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Simultaneous reduction of IMD3 and IMD5 in bisection laser diode by feedback second harmonic injection

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ABSTRACT

This paper reports a scheme for reducing third and fifth order intermodulation distortion in 1.3 μm gain lever laser diode. Third and fifth order intermodulation components are reduced in the laser diode output by second harmonic frequency signals which are extracted from the laser diode itself. The number of RF components required in the linearization circuit for distortion reduction is significantly reduced in this scheme. The active region of the laser diode is split into two sections at a ratio of 0.97:0.03 for realizing gain lever effect. The longer and shorter section currents are fixed as 20 mA and 5 mA, respectively, corresponding to maximum gain lever. The rate equation approach is used for the analysis. In this scheme, third and fifth order intermodulation components are simultaneously reduced, by injecting second harmonic of two tone signals with appropriate amplitude and phase. A 14.7 dB and 9.4 dB improvement in third order and fifth order intermodulation respectively, are predicted at 2.4 GHz. The magnitudes of third and fifth order intermodulation products are calculated from analytical expressions and the results are found to agree with simulation. Further the effect of RF carrier frequency and channel spacing on distortion reduction is also investigated.

1. Introduction

RF signal transmission through optical fiber is finding application in cable television, wireless mobile networks and phased array antennas [1,2]. This concept is referred as Radio over Fiber (RoF) technology. This approach leads to significant reduction in number of equipments and minimizes the overall system complexity. Direct or external optical modulation is used in such applications.

Requirements for RF transmission through fiber include large bandwidth, efficient RF to optical conversion and minimum distortion. Bisection laser structures usually exhibit bistability and self pulsation [3–6]. However, AM enhancement or gain lever is also observed in such devices under certain conditions [7–16]. Hence they lead to improved modulation efficiency. But, harmonic and intermodulation components produced in the optical output due to its inherent non linearity of the gain lever phenomenon limits its application potential. Under these circumstances, reduction of distortion becomes mandatory for efficient utilization of gain lever for RoF applications.

Morthier et al. [17] analyzed the effect of nonlinearity on harmonic distortion in Fabry–Perot and Distributed Feedback Laser diodes. Chen et al. [18] investigated the characteristics of intermodulation distortion in DFB laser diodes under feedback and reported improvements. Feedback harmonic injection, predistortion and feedforward linearization techniques are conventionally used to reduce intermodulation signals in single section laser diodes [19,20]. An adaptive compensation of nonlinear distortion for microwave fiber optic link is analyzed by Fernando et al. [21]. In the case of RF and microwave amplifiers, second harmonic and difference frequency injection techniques are used to reduce IMD3 signals [22]. It is well known that if the signal due to intermodulation distortion falls in the main signal band it is difficult to reduce it. Tapered cavity structure is another approach to reduce IMD3 and also to improve the modulation efficiency in two section gain lever laser diode [13].

In our earlier report, we had proposed a novel method to minimize the third order intermodulation distortion in gain lever bisection laser diode [16]. In that approach, we used IMD3 signals for distortion reduction which are generated from second harmonic signals obtained from the longer section of the bisection laser diode itself. A detailed comparison of various approaches used for linearization in gain lever laser diode are given in Table 1.

This paper presents an improved distortion reduction technique based on longer section generated, second harmonic signal injection.

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Table 1
Comparison of distortion reduction schemes for gain lever laser diodes.

Authors	Features	Remarks
L D Westbrook et al. [9]	Intermodulation distortion, Intermodulation free dynamic range (IMFDR) and Third order Intercept (TOI) are analyzed	Harmonic balance model is used. Optimum bias point is identified
C P Seltzer et al. [10]	Gain lever is analyzed with length and split ratio for MQW and bulk laser diode.IMD, IMD free dynamic range are analyzed	12 dB gain lever is obtained. Gain lever lasers can be used for analog optical links with careful control of operating point
H K Sung et al. [12]	Optical injection locking scheme is used in gain lever DBR laser diode to reduce IMD	15 dB reduction in IMD. External laser is required for injection locking
F Rana et al. [13]	Gain lever and reduced IMD are obtained via cavity geometry modification	Complex device structure (tapered cavity)
Our earlier work [16]	A novel scheme of IMD3 reduction in gain lever laser diode	First scheme to use signals from the laser diode itself for IMD3 reduction. 7.3 dB gain lever, 14 dB reduction in IMD3 at 2.4 GHz
This report	Simultaneous reduction of IMD3 and IMD5 by second harmonic injection	Second harmonic signals generated from the laser diode itself. Minimum number of RF components are required. 14.7 dB reduction of IMD3 and 9.4 dB reduction in IMD5 component. Reduction of IMD3 and IMD5 are evaluated from analytical expression and compared with simulation results

By this scheme, the third and fifth order intermodulation in the output signals are simultaneously minimized. The analysis of IMD5 components are also important as these signals provide spurious noise at adjacent bands in a subcarrier multiplexed (SCM) optical transmission systems. The rate equation model representing this bisection laser diode are numerically solved by using fourth order Runge–Kutta method, to evaluate the proposed scheme. The second harmonic frequency signals are obtained from the laser diode's longer section itself, instead of external RF sources, used in conventional schemes. This method of distortion reduction leads to overall reduction in system complexity. The merit of this linearization scheme is simultaneous reduction of IMD3 and IMD5 components in the output under second harmonic injection with less number of RF components, when compared to our earlier report [16]. The expression for third and fifth order intermodulation terms are derived and its magnitudes are evaluated. These results are compared with simulation results. The effect of carrier frequency and channel spacing on distortion reduction are also evaluated, so that the ability of the RoF link to support multiple services can be determined.

2. AM efficiency enhancement and linearization in gain lever laser diode

2.1. AM efficiency of bisection laser diode

The active region of the laser diode is divided into two sections to utilize the gain lever effect. The length of the longer section is 'a_1' and the shorter section is 'a_2'. The device has two electrodes for current injection corresponding to two regions, but has a single optical cavity. A constant DC current (I_g) is injected into longer section and shorter section is used for RF modulation. The modulation current applied to the shorter section is represented as I_a+I_{RF}. The two section laser diode must have different values of differential gain, carrier life time and section lengths to obtain large gain lever. In order to ensure lasing action in the device, the total gain should be greater than total loss. If the shorter section current (I_a) increases, the carrier density in this section (N_a) also increases. This leads to an increase in photon density in the device. The carrier density in the longer section decreases to maintain the steady state lasing condition. The increased photon density in the device is due to the decrease in longer section carrier density [7,8]. This leads to enhancement in modulation efficiency and also distortion. Hence, there is a need for linearization schemes for

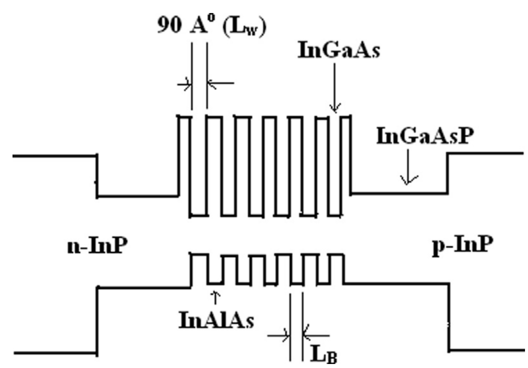

Fig. 1. Energy band diagram of quantum wells in bi section laser diode structure [3].

utilizing gain lever phenomenon effectively. In this work, we report the third and fifth order intermodulation distortion minimization in such devices. Uenohara et al. have analyzed optical bistability in two section MQW laser by theory and experiment [3]. A similar device structure with corresponding parameters are used for analysis in this work. The energy band diagram of the bisection MQW laser diode is shown in Fig. 1. The device is characterized by a ridge width of 3 μm and cavity length of 300 μm. The length of longer section is 280 μm and length of shorter section is 10 μm (97/03). The isolation region length is 10 μm. Other details of the device structure can be obtained from Ref. [3].

The rate equations for longer section carrier density (N_g), shorter section carrier density (N_a) and average photon density (S) in the laser diode can be given as [3–6,16]

$$\frac{dN_g}{dt}=\frac{I_g}{a_1qV}-\frac{N_g}{\tau_{\mathbf{g}}}-v_g g_g(N_g-N_{og})S(1-\epsilon S)-\frac{N_g}{\tau_{nr}} \tag{1}$$

$$\frac{dN_a}{dt}=\frac{I_a}{a_2qV}-\frac{N_a}{\tau_a}-v_g g_a(N_a-N_{oa})S(1-\epsilon S)-\frac{N_a}{\tau_{nr}} \tag{2}$$

$$\frac{dS}{dt}=-\frac{S}{\tau_{\mathbf{p}}}+[a_1 v_g g_g(N_g-N_{og})+a_2 v_g g_a(N_a-N_{oa})]\Gamma S(1-\epsilon S) +\Gamma\beta\left(\frac{a_1N_g}{\tau_{\mathbf{g}}}+\frac{a_2N_a}{\tau_{\mathbf{a}}}\right) \tag{3}$$

$$\tau_{\mathbf{g}}=\frac{1}{(BN_g)},\ \tau_a=\frac{1}{(BN_a)} \tag{4}$$

The total volume of the active region is 'V' and charge of the electron is 'q'. The transparency carrier densities in longer and