Ain Shams University

Faculty of Engineering

Electreonics & Communications Engineering

Injection locking of Semiconductor Lasers

By

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A Thesis

Submitted in partial fulfilment for the requirement of the degree of

M.Sc. in Electrical Engineering.

Supervised By

Prof. Dr. / Magdy Mahmoud Ibrahim

1994

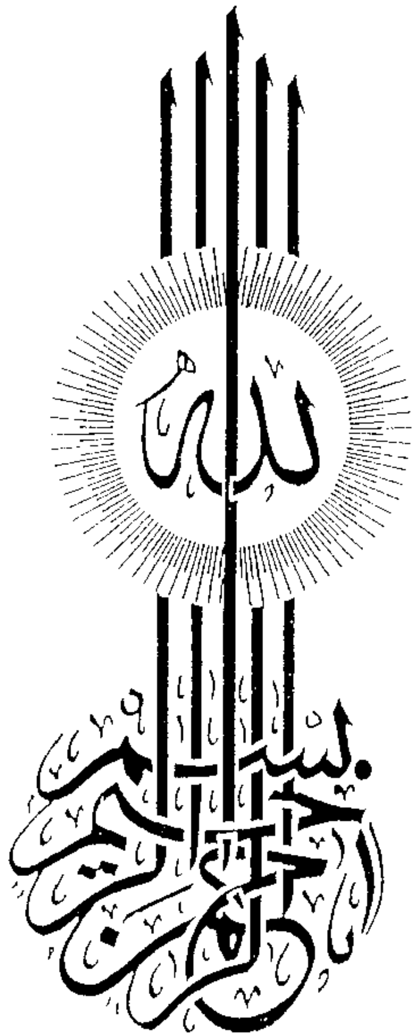
Acknowledgement

My deepest gratitude to Prof. Dr. / Magdy Mahmoud Ibrahim ,and my sincere appreciation to his outstanding supervision,continuous support,valuable suggestions,great help, encouragement and patience,during all phases of that work.

I would like to express my profound gratitude to Prof. Dr. / Mahmoud Hanafy Ahmed for his scientific support and the good example he set for the scientific research.

I would also like to express my profound gratitude to Prof. Dr. /Kamel Mohammed Hassan for the valuable advices , encouragement and moral support .

My thanks to my fellow collegues in the optical communications lab. for their support.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Statement

This dissertion is submitted to Ain Sams University for the degree of M.Sc. in Electronics Engineering .

The work included in this thesis was carried out by the author in the Department of Electronics and Communications Engineering , Ain Shams University .

No part of this thesis has been submitted for a degree or a qualification at any other university or institute .

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Abstract

"Injection Locking of Semiconductor Lasers"

The injection locking properties of semiconductor lasers have been investigated. The basic methods of analyisis which are the rate equation model and the Fabry - Perot amplifier model have been compared. Both models would give identical results at the limiting case of no ingected signal . The Fabry - Perot model is useful for large signal applications. The rate equation model is suitable for investigating the dynamic properties .

The injection - locked passively Q - switched semicondutor laser has been investigated . The injected signal enhances the c.w. operation of the system. In the pulsation regime , it causes an increase of the pulsation frequency. The injected signal can be used to change the mode of operation of the system from pulsation to c.w. or vice - versa. That technique has not been applied before on a semiconductor laser.

The modulation characteristics of an injection - locked semiconductor laser is slightly improved with injection - locking. This technique may be used to partially compensate for the effect of axial inhomogeniety due to pumping inhomogeniety or laser diode aging. The numerical results are found to be in good agreement with those obtained from previous studies.

A Glossary Of Used Symbols

A	Cross sectional area
b	Linewidth enhancement factor
c	Velocity of light
d	Active layer thickness
e	Electron charge
f	Frequency
F_d	Resonator intermode spacing
g	Gain per unit length
G	Gain per unit time
G_s	Single pass gain
G_N	The differential gain constant
h	Planck's constant
i	Small signal current
I	Electric current or Light intensity
J	Current density
L	Resonant cavity length
n	Refractive index
N	Carrier density
N_t	The carrier density at transparency

N_{th}	The carrier density at threshold
P_{in}	The input or injected signal laser power
Po	The free running laser power
P_{out}	The output laser power
P_l	The average laser power in the resonater
P_s	The saturation power
r	The field refectivity
R	The power reflectivity
S	The photon number density
t	Time
T	Power transmittance
U	The ratio between the carrier lifetimes of the gain section to that of the absorbing section
v	Velocity
V	Volume
w	Active layer width
Z	The ratio between the differential gain coefficients of the gain section to that of the absorbing section
α	Loss factor
β	Wave propagation vector
γ	The fraction of spontaneous photons that are coupled into the lasing mode

Γ	The confinement factor
θ_o	The nominal round trip phase shift
θ	The round trip phase shift
ε	The gain compression factor
Ψ	The phase difference between the injected and slave laser fields
ϕ_l	The phase difference between the injected and locked fields
τ_p	The photon life time
τ_s	The carrier recombination time
$\omega(N)$	The frequency of the resonant cavity mode
ω_o	The angular oscillation frequency of the laser mode with no injected signal
ω_{in}	The angular frequency of the injected signal
η_i	The internal quantum efficiency

CONTENTS

Introduction

The injection locking of semiconductor lasers has been investigated with different methods of analysis . That technique has many advantages that make it suitable for many applications . Injection-locking has been used to assure single mode operation under high speed modulation. It has been used to eliminate mode partition noise and frequency chirp from the spectrum of the modulated laser sources. It can be included in a coherent transmition system to be used as phase modulated optical transmitters ,optical amplifiers for angularly modulated signals and local oscillators for homodyne receivers. Injection -locking of Q-switched lasers has been reported to produce frequency stable ,high repitition rate phase coherent pulses.The subject of this research is to study the basic methods of analysis of that technique , and compare the results obtained , to study the effect of injection-locking on a passively Q-switched semiconductor laser , and the modulation characteristics of an injection- locked inhomogeneouly pumped semiconductor laser.

In the organization of this thesis we srart by reviewing in the first chapter the basic methods used to analyze an injection locked semiconductor laser [1]-[9] .These basic methods are based on the rate equation model or the Fabry-Perot amplifier model .The analysis based on the rate equation model is studied through the works of Kobayashi and Kimura [1],Roy lang [2] and Mogensen et al.[3].

Kobayashi and Kimura have studied the injection locking of semiconductor lasers with the analogy of the van der Pol theory of injection locking including an injection wave proposed by Shimoda.They did not take into consideration the carrier density dpendent refractive index [1].

Roy Lang has adopted a formalism similar to Pantell's and he has incorporated the unique feature of the semiconductor laser which is the strong dependence of the active medium refractive index on the injected carrier density. He found out that it brings about the appearance of the dynamically unstable locking range which is asymmetric around the frequency detuning [2].

Mogensen et al. used a formalism similar to that of Lang's , assuming the suppression of side modes .They have shown that there is a locking /unlocking region with a detuning just outside the locking region ,and an injected light induced pulsations in the dynamically unstable region [3] .

The analysis based on the Fabry-Perot amplifier model was studied through the work of Buczek and Frieberg for a $CO2$ laser.They have employed a reflective regenerative ring laser amplifier configuration.The resuls obtained agree in principle with those obtained from the rate equation model [4] .

The analysis of an injection - locked semiconductor laser using the Fabry-Perot model has been presented by G.R.Hadley who studied the forward and reflected amplitudes in diode laser cavity [7] .

In the second chapter a comparison between the rate equation model and the Fabry-Perot model is presented for the injection locking of a semiconductor laser concerning the laser average power, the external phase and the locking range. The results obtained from the rate equation model are found to be in good agreement with previous studies[8].

In the third chapter , the injection locking of a passively Q-switched semiconductor laser has been investigated.The laser cavity is assumed to be divided into an amplifying (gain) region and a less excited (loss) region.The basic equations are the rate equations for the carrier densities in each section,and the average photon density in the cavity.The effect of the main parameters on the performance of the injection-locked laser is presented.The results obtained are in good agreement with the previous studies [14] for the special case of no injected signal.

In the fourth chapter the modulation characteristics of an injection-locked inhomogeneously pumped semiconductor laser have been investigated . The analysis of K.Petermann is extended to enclude an injected signal applied on a two -section laser. It is found that the frequecy response is improved and the modulation bandwidth is increased with the application of an injected signal .On the other hand the presence of an absorbing section is found to cause a reduction of the modulation characteristics peak , and a reduction of the modulation bandwidth for the used set of parameters.The application of an injected signal partially compensates for the effect of the absorbing section.The numerical results are in good agreement with the previous results [25] for the special case of a single -section injection-locked laser.