Wireless/Photonics Interfaces based on Resonant Tunneling Diode Optoelectronic Oscillators

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Abstract: We employ phase synchronization for converting low power wireless signals to the optical domain and optical injection locking for converting optical sub-carrier signals to the electric domain by using resonant tunneling diode oscillator circuits.

OCIS codes: (250.3140) Integrated optoelectronic circuits; (140.2020) Diode lasers;

1. Introduction

The demand in the coverage and speed of optical communications networks, together with rapid growth in wireless networks, has motivated an increasing attention into hybrid wireless-optical communication systems. The integration and transmission of radio-frequency (RF) signals over fiber, RoF systems, can provide the solution for economic radio access points bringing the fixed network bandwidths closer to the mobile users at lower costs [1].

In this paper we present experimental results on phase locking of broadcasted signals in a hybrid optoelectronic oscillator circuit consisting of a communication laser diode (LD) driven by a resonant tunneling diode (RTD), the RTD-LD, that can work as an electrical-to-optical (E-O) converter (the circuit operation is described in [2]). We also show preliminary results on optical-to-electrical (O-E) conversion using a waveguide photo-detector incorporating a RTD. The RTD-LD phase locking characteristics, including phase noise reduction, frequency locking tunability, laser modulation, and the RTD optical injection are analyzed.

Resonant tunneling diodes are semiconductor nanostructures with strong nonlinear current-voltage (*I-V*) characteristic that show wide-bandwidth negative differential conductance (NDC) at room temperature. A circuit showing NDC can act as an electronic amplifier. The hybrid RTD-LD optoelectronic integrated circuit (OEIC) preserves the nonlinear dynamical behavior of the RTD, increasing the laser diode functionalities such as high modulation depth with very low driving voltage and high speed operation [2]. The OEICs small size, the need of low power broadcasted signals for wireless to optical conversion and the noise reduction observed seems to indicate that RTD based OEICs have high potential as simple and efficient solutions for radio access points, namely pico-cells, needed for the forthcoming RoF communication systems.

2. Wireless injection locking, noise reduction and phase modulation

The microwave-photonics circuit converter consists of a RTD-LD oscillator which incorporates patch antennas for directional broadcast emission and reception. When the circuit is DC biased in the NDC region autonomous relaxation oscillations in the microwave frequency band are produced, with natural oscillation frequency range determined by the bias voltage [2], and the external components. The RTD-LD oscillation locks to broadcasted signals with frequency close to the circuit natural frequency or to its harmonics, with the laser output being modulated by the broadcasted signal. We observed locking with considerable noise reduction with broadcasted powers lower than -32 dBm. Figure 1(a) shows the RF spectra of the detected laser optical output due to circuit relaxation oscillations at 600 MHz and due to wireless phase-locking at the same frequency. As presented in Fig. 1(a), the relaxation oscillations have a broad spectrum with a gradual decrease of spectral power density as we move way from the circuit natural frequency. When the wireless signal at 600 MHz is present, stable frequency locking with significant noise reduction occurs, as shown in Fig. 1(a). Under these conditions the measured frequency-locked bandwidth was around 1% of the natural frequency, increasing with the power of the broadcasted signal. The phase locking was also observed for broadcasted signals with frequencies close to the harmonics of the circuit's natural frequency. In all cases, the frequency locking range could be adjusted using either the DC bias or the wireless power. A locking range of 90 MHz was measured for broadcasted signals at 1.8 GHz (2nd harmonic) with tuning bandwidth of 5%.

Figure 1(b) presents the photo-detected RF power spectra of the laser output when the broadcasted signal at 600 MHz was phase modulated by sub-carrier sinewaves at 1 MHz with phase $\pi/2$ and $3\pi/2$, with both signals

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showing the same sidebands with 1 MHz offset. The analogue phase modulation was tested at several phase angles using sinusoidal, quadratic and triangle waveforms. We observed the laser output cleary follows the modulation of the broadcasted carrier independently of the modulation conditions. We believe this characteristic can be employed for phase shift keying (PSK) modulation.

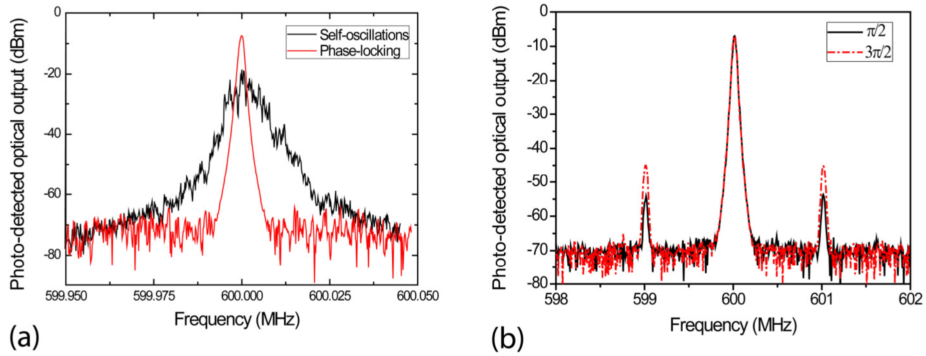

Fig. 1. (a) Photo-detected spectra of laser diode outputs due to self-sustained oscillation at 600 MHz and to phase-locking when a broadcasted signal with -25 dBm power was received. The phase noise is reduced by ~35 dB at a 10 kHz offset of the carrier frequency. The spectrum analyzer resolution and video bandwidths are 1 kHz. (b) RF spectra of photo-detected laser outputs due to a phase modulated broadcasted signal at 600 MHz and -32 dBm power. The broadcasted carriers were phase modulated by sinusoidal signals at 1 MHz with phase $\pi/2$ and $3\pi/2$.

3. Optical injection locking

We have also observed optical injection locking of an RTD oscillator and synchronization between a modulated optical signal and RTD oscillations. The RTD oscillator was embedded within the core of an optical waveguide (as described in [3]) that acted as a photo-detector. Figure 2(a) presents the RF injection locking capture level using light from a tuneable laser diode modulated by a sinusoidal signal at 1 GHz, showing that the responsivity increases with the transition from RTD peak to valley voltage, V_p and V_v; Fig. 2(b) presents the photo-detected RF power as function of the light wavelength with the DC bias voltage as parameter. The synchronization between the optical sub-carrier and the RTD oscillations can be used to transfer information from the optical to the RF domain.

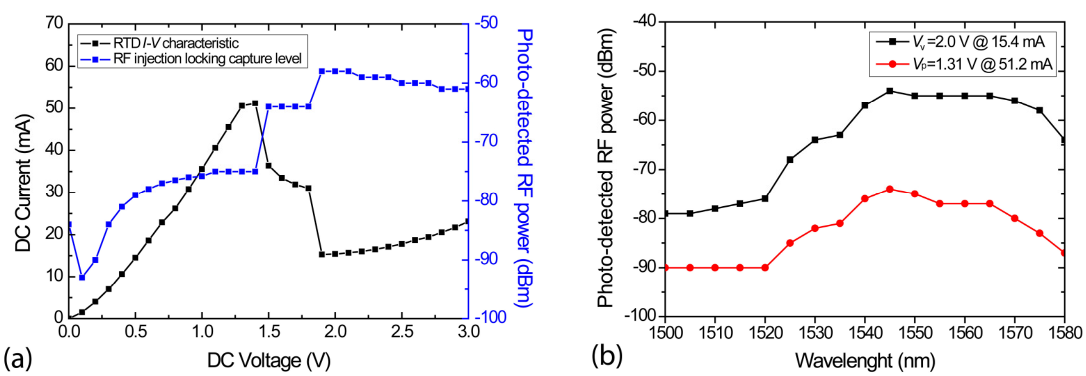

Fig. 2. (a) RTD *I-V* characteristic and RF injection locking capture level for 1 mW@1550 nm CW optical signal modulated at 1 GHz. (b) Photo-detected RF power as function of wavelength with DC bias voltage as parameter for 1.9 mW CW optical signal modulated at 1 GHz.

4. Conclusion

We have experimentally demonstrated phase-locked operation between wireless and optical signals by using phase synchronization of an optoelectronic RTD-LD nonlinear oscillator. The circuit is capable of wireless to optical locking with very low injected powers and to follow the phase modulation of broadcasted carriers. The locked oscillation frequency is tunable by adjusting the circuit natural frequency using the DC bias or the broadcasted power. We have also shown optical injection locking of a RTD oscillator which provides a simple way to convert an optical signal sub-carrier onto an RF signal. The RTD based OEICs applications can include single chip platforms with reduced size and low cost microwave/photonics interfaces in RoF communication networks.

5. References

[1] M. Sauer, A. Kobyakov, "Radio over fiber for picocellular network architectures," IEEE JLT **25**, 3301 (2007).
[2] J.M.L. Figueiredo, *et al.*, "Self-oscillation and period adding from a resonant tunneling diode-laser diode circuit," EL **44**, 876 (2008).
[3] J.M.L. Figueiredo, *et al.*,"Electric Field Switching in a Resonant Tunneling Diode Electroabsorption Modulator," IEEE JQE **37**, 1547 (2001).