

Wireless-Photonics-Wireless Interfaces Based on Resonant Tunneling Diode Optoelectronic Oscillators

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Abstract – Resonant tunneling diode voltage controlled oscillators integrated with laser diodes and photo-detectors can work as wireless to optical and optical to wireless converters, respectively, with high-potential to act as low-cost wireless/photonic interfaces in future picocellular networks.

Introduction – The rapid growth of wireless network users demanding higher coverage and higher data rates has motivated an increasing attention into hybrid wireless-optical communication systems to take advantage of the large bandwidth of optical communications networks [1]. Recent work on an Optoelectronic integrated circuit (OEIC) based on the integration of a resonant tunneling diode (RTD) oscillator with a laser diode (LD), the RTD-LD, has demonstrated it can act as an optoelectronic voltage controlled oscillator (OVCO) [2,3]. Resonant tunneling diodes are semiconductor nanostructures with strong nonlinear current-voltage (I - V) characteristic showing wide-bandwidth negative differential conductance (NDC) at room temperature [4]. Since circuits showing NDC can act as oscillators with built-in amplifiers, simply dc biasing the RTD-LD circuit in the NDC region produces relaxation oscillations at frequencies determined by both the circuit components and the dc voltage value, with the relaxation oscillations modulating the laser optical output [3]. Both monolithic and hybrid (separate RTD and LD chips) have been investigated. A hybrid RTD-LD circuit showing oscillation frequency as high as 2.2 GHz, tunable from 1.8 GHz to 2.2 GHz as the dc voltage cross the NDC region (a voltage range around 0.5 V) was already demonstrated [3]. This is a simply way of converting a RF signal into an optical subcarrier.

Here we describe the work on RTD OVCOs that are capable to phase-lock to wireless signals with significant noise reduction, and produce broadband chaotic signals. We also present preliminary results on optical to electrical conversion using another OEIC consisting of a RTD VCO incorporating a photoconductive region.

Synchronized and chaos wireless-photonic conversion – The RTD based wireless microwave-photonic circuit converter consists of a RTD-LD OVCO which incorporates a patch antenna for wireless detection, Fig. 1(a). In the presence of a wireless signal with frequency close to circuit free

running oscillation frequency, the RTD-LD phase-locks to broadcasted signals with the laser output being modulated by the broadcasted signal [5]. We have observed locking with considerable noise reduction for broadcasted powers as lower as -40 dBm. Figure 1(b) shows the RF spectra of the detected laser optical output at the second harmonic (1.8 GHz) of the circuit relaxation oscillations at 600 MHz and when phase-locked to a 1.8 GHz injected wireless signal. When the 1.8 GHz wireless signal is present, stable frequency locking with significant noise reduction occurs, as shown in Fig. 1(b). Phase-locking was also observed for broadcasted signals with frequencies close to other harmonics of the circuit's free running frequency. In all cases, the frequency locking range was adjusted using either the DC bias or the wireless power. The circuit operation mode applications includes phase modulated wireless to phase modulated optical sub-carrier conversion [5]. We propose that these characteristics could be employed in a digital wireless access network employing phase shift keying (PSK) modulation.

Outside the above phase-locked regions and under appropriate wireless injection conditions the RTD nonlinear characteristics can induce the RTD-LD OVCO to operate on other nonlinear regimes including period-adding and intermittence routes to chaos, producing broadband (GHz-wide) chaotic current oscillations that modulate the laser diode optical output, generating optical sub-carriers with the same broadband chaotic features, Fig. 1(c). The numerical model of the RTD OVCO based on the circuit differential equations in the form of a Liénard's system and the laser diode rate equations accurately predicts the observed circuit optoelectronic operating regimes including synchronization, quasi-periodicity and chaos generation [6].

Photonics-wireless conversion – A RTD oscillator containing a photo-conductive region can be used to extract a RF carrier from an optical signal, using the synchronization between a modulated optical signal and RTD oscillations [7]. Embedding a RTD within

an optical waveguide core (as described in [4]) we have implemented a photo-detector with a built-in amplifier that can act as a photonics-wireless converter, Fig. 2(a). Figure 2(b) presents the RF injection locking capture level using light from a tuneable laser diode modulated by a sinusoidal signal at 1 GHz, showing the RTD-PD *responsivity-gain* increases with the transition from RTD peak to valley by more than 15 dB. Figure 2(c) illustrates photo-detection capabilities at 5 GHz. We are currently investigating the synchronization between optical sub-carriers and RTD oscillations to take advantages of the RTD NDC to transfer and amplify the information bearing signal from the optical to the RF wireless domain. Circuit applications include optical sub-carrier to wireless conversion and optical control of microwave circuits. We believe the conversion characteristics can also be employed for phase shift keying (PSK) modulation.

Conclusion – We have described the current activity on design, fabrication, characterization and modeling of a new class of wireless-photonic-wireless interfaces based on integration of RTD with optoelectronic devices such as laser diodes and photo-detectors to convert phase modulated wireless/optical signals into phase modulated optical sub-carriers/wireless signals. Phase-locking of a RTD-LD OEIC relaxation oscillator by direct injection of low power wireless signals has been demonstrated. The frequency locking range is tunable by adjusting the circuit natural frequency using the dc bias or the wireless power. We have also shown a RTD with a photoconductive region that 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/photonic interfaces for Radio-over-Fiber communication networks.

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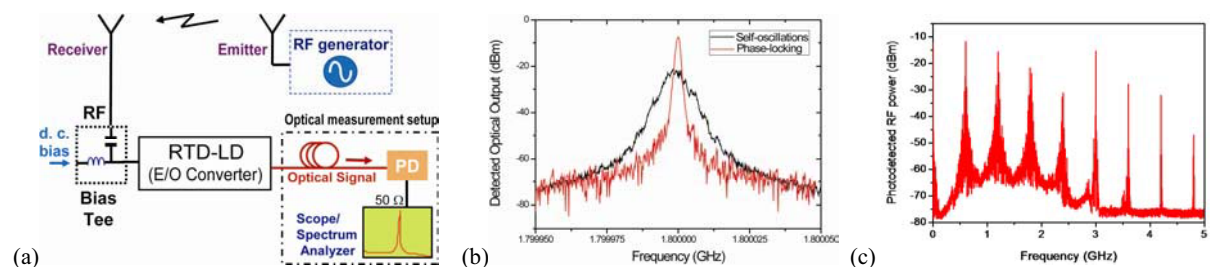


Fig. 1. (a) Wireless microwave-photonics circuit converter. (b) Phase-locking at 1.8 GHz induced by a broadcast signal of -40 dBm at the RTD-LD receiving antenna. A phase noise reduction of ~25 dB at 10 kHz offset is observed (resolution and video bandwidths of 1 kHz). (c) Generation of chaotic signals induced by a 3 GHz injected wireless signal.

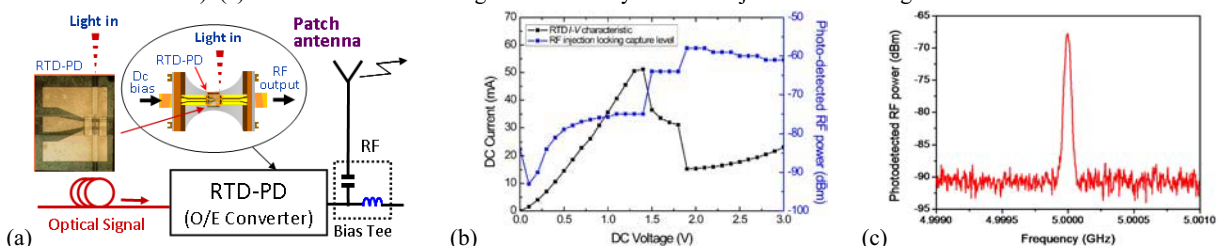


Fig. 2. (a) RTD-PD photonic-wireless converter. (b) RTD-PD *I-V* characteristic and RF injection locking capture level of an optical signal 1 mW@1550 nm modulated at 1 GHz. (c) Photo-detection of a 5 GHz modulated optical signal at the valley region.