OFC with 40 GHz repetition rate regarding as the optical source of the microwave photonic filters to generate a tunable multi-taps negative coefficient microwave photonic filter. The filter is more stable and power consumption effective.

2. Properties of the integrated OFC

The OFC module is packaged as shown in Fig. 1. It is based on a mode locking semiconductor quantum dot laser. The phase of longitudinal modes of the semiconductor quantum dot laser is locked through passive mode locking technique to generate a short pulse. The passive mode locking is provided with the use of a saturable absorber, which is responsible for the self-start of mode locking and plays a crucial role in shortening the circulating pulses without the need of a RF source. Furthermore, with a F–P cavity integrated into the semiconductor quantum dot laser, a series of pulses in time domain is generated with a repetition rate which corresponds to the cavity round-trip time, and in the frequency domain, a comb is generated on optical frequency.

The stability of the OFC is studied by introducing a specially designed current driver and a temperature controller. The OFC driver is a high precision stable current source which provides