Study of Reduction of Nonlinear Chirp Distortion Directly Modulated Semiconductor Lasers by using Pulse Shaping

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Abstract

A modulation of the device current leads to laser-power modulation and is useful for transmitting information as a sequence of optical pulses .However , modulation of the current also affects the optical frequency which emphasize that carriers influence the optical phase . The center frequency of the out put laser shifts by an amount during modulation . The phenomenon of the dynamic shift of the laser frequency is referred to as frequency chirping or wavelength chirping . The chirp is directly proportional to the line-width enhancement factor and has its origin in the carrier induced index change that accompanies any gain change in semiconductor laser . This chirp may be reduced by a suitable shaping of the injection current .

الخلاصـــــة

يستخدم تيار السوق المضمن لليزر اشباه الموصلات لنقل المعلومات على شكل نبضات ليزرية متسلسلة كونه يمتلك قدرة ليزرية مضمنة . علاوة على هذا فان التيارالمضمن سوف يؤثر على التردد البصري حيث ان حاملات الشحنة تؤثر على الطور البصري لذلك فان تردد المركز للخرج الليزري يزحف خلال عملية التضمين .

ظاهرة التزحيف الديناميكي للتردد الليزري يشير الى تردد الزقزقة (frequency chirping) . الزقزقة تتناسب مباشرة مع عامل تحسين عرض الخط وهذا يؤدي الى تغير في معامل الانكسار والربح لمعالجة وتقليل ظاهرة الزقزقة يتم حقن ليزر اشباه الموصلات بتيار مناسب على شكل نبضي (Pulse shaping) .

1. Introduction

When a semiconductor laser exhibits a dynamic signal-mode emission like DFB laser , its spectral line is considerably broadened under direct modulation , since the intensity modulation is always accompanied by a frequency modulation [1] . this spectral broadening , also denoted as laser chirp , may be transmitted over single –mode fibers . Different spectral components will suffer different delays through the fiber ,yielding a pulse broading at the fiber end and a related dispersion penalty [2]. Especially if laser diode at λ =1.5,1.52,1.54 ……. 1.6 μm are used , having regard to minimum fiber loss, the bit rate –length product is severely restricted because of the considerable dispersion of 15 ….20 ps /(km nm) for ordinary single-mode fibers [1,2] .

Because of this sever limitation for achievable band width –length products ,chirp-effects have been discussed .

2. Analysis

The dynamic semiconductor laser is described by the single-mode rate equations. Using normalized quantities [3] . these can be written as

$$\frac{dn}{dt} = j - n - (n - n_{om})(1 - \xi p)p \qquad \text{…. (1)}$$

$$\frac{dp}{dt} = \gamma[\Gamma(n - n_{om})(1 - \xi p)p - p + \Gamma \beta n] \qquad \text{…. (2)}$$

$$\frac{d\phi}{dt} = \frac{\alpha\gamma}{2}[\Gamma(n - n_{om}) - 1] \qquad \text{…. (3)}$$

Where n and p are the normalized electron and photon densities ,respectively , ϕ is the optical phase , Γ is the optical confinement factor , n_{om} is normalized electron density at which the net gain is zero , γ is the ratio of the spontaneous recombination lifetime τ_s to the photon lifetime τ_p , β is the fraction of the spontaneous emission coupled into the lasing mode and ξ is the normalized gain compression factor which describes a first-order gain reduction due to spectral hole burning and other gain nonlinearities ; t is a normalized relative to τ_s .

The optical frequency (or wavelength) shift of the lasing mode is related to the phase variation ϕ [4] through

$$\Delta\upsilon(t) = \frac{1}{2\pi}\frac{d\phi}{dt}$$

$$= \frac{\alpha\gamma}{4\pi}\left[\Gamma(n - n_{om}) - 1\right] \qquad \text{.... (4)}$$

Where α is the line width enhancement factor defined as the ratio of the real part (μ') to the imaginary part (μ'') of a change in the active region refractive index due to a change in the carrier density n, $\alpha = (\partial\mu'/\partial n)/(\partial\mu''/\partial n)$, with a typical value of $\alpha \approx 5$ [4].

We can used the volterra series analysis to the presentation of intensity and frequency as nonlinear transfer functions [5]. The transfer functions G_n(f),H_n(f0, and F_n(f) (with f=f_1……f_n) associated with the carrier density ,photon density , and the laser frequency modulation response , respectively . The transfer function F_n(f) is directly proportional to the transfer function G_n(f) for the electron density [5] .

$$F_n(f_1,\ldots\ldots,f_n) = \frac{\alpha}{4\pi}\gamma\Gamma G_n(f_1,\ldots\ldots,f_n) \qquad \text{.... (5)}$$

Alternatively ,we would like to relate F_n with H_n .this is achieved starting from eq. (2) and neglecting spontaneous emission by expanding the gain $G = \Gamma(n - n_{om})(1 - \xi p)$ around the threshold point

$$G(n,p) \approx 1 + \Gamma(n - n_{th}) - \xi p \qquad \text{.... (6)}$$

Solving eq.(2) for $\Gamma(n - n_{th})$ and substituting the result in eq. (4) yields

$$\Delta\upsilon \approx \frac{\alpha}{4\pi}\left[\frac{d}{dt}\ln(p) + \gamma\xi p\right] \qquad \text{.... (7)}$$

We can calculated the transfer functions H_n and G_n by harmonic input method [5] and upon expanding ln(p) by a taylor series around the bais point , for which the photon and carrier densities are P_o and n_o , the final result for the n_{th} –order transfer function is

$$F_n(f_1,\ldots\ldots,f_n)=\frac{\alpha}{4\pi p_o}\left[i2\pi(f_1,\ldots\ldots,f_n)+\gamma\xi P_o\right]H_n(f_1,\ldots\ldots,f_n)+D_n \qquad \text{… (8)}$$

First ,when the semiconductor laser is modulated by tow frequency (f_1),D_1=0 and if it is modulated by two frequencies (f_1,f_2) , the term $D_2$is given

$$D_2=\frac{1}{P_o}\left\{\frac{\alpha}{4\pi}\gamma\xi H_1(f_1)H_1(f_2)-\frac{1}{2}\left[F_1(f_1)H_1(f_2)+F_1(f_2)H_1(f_1)\right]\right\}$$

Finally ,when the semiconductor laser is modulated by three frequencies (f_1,f_2,f_3), the term $D_3$is given

$$\begin{aligned}D_2=\frac{1}{P_o}\Big\{&\frac{\alpha}{6\pi}\gamma\xi\big[\,H_1(f_1)H_2(f_2,f_3)+H_1(f_2)H_2(f_1,f_3)+H_1(f_3)H_2(f_1,f_2)\,\big]\\&-\frac{1}{3}\big[F_1(f_1)H_2(f_2,f_3)+F_1(f_2)H_2(f_1,f_3)+F_1(f_3)H_2(f_1,f_2)\\&+H_1(f_1)F_2(f_2,f_3)+H_1(f_2)F_2(f_1,f_3)+H_1(f_3)F_2(f_1,f_2)\,\big]\Big\}\end{aligned}$$

3. Results

We are used the parameter values given in table (1) for typical 1.3 μm buried –hetero structure laser [6] ,and by using eq. (8) to show the frequency response and effect of nonlinear chirp distortions on the output of laser as shown in fig. (1) .

Table (1) [6]

Parameter	*Symbol*	*Value*
Cavity length	L	250 μm
Active region value	W	2 μm
Active layer thikness	d	0.2 μm
Confinement factor	Γ	0.3
Effective mode index	$\overline{\mu}$	3.4
Group refractive index	μ_g	4
Line – width enhancement factor	α	5
Fact loss	α_m	45 cm^{-1}
Internal loss	α_{int}	40 cm^{-1}
Gain constant	a	2.5×10^{-16} cm^2
Carrier density at the net gain	n_{om}	1×10^{18} cm^{-3}
Nonradiative recombination rate	A_{nr}	1×10^{8} S^{-1}
Radiative recombination coefficient	B	1×10^{-10} cm^3/s
Auger recombination coefficient	C	3×10^{-29} cm^6/s
Threshold carrier population	n_{th}	2.14×10^{8}
Threshold current	I_{th}	15.8 mA
Carrier lifetime at threshold	τ_s	2.2 ns
Photon lifetime	τ_p	1.6 ps
Gain compression factor	ξ	8.62×10^{-3}
The fraction of the spontaneous emission coupled into laser mode	β	1×10^{-4}

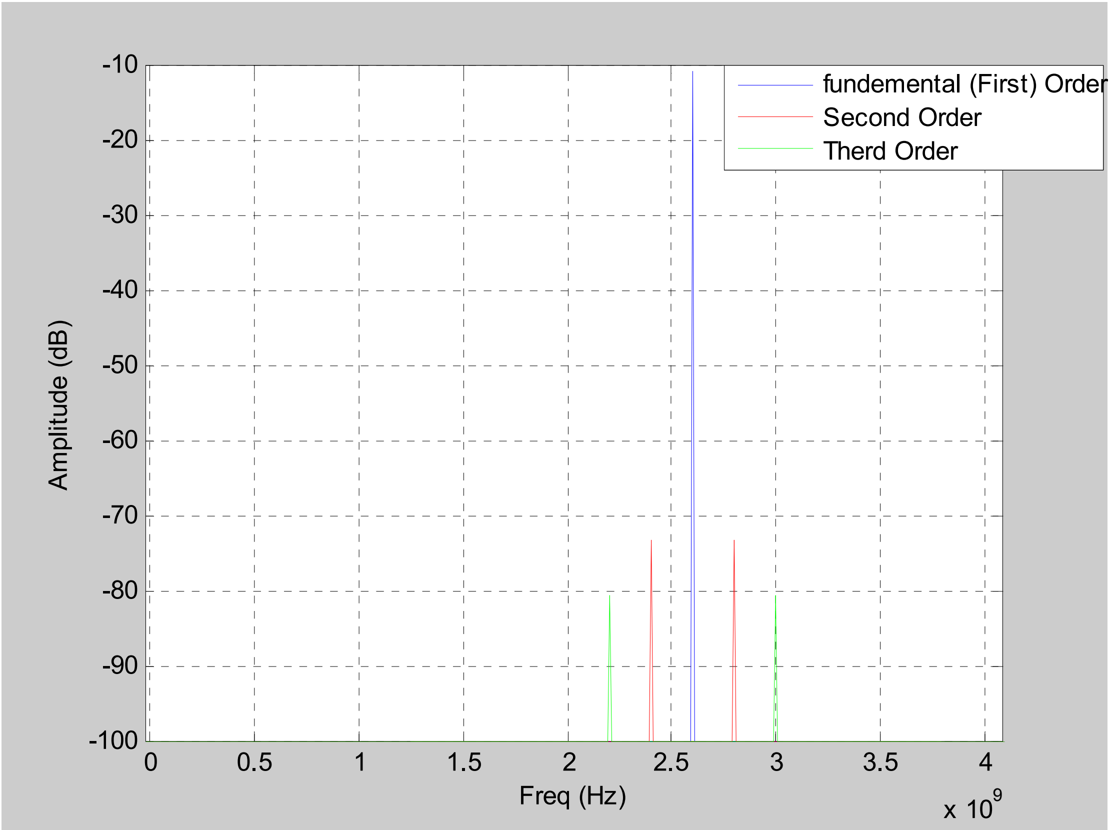

Fig. (1) Frequency response and effect of nonlinear chirp distortions

$$f_1 = 2.6GHz, \Delta f = 0.2GHz, f_2 = f_1 + \Delta f, f_3 = f_1 + 2\Delta f$$

To reduce the nonlinear chirp distortions, we are used a pulse shaping in the injection current to increase the bias level (bias current) ,therefore the carrier density cannot grow significantly above the stationary value and the over shoot remains within reasonable limits .Fig.(2) show the effect of pulse shaping on the nonlinear chirp distortions.

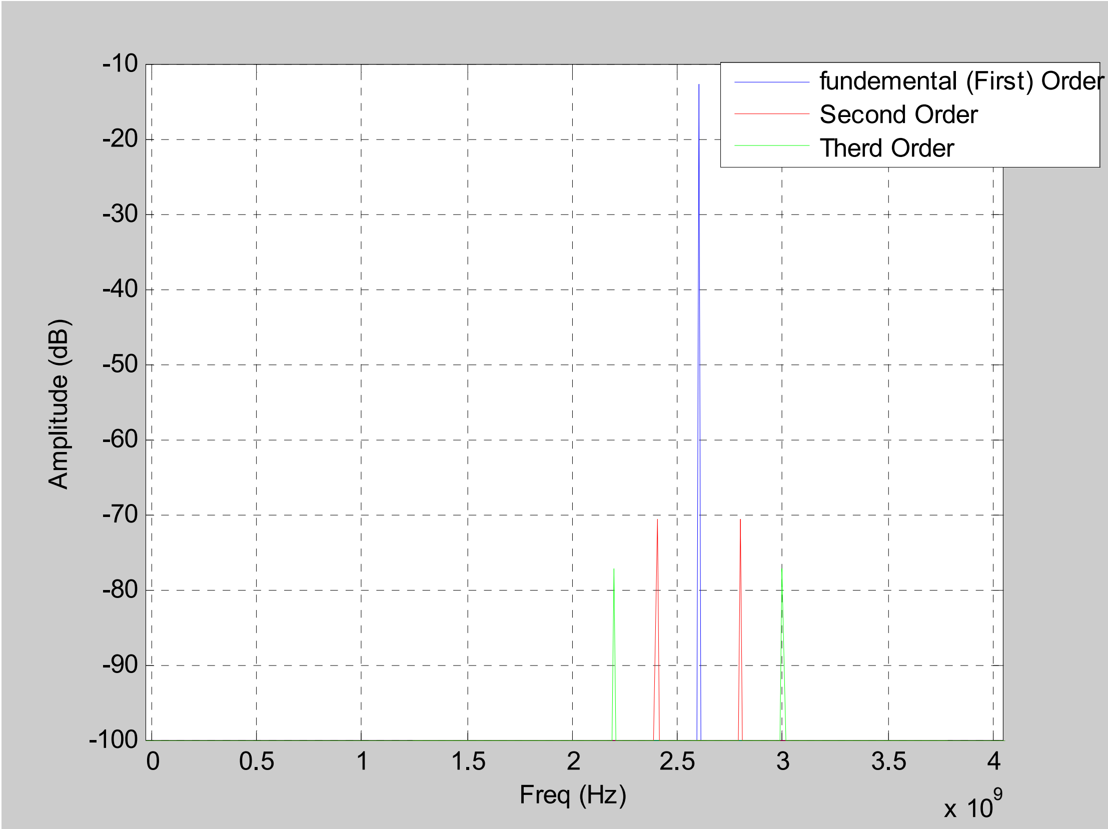

Fig. (2) Effect of pulse shaping on frequency reasonable

$$f_1 = 2.6GHz, \Delta f = 0.2GHz, f_2 = f_1 + \Delta f, f_3 = f_1 + 2\Delta f$$

4. Conclusion

We have used volterra series analysis to assess the frequency modulation nonlinear distortions of the semiconductor laser when directly modulated and we have shown the nonlinear chirp distortion and how reducing this distortions by using the pulse shaping in the injection current to increase the bias current for the carrier density cannot grow significantly above the stationary value and the over shoot remains within reasonable limits .

5. References

1. T. L. Koch and J. E. Bowers : ***"natura of Wavelength Chirping in directly modulated semiconductor lasers "*** ; Electron . Lett., Vol. 20 , pp. 1038-1040 , 6_{th} Dec. 1984 .
2. R. Schimpe, J. E. Bowers , and T.L.Koch : ***" Characterization of frequency response of 1.5*** μm ***InGaAsP DFB laser diode and InGaAs pin photodiode by heterodyne measurement technique "*** ; Electron . Lett., Vol. 22 , pp. 453-454 , 24_{th} April 1986 .
3. M. J. Adams ***:"Rate equations and transient phenomena in semiconductor lasers "*** ; opto-electronics Vol. 22 ,pp. 201-215 ,1990
4. [4] D. welford and S. B. Alexander : ***" Magnitude and phase characteristics of frequency modulation in directly modulated GaAlAs semiconductor diode lasers "*** ; J. Light wave Technology , Vol. Lt-3 , pp.1029-1099, Oct. 1985 .
5. H.M. Salgado and J.J. O'Reilly : ***" Volterra series analysis of distortion in semiconductor laser diode "*** ; IEE proc. ,Vol. 138 ,No.6 , part J , pp.379-382 . Dec. 1991 .
6. J. P. Van , T. Tanbunek and F. Koyama : ***"Single – mode operation of 1.3*** μm ***InGaAsP/Inp buried –hetero structure lasers using a short external optical cavity "*** , IEEE J. Quant. Electron. Vol. QE-20 , No. 3 ,pp. 223-229 ,Jun 1983 .