Microwave Photonics Oscillators for Femtocellular Access Networks

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In this paper we report recent developments on a novel femtocellular interface for radio-optical and optical-radio conversion in a fiber optic link transmission. The microwave photonics interface is based on the integration of a resonant tunnelling diode oscillator with an optical waveguide photodetector driving a laser diode.

1. Introduction

In recent years, there has been an increasing interest in providing broadband communications for densely populated buildings with low power transmitter-receiver interfaces operating in single-cell-per-room configurations [1]. These systems, called femtocells, which are about the same size as a regular home gateway or router, include a radio transmitter and receiver and enable more consistent indoor reception. The architectures proposed use the optical fibre as a transparent tunnel to transport Gb/s data over short distances (typically less ten 50 m), Fig. 1(a). In such systems, the radio access points must be very cheap and simple, with low power consumptions only performing radio to optic and optic to radio conversions.

The use of optoelectronics in microwave systems provide the technology necessary to simplify the base station architectures in antenna remote applications where base stations are located far away from a central processing unit, Fig. 1(a) [2]. Figure 1(b) shows an example of a femtocell base station consisting of a laser diode and a photo-detector for uplink and downlink operations, respectively.

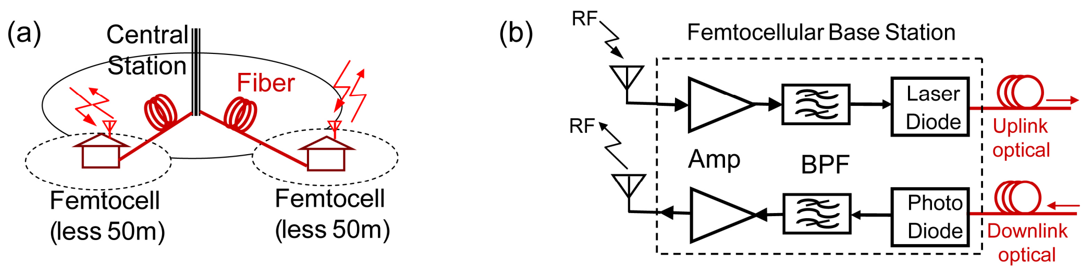

Figure 1: (a) Example of a radio-over-fiber system. The RoF system delivers the broadband services to the customers by a radio. (b) Example of a femtocellular base station. RF signals are selected and amplified using band pass filters (BPF) and low noise and high power amplifiers (Amp), respectively.

In recent work on a hybrid optoelectronic microwave photonics circuit consisting of a laser diode (LD) driven by a resonant tunneling diode (RTD) oscillator, we have presented experimental evidence of the potential application of the RTD-LD oscillator as an electrical-to-optical converter [3]. Furthermore, the RTD contained a photoconductive region [optical waveguide (OW)] and when an optical fiber was used to couple light to the circuit optical injection locking was observed. The device has considerable potential as microwave/optical interface by removing the need for large drive voltages.

In this paper we discuss the RTD microwave photonics oscillator interface performance in a fiber optic link transmission. This configuration provides a novel driving interface taking advantage of RTD-based oscillator. The RTD removes the need of low noise and high power amplifiers as the RTD exhibits negative differential resistance (NDR) over a wide range of frequencies, with gigahertz bandwidth electronic gain. This provides the implementation of a self-sustained oscillator interface that synchronizes with both electrical and optical signals and can be realized in a compact and single chip. The RTD-based radio access point could be an alternative to make available lower cost radio-over-fiber femtocellular networks.

2. Microwave photonics RTD oscillator

The RTD consists of a unipolar n-type device with a AlAs/InGaAs/AlAs double barrier quantum well structure embedded in a ridge InAlAs/InGaAlAs/InP optical waveguide (more details can be found in [4]). The RTD optical waveguide was implemented in an external circuit consisting of a microstrip transmission line and wire bonded in series with a laser diode, with light emission controlled by the RTD operation. Figure 2(a) presents a schematic of the RTD-OW connected in series with a laser diode, showing both RF and light input and output ports. In Fig. 2(b) is presented a typical current-voltage (*I*-*V*) characteristic showing negative differential resistance. A detailed description of the hybrid circuit components, implementation and optoelectronic characterization can be found in [3].

When the circuit is DC biased in the NDR region, free-running relaxation oscillations in the microwave frequency band are produced, with natural oscillation frequency range determined by the bias voltage and the external circuit [3]. The RTD microwave photonics oscillator works at room temperature and consumes low power. In Fig. 2(b) is presented a typical tuning range curve biasing in the NDR region, with oscillation frequencies ranging from 0.98 GHz to 1.25 GHz. When an appropriate excitation is applied by means of optical or electrical injection the oscillator can be synchronized and generate electrical and optical locked outputs for low injection powers.

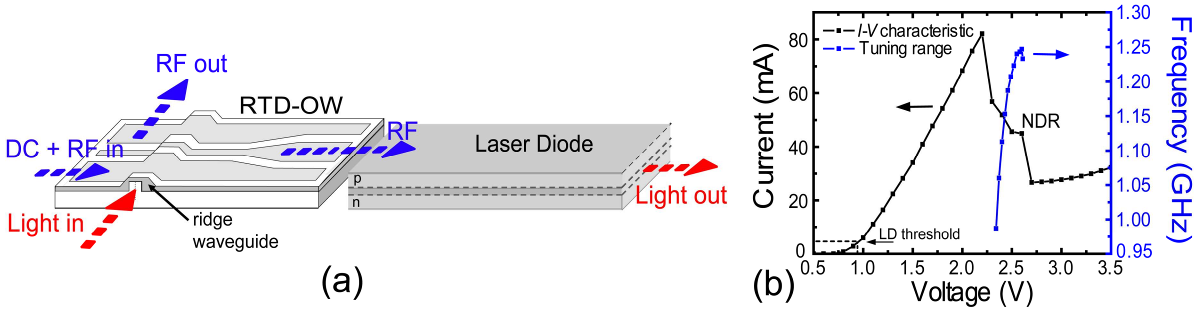

Figure 2: (a) Schematic (not scaled) of the hybrid RTD microwave photonics oscillator interface. (b) Current-voltage characteristic of interface and tuning range frequency oscillation.

2.1 Experimental setup

The experimental results were obtained using a proof-of-principle implementation of a RTD-based fiber optic link transmission. In Fig. 3 is shown schematically the fiber optic link architecture using the RTD microwave photonics oscillator. The schematic consists of a laser light source transmitter around 1.55 μm, intensity modulated by an RF signal input, an optical fiber transmission medium and a RTD-OW photodetector oscillator DC biased using a bias-T that converts light intensity to electrical current. Light was incident directly into RTD optical waveguide using a single mode lensed fiber. Because the RTD-OW is driving a laser diode operating arount 1.55 μm, received signals were also transmitted through an optical fiber to a remote location and detected using a commercial photodetector. Both light and RF outputs were measured using an electrical spectrum analyzer and oscilloscope.

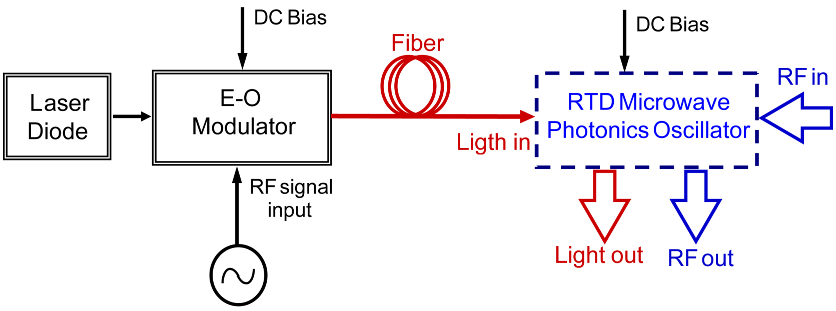

Figure 3: Fiber optic link transmission setup.

3. Experimental results

As discussed, the RTD shows free-running oscillations when DC biased in the NDR region and can be injection-locked by optically and electrically received signals. Figure 4(a) presents the free-running spectrum of the oscillator operating around 1.2 GHz. When a modulated light at 1.2 GHz was incident upon the RTD optical waveguide, the oscillator was optically locked with RF sub-carrier. Figure 4(a) also shows the frequency spectrum of the locked signal in both electrical and laser optical outputs for an optical power of 2 mW. This is a good performance considering the fiber to waveguide light low coupling efficiency.

Figure 4(b) presents the phase noise measurement of phase-locked signals varying the incident optical power level. Phase noises of frequency converted signals are significantly reduced by optical injection-locking when compared with free-running signal (-70 dBc/Hz at 20-KHz), resulting in phase-noise values lower than -100 dBc/Hz at 20-KHz frequency offset (the RF signal input phase noise was -118 dBc/Hz. Such phase-noise characteristics should be sufficient for many radio-over-fiber applications as long as the locking condition is achieved with relatively small optical power.

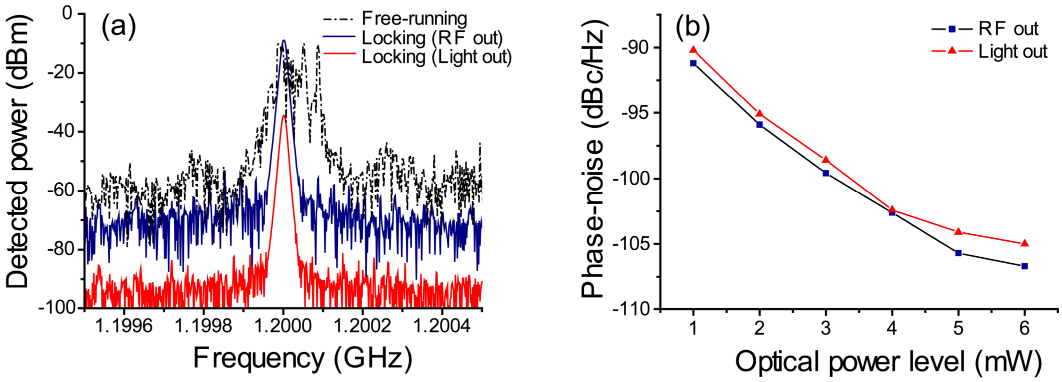

Figure 4: (a) Spectra of free running oscillation and RF and light detected outputs for a 2 mW light input signal modulated at 1.2 GHz and 10 dB extinction ratio (the RBW and VBW were 10 kHz). (b) Measured phase noises at 20 kHz offset as a function of optical power level input.

4. Conclusion

We proposed an RTD microwave photonics oscillator that can be used for simplifying femtocellular networks in remote conversion of radio/optical signals. Using this configuration, femtocells for remote down- and up-conversions can be significantly simplified because a single RTD oscillator plays the roles of photodetector and high-power phase-locked oscillator. Because the output power of optical or electrical injected oscillator depends not on incident optical/electrical signal power but on the RTD free-running oscillator, RTD microwave photonics oscillator provides both high power and efficient frequency conversion. RTD-based radio access points could be an alternative to make available simple and low cost radio-over-fiber femtocellular networks.

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