Official URL: https://doi.org/10.1364/LAOP.2016.LW4C.5

To cite this version :

Muñoz-Arcos, Christian Daniel and Coronel-Rico, Juan Fernando and Chamorro, Jhonatan and Rissons, Angélique and Varón-Durán, Margarita Microwave Signal Generation using Optical Injection Locking. (2016) In: Latin America Optics and Photonics Conference, (Optical Society of America, 2016), (LAOP 2016), 22 August 2016 - 26 August 2016 (Medellin, Colombia)

Microwave Signal Generation using Optical Injection Locking

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Abstract: In this article, microwave signal generation is implemented by using the optical injection locking technique. Two semiconductor laser sources are used: a Fabry-Perot laser is mode-locked to a single mode Vertical-Cavity Surface Emitting Laser (VCSEL). From the laser mode interference, a microwave signal is produced at a frequency equal to the two modes frequency spacing. 4.9 and 6 GHz carriers are generated using this technique.
OCIS codes: (140.3570) Lasers, single-mode; (140.4050) Mode-locked lasers (140.3298) Laser beam combining; (140.7260) Vertical cavity surface emitting laser; (230.0250) Optoelectronics;

1. Introduction

The microwave signal generation by using optical techniques is presented as a solution to satisfy the data rate requirements of a society that is always connected. Several techniques had been implemented to obtain high frequency carriers, the most known is the optoelectronic oscillator, implemented in the 90's by Maleki [1]. The optoelectronic oscillator is composed by several elements as an amplitude modulator, a long optical fiber delay line and a microwave filter. Such elements increases size, cost and power consumption of the device. In this article it is presented a microwave signal generation setup using the optical injection locking technique that consists on the beam injection of a laser (master laser) into the cavity of another one (slave laser). The result of the injection will generate two modes: one is the lasing mode at the master laser wavelength and a mode caused by the population inversion in the laser cavity. By tuning the frequency of the master beam, the frequency difference (detuning) between the master mode and the self-generated mode involves various operation stability regimes. One regime is when two modes are locked and the other one is the beating regime. This last regime is responsible of the tunable RF signal.

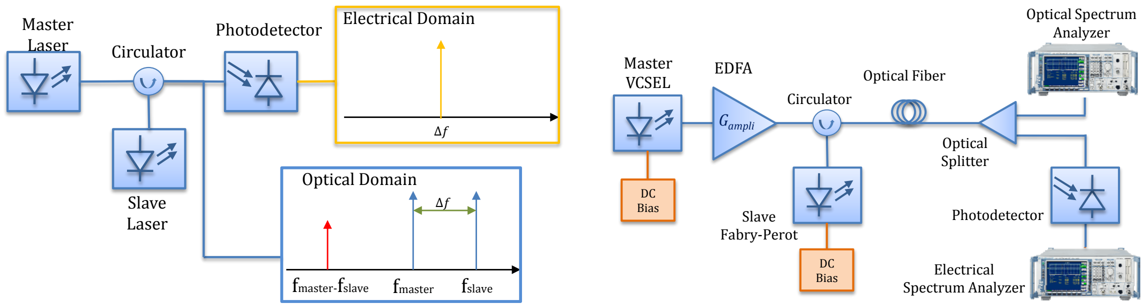
The advantage of this technique is that the use of sophisticated instrumentation and complex microwave laser packaging is avoided.

This article is organized as follows: the second section presents a brief theoretical background of the optical generation of microwave signals, the third section presents the experimental implementations and results analysis; and the last section presents the work conclusions.

2. Optical Generation of Microwave Signals

The optical injection locking technique is used to produce a laser beam interference inside the slave laser cavity. The optical injection locking technique is described using the semiconductor laser rate equations that permit the prediction of the microwave performance of an optically injection locked laser [2], [3]. The photodetected beat signal is generated by the two mode oscillation. The frequency difference of the optical wavelength is the beating mode frequency, as described in Fig. 1 a). The basic principle of the beating mode generation is similar to that one of the heterodyne detection, but in this case there are not modulated sources and this avoid the use of complex driving circuits.

In this article, the master laser with a frequency emission (f_{Master}) injects a light beam through a fibered optical circulator into the cavity of the slave laser with a frequency emission (f_{slave}). The optical injection locking conditions are controlled through the power of the injected beam into the cavity and the frequency detuning between the two lasers ($\Delta f = f_{Master} - f_{Slave}$). When the slave laser is mode-locked to the master laser frequency emission, it will follow the master laser frequency emission. In the optical domain, the mode locked slave laser will enhance its optical spectral purity by reducing any secondary mode present in the slave laser in free running condition, including multimode lasers that will behave as single mode lasers. In the electrical domain, it is not possible to observe the frequency emissions of the lasers because of their order of magnitude ($192\ THz$) but the frequency difference (Δf) is easier to be detected using electrical instrumentation taking into account that their order of magnitude is much lower than the laser emission frequency (from $10^8 - 10^{10}$ Hz). As mentioned before, the beating mode frequency is equal to Δf in the electrical domain.

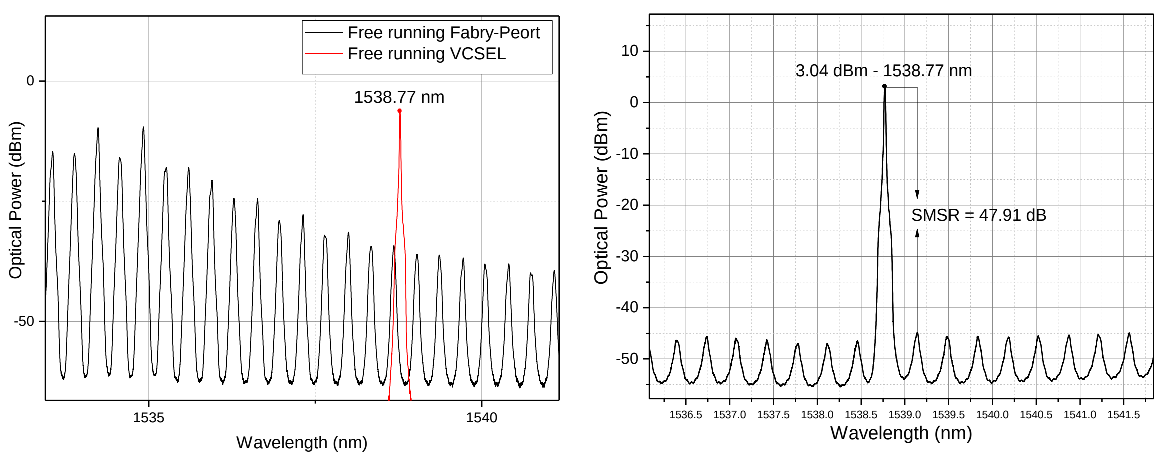


a) b)

Fig. 1. a) Basic principle of the optical generation of microwave signals using optical injection locking. b) Experimental injection locking setup.

3. Experimental Implementations and Results Analysis

The Fig. 1. b) shows the experimental setup used to microwave signal generation using Fabry-Perot by VCSEL injection locking. A C-band VCSEL is used as master laser and a Fabry-Perot is used as slave laser. The output of the VCSEL is connected to the Erbium Doped Fiber Amplifier (EDFA) to increase the optical power of the beam injected into the Fabry-Perot cavity through fibered optical circulator. Finally, the generated microwave signal is photodetected and observed in the Electrical Spectrum Analyzer.



a) b)

Fig. 2. a) Free running VCSEL and Fabry-Perot spectrum. b) Fabry-Perot Injection locked

The free running for both lasers is shown in Fig. 2. a). To achieve a total injection locking, the VCSEL wavelength has to be tuned to one mode of the slave laser with a sufficient optical power. For a VCSEL bias current reach 3.45 mA and the EDFA gain is 10.23 dB, the injected power into the Fabry-Perot laser cavity is 10.23 dB, the 1538.77 nm mode appears and the other cavity modes are suppressed.

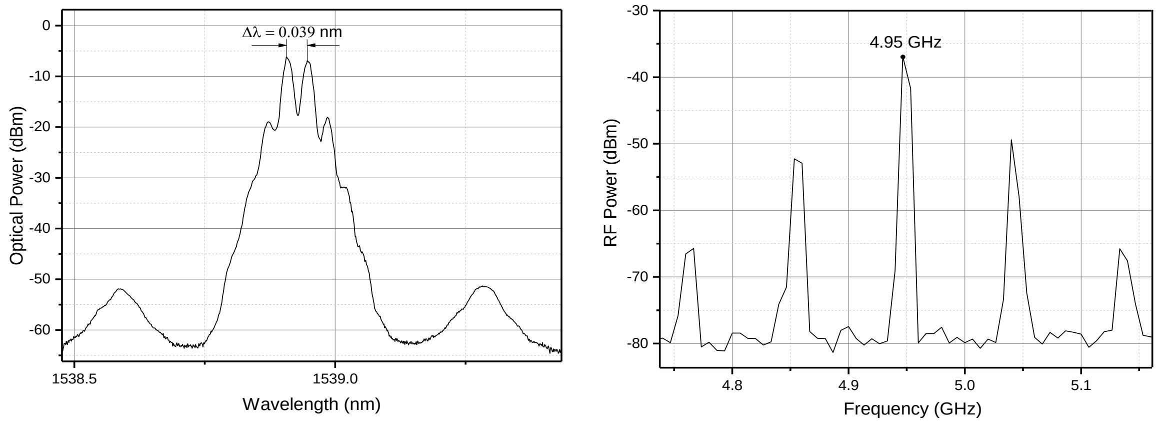
The result of injection is presented in Fig. 2. b). In this case, the sides modes of Fabry-Perot laser are reduced and they have lower power than in free-running conditions. The amplitude difference between the main mode of the injection locked Fabry-Perot emission and the side mode is measured using the Side Mode Suppression Ratio (SMSR). Due to multimodal nature of the slave laser, the SMSR can be measured with a large number of modes, but in this case the SMSR is measured with respect to the closest side-mode. The SMSR measured for several side modes is around 47.91 dB

Additionally, to generate a microwave signal from the beating mode, Fabry-Perot mode is locked by the main mode VCSEL with a specific wavelength detuning (frequency detuning) according to the desired carrier frequency. This difference defines the beating mode frequency. Using the same setup shown in Fig.1. b), it is possible to tune the wavelength VCSEL varying its bias current or cavity temperature.

To achieve a frequency on the order of several GHz, the two main modes need closer wavelengths, which indicates a lower frequency than the emission frequency laser. In the Fabry-Perot case, there is one advantage: the possibility to choose one specific mode (λ_{slave}) and then tuning the master slave. The equation (1) shows the relation between wavelength master (λ_{master}) and the frequency signal(Δf).

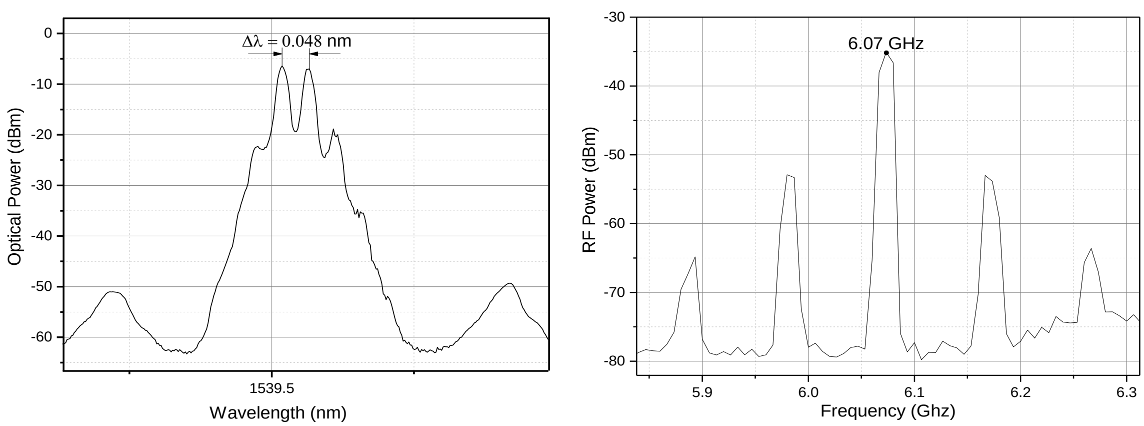
$$\lambda_{master} = \frac{\Delta f}{c}\lambda_{slave}^2 + \lambda_{slave} \quad (1)$$

For example, when the frequency signal is $\Delta f = 4{,}9GHz$ and the selected mode is $\lambda_{slave} = 1538.9465\ nm$, the wavelength master should be $\lambda_{master} = 1538.9851\ nm$. The difference between both modes is ($\Delta\lambda = 0{,}039\ nm$) and represents the frequency signal when a photodetector and electrical analyzer spectrum are used. Fig. 3 and Fig 4 show the results for 4,9 GHz and 6 GHz frequencies. For 6 GHz frequency, the mode difference is $\Delta\lambda = 0{,}048\ nm$.



a) b)

Fig. 3. Microwave generation: 4.9 GHz a) Optical spectrum. b) Electrical spectrum.



a) b)

Fig. 4. Microwave generation: 6 GHz a) Optical spectrum. b) Electrical spectrum.

The measurements are in good agreement with the theory.

4. Conclusions

This document presents the results of injection locking used as a microwave signal generation technique. In order to generate a microwave frequency carrier, it is necessary to define and select one mode of a multimode laser and tune the master slave as close as the required frequency. This kind of optical technique permits to obtain frequencies as high as the instrumentation allows with the use of two semiconductor lasers and one optical circulator.

The injection locking is also used as a technique to change the multimode lasers behavior in a single mode because it suppresses all modes except the mode locked.

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