Optically generated radio frequency signals by sub-harmonically injection locked semiconductor lasers

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Abstract: The heterodyne beating of two laser signals synchronized on different modulation sidebands of another laser results in a spectrally pure radio frequency signal when the lasers spectra, injection rate, and frequency detuning are simultaneously optimized.

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1. Introduction

Future generations of local wireless networks will operate with carrier frequencies in the centimeter and millimeter ranges. At these frequencies, atmospheric attenuation adds to free space divergence resulting in an increased cell orthogonality and a reduced cell size. These characteristics implicate several advantages such as more users per unit of area, a high frequency reuse factor, and reduced interferences. A major drawback, however, is the large number of base stations needed to cover a given area. Consequently, their interconnection is best suited by optical transport and remote control to overcome costly and lossy difficulties associated to classical microwave transmission lines.

Optically heterodyning phase-correlated signals constitutes an elegant solution that allows considerable cost reductions of the base stations. The phase correlation required between optical signals may be obtained by synchronizing different lasers to different sidebands of a sub-harmonically modulated master laser [1].

2. Optimization of master laser spectrum

The lateral modulation sidebands of the ideal master laser spectrum are evenly distributed in a large frequency range, allowing a greater tunability of the RF generated signals, by allowing a wider choice of possible harmonics for the slave lasers synchronization. Considering the cost increase associated to an electrical impedance matching device for the laser-modulator interface, the feasibility of the technique is kept by simply modulating the master laser with a strong modulation index. In our experiments, Alcatel R&I multiple quantum-well distributed feedback semiconductor lasers were used where a 3-GHz modulating signal was directly applied to the laser diode. Due to the large bandwidth of the gain spectrum in semiconductor lasers, a high modulating power of 36 dBm resulted in a spectrum where more than 20 modulation sidebands with appropriate individual power were distributed in a range of 82 GHz. This range sets the maximum frequency that can be generated by optically heterodyning two synchronized signals. In general, it was found that the modulation frequency should be higher than 2 GHz in order to avoid instabilities caused by locking bandwidth overlapping of adjacent sidebands.

3. Optimization of slave lasers spectra

The optimization of the slave lasers spectra consists in carefully adjusting the injection locking conditions, namely, the injection rate and frequency detuning between the master and slave laser. A tradeoff between a high injection rate within the stable-locking bandwidth and, spectral degradation due to adjacent modulation sidebands must be found. The first broadens the locking bandwidth and increases the synchronization stability, whereas the latter compete with the concerned sideband for synchronization and the overlapping of their respective locking bandwidths degrade the emission spectrum. Figure 1 presents the improvement obtained in the emission spectrum.
by reducing the injection rate by 10 dB, the rejection rate of the residual adjacent sidebands are consequently reduced from 8 to 14 dB.

Another key parameter for optimizing the slave laser spectrum is the frequency detuning between the master and slave laser. A distributed feedback laser is susceptible of being synchronized by a non-cooperative injected field because the Bragg grating of the laser strongly selects a single-mode and there is no opportunity for mode-hopping. In Fabry-Perot semiconductor laser this is not the case, where the frequency of the injected field tends to favor the synchronization of the mode with lowest threshold gain [2]. This corresponds to a positive frequency detuning where the injected field tends to oppose to the free laser field. As a result, the threshold gain is higher, and the adjacent sidebands take benefit from it, reducing their rejection rate. Figure 3 presents a 7-dB improvement of the rejection rate of the residual modulation sidebands, increased from 13 to 20 dB. This was done simply by changing the frequency detuning sign of 650 MHz that was used. It is interesting to notice that the slave laser works as an active optical filter with a bandwidth controlled by the injection rate and the frequency detuning.

4. Optimization of the RF spectrum

The optimization of the radio frequency spectrum helps to reduce dramatically the filtering requirement at each base station. The starting point for this optimization is a careful choice of the master laser modulation frequency, acknowledging that a low value reduces the implementation cost, but simultaneously increases the risk of partial overlapping of the locking bandwidths associated to the different modulation sidebands [3]. The optimization of the master and slave lasers spectra under the criteria previously mentioned and the selection of favorable modulation sidebands for the locking process results in a rejection rate of non desirable frequencies of over 23 dB, as shown in
the example on Figure 3. Favorable modulation sidebands means that their selection is based on the desired radio frequency and on the principle that adjacent sidebands should have preferably less power than the locking sideband in order to avoid multiple solicitations for the emission frequency of the slave laser. The results on Figure 3 show, in addition, a carrier to noise ratio of 45 dB and a sub-Hertz spectral linewidth. The spectral linewidth is conditioned by the injection locking conditions and by the preservation of the phase correlation between the slave laser signals obtained by a conjoint management of fiber chromatic dispersion and propagation delays.

Fig. 3. Optimization of a 15-GHz radio frequency spectrum by sideband injection locking of two slave lasers on a 3-GHz modulated master laser. (a) The optical spectrum of both slave lasers leads to (b) an non-optimized radio frequency spectrum, where as (c) selection of different sidebands improves (d) the carrier to noise ratio by 13 dB and the rejection rate of undesirable frequencies by 15 dB.

5. Conclusion

The feasibility of the sideband injection locking technique for remote generation and control of RF signals, having been demonstrated, an optimization method of the RF spectrum is presented. Not only the rejection rate of undesirable frequencies, important for simplification of the numerous base stations, is improved, but the RF carrier power and carrier to noise ratio is maximized with the goal of eliminating the need for RF amplification and filtering at the base station.