Spectral Characteristics of Semiconductor Lasers under Strong Optical Injection

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Abstract – We analyze the spectral characteristics of semiconductor lasers under strong optical injection, and show that widely separated multiple sidebands are generated if the laser is in the dynamically unstable regime. Using this, it may be possible to generate optical μ/mm-waves without any external RF-sources.

I. Introduction

One method of generating optical μ/mm-wave signals is using the optical injection locking (OIL) technique [1-5]. In this technique (Fig. 1-a), the master laser (ML) is directly RF-modulated and has multiple optical sidebands, separated by the modulation frequency, f_m. Two slave lasers (SL's) are then injection locked by two sidebands separated by the desired frequency offset, generating two coherent optical signals that can produce the desired beat frequency signal in the photodetector. In order to obtain high frequency signals, the RF-modulated ML should provide a large number of sidebands that are widely separated. The sideband generation, however, sensitively depends on the modulating RF-power and frequency. A technique that does not require external RF source would be highly desirable. Realizing such an OIL system is the goal of the present investigation.

Recent studies on OIL have found that the modulation bandwidth of a semiconductor laser can be significantly enhanced under the strong optical injection [6-8]. However, the locking properties under the strong optical injection have not been fully analyzed outside the dynamically stable locking range, where such effects as undamped relaxation oscillation and chaos can occur. We analyze the spectral characteristics of semiconductor lasers under strong optical injection, and show that the generation of multiple optical sidebands having large frequency separation is possible. Feeding these sidebands into two SL's, as shown in Fig. 1-b, it is possible to generate optical μ/mm-waves without using any external RF source.

II. Analysis

When light from ML is injected into SL, the locking characteristics can be classified into three distinctive regimes: unlocking, dynamically stable locking, and dynamically unstable locking. Both dynamically stable and unstable locking regimes can be grouped together as the static locking regime. These characteristics are determined based on the injected optical power and the lasing frequency offset between ML and SL. For the analysis, the laser rate-equations including injected light [9, 10] are used for a sample LD whose parameters are obtained from [11]. Figure 2 maps the characteristic regimes determined from the rate-equation analysis. In the figure, Δf is the frequency difference between the ML (f_{ML}) and SL lasing frequency (f_{SL}), and the injection power ratio, $\Re$, is the ratio between the injected ML optical power (P_{inj}) and SL optical power (P_{out}^{fr}) without optical injection. The boundaries for the static locking regime can be obtained from the steady-state solutions of the OIL rate equations. Within the static locking regime, the stability analysis of the linearized transfer function determines the dynamically stable locking regime

The calculated power spectra at the