

Wireless to optical frequency locking and chaos using a resonant tunnelling - laser diode circuit

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Abstract—We report experimental and numerical results on frequency locking, quasi-periodic and chaotic outputs induced by wireless signals on a nonlinear photonics interface consisting of a laser diode driven by a resonant tunnelling diode.

I. INTRODUCTION

Resonant Tunnelling Diodes (RTDs) are nonlinear devices showing pronounced nonlinear current-voltage (I - V) characteristic at room temperature, wide-bandwidth negative differential resistance (NDR), and ultra-high speed up to THz frequencies [1]. Because of their simple structure and small size, RTDs can be easily integrated with electronic and optoelectronic devices, including optical waveguides and laser diodes [2].

Previous work on OptoElectronic Integrated Circuits (OEICs) has shown that it is possible to monolithically integrate a resonant tunnelling diode with a laser diode (RTD-LD) [2]. In very recent work on an OEIC consisting of a hybrid integrated circuit (separate RTD and LD components) of a laser diode with an RTD driven by Radio Frequency (RF) signals we have demonstrated this circuit is capable of behaving nonlinearly, emulating RTD nonlinear characteristics in the laser diode output, which gives rise to a variety of additional operation modes that include nonlinear optoelectronic voltage controlled oscillations (OVCO) [3, 4], and period-adding [4], where the generation of quasi-periodic and chaotic electrical and optical outputs is expected.

Here we present a similar circuit configuration, Fig. 1, comprising a resonant tunnelling diode (RTD) with a laser diode (LD) that can act as a nonlinear microwave photonics interface and present synchronization and chaotic behaviour results when wireless radio frequency signals are emitted on the RTD-LD circuit using a transmitter patch antenna. The RTD-LD responds to the wireless electromagnetic radiation which is amplified by the RTD negative differential resistance, and gives rise to the production of locked and unlocked signals in the RTD-LD electrical and optical outputs.

II. EXPERIMENTAL RESULTS

The microwave-photonics interface circuit consists of an RTD-LD circuit (a detailed description and operating principle of the RTD-LD can be found in [2, 3]). Figure 1 shows a schematic of the RTD-LD optoelectronic interface that includes a microstrip patch antenna for wireless emission of a 16 dBm (~1.4 V) RF signal incident directly into the circuit

and placed ~10 cm away from the RTD-LD circuit in a vertical position (there is no receiver patch antenna connected to the circuit). The microstrip patch antenna consists of a rectangular metallic patch on a dielectric substrate with a ground plane designed to have the best performance at 3.0 GHz.

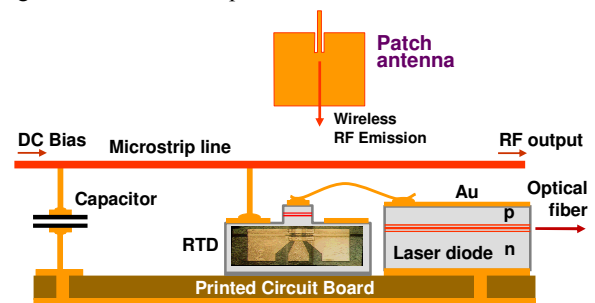


Fig. 1. Schematic of the RTD-LD optoelectronic circuit-wireless interface.

When biased in the NDR region and without external excitation the RTD-LD circuit operates as an autonomous self-sustaining OVCO [3, 4], changing oscillator natural frequency from 563 MHz oscillations up to 1.0 GHz, depending on bias voltage. In the presence of the wireless signal the RTD synchronizes to the wireless frequency modulating the laser diode with the wireless signal. Frequency locking regions in a nonlinear dynamics sequence of $1/6$, $1/5$, $1/4$ and $1/3$ of the 3.0 GHz broadcasted frequency, both in the electrical and optical outputs, were measured changing the DC bias from 3.56 V to 4.05 V. Figure 2 shows experimental synchronization of the laser diode output at $1/4$ of the 3 GHz broadcasted signal when the DC bias voltage is 3.67 V. The frequency locking regions can be controlled by tuning either the bias voltage or power of broadcasted signal.

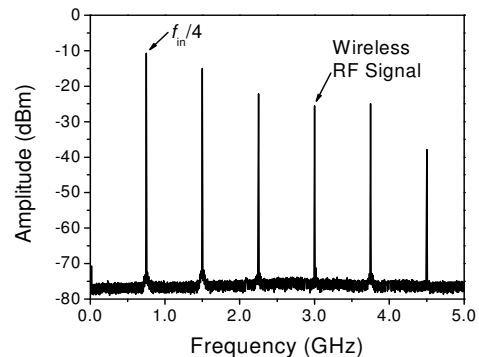


Fig. 2. Frequency division by 4 in the laser diode output, using a 3 GHz broadcasted signal when the DC bias voltage is 3.67 V.

When the system is not locked with the wireless signal, complex nonlinear behaviour showing unlocked signals was observed. Figure 3(a) shows an example of a spectrum of a quasi-periodic signal with high harmonic content; Fig. 3(b) presents the RF spectrum of a chaotic signal showing a broadband region with a rise in the spectrum background up to 10 dBm over 3.0 GHz bandwidth.

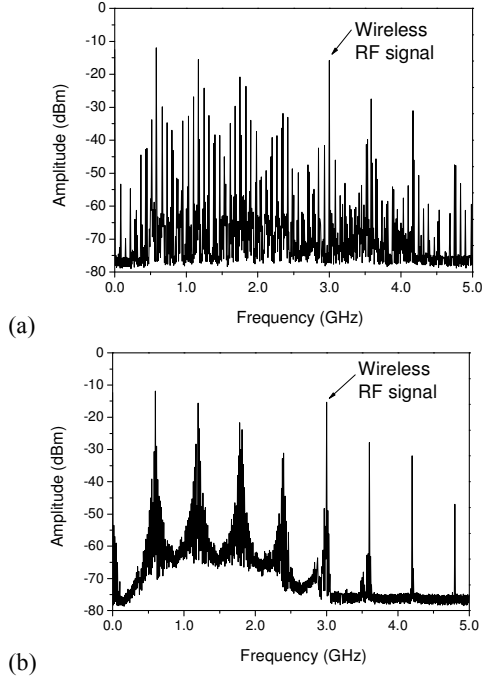


Fig. 3. Spectra of unlocked signals when a wireless signal with 3 GHz and 16 dBm is broadcasted. (a) Quasi-periodic output when the DC bias is 3.57 V. (b) Chaotic output when the DC bias is 3.58 V.

III. CIRCUIT NONLINEAR DYNAMICS MODEL

The nonlinear RTD-LD OEIC driven by a wireless carrier signal can be described by the following two first-order nonlinear coupled differential equations, adapted from [3]:

$$\dot{V} = \frac{1}{C} [I - F(V)] \quad (1)$$

$$\dot{I} = \frac{1}{L} [V_{DC} - RI - V + V_{AC} \sin(2\pi f_{in} t + \phi_m(t))], \quad (2)$$

where $V_{AC} \sin(2\pi f_{in} t) = c(t)$ is the wireless carrier signal and $\phi_m(t)$ is the phase modulation function. The RTD-LD laser output is modelled using laser diode rate equations [3]:

$$\dot{N} = \frac{I}{q\vartheta} - \frac{N}{\tau} - g_0(N - N_0) \frac{S}{1 + \epsilon S} \quad (3)$$

$$\dot{S} = g_0(N - N_0) \frac{S}{1 + \epsilon S} - \frac{S}{\tau_p} + \frac{\beta N}{\tau} \quad (4)$$

Figure 4 shows numerical simulation results using the model given by equations (1-4) and choosing circuit and laser parameters to fit the experimental results [3]. In Fig. 4(a) an example of frequency locking in the optical output, S , is shown at 1/4 of the 3 GHz injected signal for low AC voltage. Figure 4(b) shows an example of an unlocked signal.

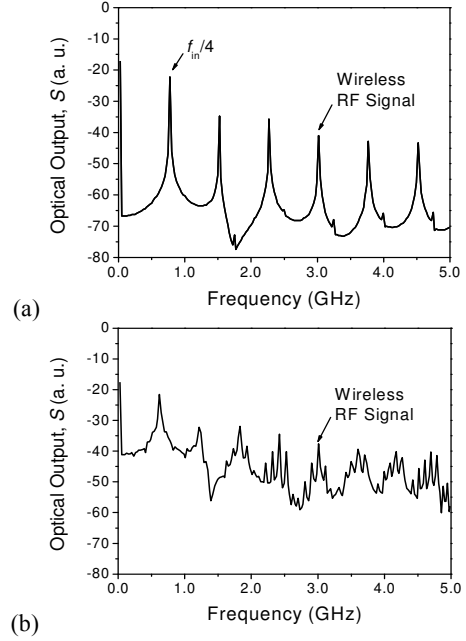


Fig. 4. Numerical simulation results showing locked (a) and unlocked (b) RF spectra of the laser diode output, S , for low modulating wireless signals, $V_{AC} = 50$ mV, when the injected frequency is $f_{in} = 3.0$ GHz.

IV. CONCLUSION

We have demonstrated numerically and experimentally synchronized and desynchronized operation between emitted wireless signals and electrical and optical outputs on a RTD-LD circuit. Although the experimental results presented here are addressed to a single transmitter patch antenna, identical synchronized and chaotic results are expected adding a receiver antenna in the RTD-LD input. In fact, best performance on wireless to optical synchronization was already demonstrated with a wireless transmitter-receiver antenna setup for large distances (a few meters) adding a receiver antenna to the RTD-LD electrical input [5]. These results anticipate microwave photonics wireless applications using nonlinear dynamics of RTD-LD circuits.

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