Microwave Circuit Design for Chirp or Intensity Fluctuation Suppression in Multielectrode DFB Lasers

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***Abstract*— Realizable microstrip circuits have been designed to provide the required modulation current characteristics to suppress the chirp or intensity fluctuations occurring in a multielectrode distributed feedback laser structure under intensity or frequency modulation schemes, respectively. The designs have been performed using the combination of a commercial microwave circuit simulator and a time domain laser model. It is shown that good chirp or intensity fluctuation suppression can be achieved without significantly affecting the desired intensity or frequency modulation performance.**

***Index Terms*—Microstrip circuits, optical transmitters.**

I. Introduction

Direct modulation in distributed feedback (DFB) laser diodes provides an easy and convenient feature that is widely used for light sources in optical communication systems. The coupling between the amplitude and phase within the laser, however, causes frequency chirping under intensity modulation (IM) and intensity fluctuation under frequency modulation (FM) schemes. Various methods using multielectrode lasers have been reported to suppress the unwanted chirp and intensity fluctuation [1]–[3]. One method, by Yoshikuni and Motosugi [1], suggested that suppression in chirp and intensity fluctuation can be achieved by supplying appropriate nonuniform bias currents and push–pull modulation currents to the front two electrodes. Using a similar modulation technique, Ishida *et al.* [2] used external adjustable attenuators and phase shifters to achieve the required modulation currents, which involved manual adjustments for broad-band operation. In [3], a similar push–pull modulation scheme was investigated experimentally and through simulation for chirp reduction in digital systems.

The relationship between the required modulation current amplitude and phase has been previously reported for a DFB laser for a frequency band from 0.5 to 1.0 GHz [4]. It was also suggested that a modified ring hybrid structure can be used to provide the correct amplitude and phase of the modulation currents. It is the aim of this work to extend the study to a higher band from 1.5 to 2.0 GHz and to design modulation circuits that avoid readjustments to attenuators or phase shifters at different frequencies across the frequency band of interest. Microstrip structures, which have been designed for laser impedance matching [5]–[7], were chosen to realize the circuits. Unlike the work in [3], the main application area here is in analog/subcarrier systems; laser parasitics (not considered in [3]) have been taken into account as these will affect the driving conditions when a broad band of frequencies are to be used.

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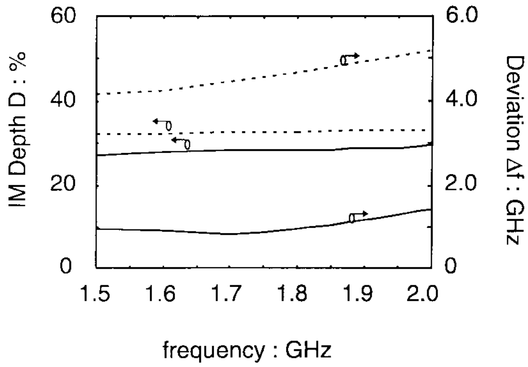
II. DFB Laser Modulation

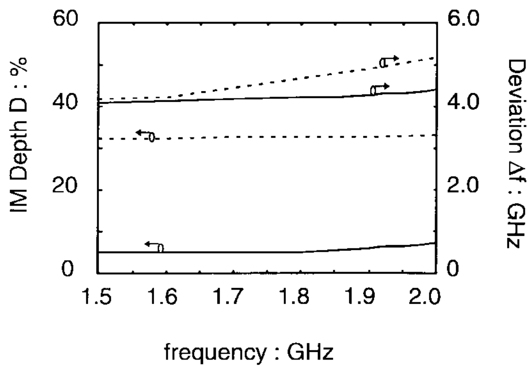
The simulation of a three-electrode uniform DFB laser diode was performed by a time-domain-based model (TDM), while an electrical equivalent circuit model was used to calculate the active region current along different parts of the laser. The TDM used is similar to the model developed by Tsang and Marcenac [8]. The modeled device was 500 μm long and modeled by 30 elements with typical parameter values based on those of [9]. A microwave circuit simulator (Hewlett Packard's Microwave and RF Design System, *MDS*) was used to implement the electrical equivalent circuit model. The equivalent circuit model is based on the model developed by Tucker and Kaminow [10] which covers: 1) chip and package parasitics and 2) a small-signal model for the active region of the laser. Parasitics values based on [10] were used. Following [3], the separation resistance between the electrodes has been assumed large, but no detailed modeling of this effect has been incorporated. The aim of this work is to demonstrate that chirp or intensity fluctuation for a typical laser structure can be suppressed through the use of external modulation circuits. For other real laser diodes, modifications will be needed to the details of the microstrip modulation circuit designs, but the method will be the same.

III. Simulated Laser Modulation Performance

In order to achieve an IM depth (D) of at least 25% for IM or a frequency deviation (Δf) of 3.8 GHz for FM across a frequency band of 1.5–2.0 GHz, a sinusoidal modulation current of 12 mA was first applied to the center electrode of the laser diode as a reference modulation scheme. The laser diode was biased above threshold at 60 mA in the center electrode while bias currents of 20 mA were applied to both the front and rear electrodes. This bias condition was used for all simulations presented. Other modulation schemes, such as



(a)



(b)

Fig. 1. Performance of suppression schemes with modulation circuits reference modulation scheme push–pull scheme: (a) chirp-suppressed IM and (b) IM-suppressed FM.

TABLE I
REQUIRED AMPLITUDE AND PHASE RELATIONSHIPS OF MODULATION CURRENTS FOR SUPPRESSION SCHEMES AND THE CORRESPONDING LASER PERFORMANCE. (a) CHIRP-SUPPRESSED IM. (b) IM-SUPPRESSED FM

Chirp-suppressed IM

fm: GHz	If: mA	Ic: mA	θIf-θIc: rad	IM D: %	Δf: GHz
1.5	15.0	13.0	0.40π	30.244	1.058
1.6	16.5	13.0	0.40π	31.107	1.194
1.7	17.5	13.0	0.42π	30.636	1.079
1.8	18.8	13.0	0.42π	31.552	1.208
1.9	19.8	13.0	0.45π	30.392	1.072
2.0	20.8	13.0	0.45π	31.332	1.145

(a)

IM-suppressed FM

fm: GHz	If: mA	Ic: mA	θIf-θIc: rad	IM D: %	Δf: GHz
1.5	16.5	9.0	0.70π	3.331	3.777
1.6	17.5	9.0	0.73π	3.658	4.027
1.7	18.5	9.0	0.73π	3.733	3.985
1.8	19.5	9.0	0.73π	3.744	3.907
1.9	20.5	9.0	0.73π	4.071	3.845
2.0	21.5	9.0	0.73π	4.678	3.779

(b)

uniform current injection to the three electrodes, could have been used as the reference, but simulations show that similar results are obtained. With the reference modulation scheme applied across the frequency band, the maximum frequency deviation was 5.1 GHz, while the modulation depth was about 33%. The simulated laser performance using this reference modulation scheme is shown as dotted lines in Fig. 1.

Two different sets of bias and push–pull modulation conditions were also obtained from the simulations. One was used to suppress chirp and the other was for intensity fluctuation suppression. The required modulation current characteristics and the corresponding simulated laser performance are listed in Table I. For the IM scheme, the required front electrode current varies from 15–20.8 mA while the center electrode remains at 13 mA, and a phase difference of 0.4–0.45π rad is necessary between the front and center electrodes. For the FM scheme, the required front electrode current is found to be between 16.5–21.5 mA, while the center electrode current is kept at 9 mA; a front and center electrode phase difference of 0.7–0.73π rad is required. In both cases, the rear electrode current is not modulated.

IV. MICROSTRIP-CIRCUIT DESIGN AND SIMULATION

The microstrip circuits are required to provide the correct amplitude and phase difference for the two electrode currents from a single source across the frequency band of 1.5–2.0 GHz; the provision of an almost constant phase difference for all frequencies across the bandwidth makes this a difficult task. Ring hybrid structures were found to offer a π rad phase shift value between the two output ports across a narrow band. In order to satisfy the bandwidth requirement, a modified ring hybrid structure described in [11] was used. Special consideration was paid to the stripline and gap dimensions for the realization of the circuit, and it was found that a suitable substrate should have a thickness of 2.54 mm and high permittivity ε_r of 10.2.

Signals from the two output ports of the modified hybrid structure were applied to the front and center electrode by two arms, which are 50-Ω lines, via a high-pass filter and an attenuator, respectively. The high-pass filter was used to provide the appropriate current amplitude and minor phase adjustment to the front electrode. Two different circuit layouts were developed for the IM and FM schemes, respectively. The layout of the complete microstrip circuit for intensity fluctuation suppression with the FM scheme is shown in Fig. 2.

The complete circuit layouts and laser electrical equivalent circuit model have been simulated using *MDS*. The simulation of the circuit layouts was made as realistic as possible. The layouts include footprints for surface mount components, short circuit-to-ground via-holes, and bias feed lines. The simulated modulation performance of the laser is shown as solid lines in Fig. 1. From Fig. 1, it can be seen that for the IM scheme, a reduction in maximum Δf, is achieved from the reference value of 5.17–1.42 GHz, while a modulation depth (D) of at least 27% is maintained. For the FM scheme, the maximum intensity fluctuation is reduced from 33% to 7.2%, while the Δf is kept between 4.2–4.3 GHz. These results indicate that good suppression in the unwanted characteristics can be

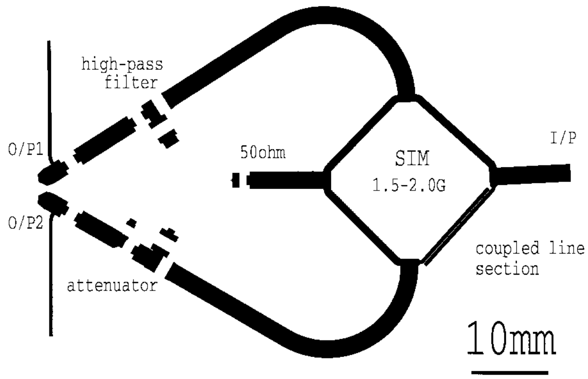


Fig. 2. Layout of the modulation circuit for the IM-suppressed FM application.

achieved without significantly affecting the wanted IM and FM responses.

V. Conclusion

It has been demonstrated, using a combination of a large-signal time-domain model and an equivalent circuit model implemented in a microwave-circuit simulator, that realizable microstrip circuits based on ring hybrid structures can be designed to achieve chirp-suppressed IM and intensity fluctuation-suppressed FM over a broad bandwidth. The circuit design approach is eminently suitable to higher frequency (higher than 1 GHz) signal transmission, where microstrip techniques are appropriate, when wide-band lasers are employed. It should also be noted that the circuit design will become more difficult for wider bandwidth operation.

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