Journal of College of Education for pure sciences(JCEPS)
Web Site: http://eps.utq.edu.iq/ Email: eps_tqr@yahoo.com
Volume 7, Number 2, May 2017

Dynamics of mutually coupled semiconductor lasers

M. O. Oleiwi(1),H. A. Sultan(2),D. H. Hashim(2), A. M. Chekheim(3) and C. A. Emshary(2)

(1) Physics Department, College of Sciences, Thi-Qar University, Thi_Qar,

(2) Physics Department, Education College for Pure Sciences, Basrah University, Basrah,

(3) Directorate of Education, Thi-Qar Province, Thi-Qar, IRAQ

Abstract:

We present the results of a numerical study of the dynamical behavior of two mutually coupled semiconductor lasers.To do so a four- equations model is adopted together with injection current pulse shaping of each laser alone together with sinusoidal modulation of the injection current of each laser.

The obtained results revealed varieties of dynamics in all the studied cases, which suggest the possibility of safe communication through beating of both lasers signals.

Keywords:

Semiconductor lasers, Mutual coupling, Injection pulse shaping, Injection current modulation, Chaotic dynamics.

Journal of College of Education for pure sciences(JCEPS)
Web Site: http://eps.utq.edu.iq/ Email: eps_tqr@yahoo.com
Volume 7, Number 2, May 2017

حركيـــات ليـزري شبــه موصــل متبادلـي الأقتـران

مشتاق عبيد عليوي[1]،حسن عبدالله سلطان[2], دعاء حسين هاشم[2], علي مهدي جخيم[3], جاسب عبدالحسين مشاري[2]

(1) قسم الفيزياء/ كلية العلوم/ جامعة ذي قار

(2) قسم الفيزياء/ كلية التربية للعلوم الصرفة/ جامعة البصرة

(1) مديرية التربية/ محافظة ذي قار. العراق

الخلاصــة:

نقدم في هذا البحث دراسة عددية للتصرف الحركي لليزري شبه موصل متبادلي الأقتران باستعمال انموذج رباعي المستويات والتحكم بشكل نبضة تيار الحقن لكل ليزر على حدة وعن طريق تضمين تيار حقن جيبي الشكل لكل ليزر.

أضفت النتائج المحصلة الى حركيات متنوعة في كافة الحالات المدروسة وإمكانية استخدامها جميعا في الأتصالات الآمنة خصوصا بعد مضاربة خرج الليزرين معا وفي جميع الحالات.

الكلمات المفتاحية: ليزر أشباه الموصلات، الأقتران المتبادل، السيطرة على نبضة الحقن، حركيات فوضوية.

Introduction:

Dynamical behavior of delay- coupled semiconductor lasers (SCLs) studies are of continuing interest for fundamental and technical curiosities. For the former SCLs are an excellent model systems for studying the properties of delay- coupled oscillators that occur in many systems, like complex networks [1], excitable layers [2], neural networks [3], etc.

The delay time arises naturally as a result of the finite propagation time of light from one laser to the other. The influence of time delay in the coupling becomes important when the delay introduced for example by the spatial distance of the individual oscillators is of the same order or larger than the characteristic frequencies of the oscillators [4].

In coupled SCLs system, an amplitude fluctuation in one laser leads to a carrier density fluctuation through amplitude- phase coupling or linewidth enhancement factor, α, in the same laser. The α - factor influences several fundamental aspects of all SCLs, such as linewidth, the chirp under current modulation and the mode stability [5].

In the present article we present results of numerical simulation studies of the effect of pulse shaping of the injection of SCLs dynamics on each laser alone together with the modulation of injection current on the dynamics of each and both lasers at the same time.

Mathematical Model:

The mutually coupled semiconductor lasers were studied numerically by number of authors using varieties of theoretical models [6-12]. The following set of equations describe the time evolution of the complex, slowly varying electric field of laser (1) and laser (2), E_1 and E_2 respectively, and the carriers number in both lasers, N_1 and N_2 respectively [13]. Both lasers beams enter each laser via the rare mirror of each laser while the laser output leave each laser via the output coupler of each laser, is shown in fig. (1):

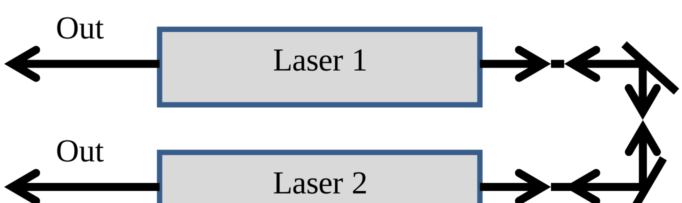


Fig. (1): Two coupled semiconductor lasers.

$$\dot{E}_1(t) = \frac{1}{2}(1 + i\alpha)[G_{1-}\gamma]E_1 + kE_2(t - \tau) \qquad \ldots(1)$$

$$\dot{E}_2(t) = \frac{1}{2}(1 + i\alpha)[G_{2-}\gamma]E_2 + kE_1(t - \tau) \qquad \ldots(2)$$

$$\dot{N}_1(t) = \frac{I}{q} - \gamma_e N_1 - G_1|E_1|^2 \qquad \ldots(3)$$

$$\dot{N}_2(t) = \frac{I}{q} - \gamma_e N_2 - G_2|E_2|^2 \qquad \ldots(4)$$

α ,is the linewidth enhancement factor, γ is the cavity losses, k is the coupling rate between the two lasers, τ is the coupling or delay time, I is the injection current of each laser ($I_1=I_2=I$), q is the electronic charge, γ_e is the carrier decay rate,G_1 and G_2 are taken as follows:

$$G_1 = \frac{g(N_1 - N_t)}{1+\epsilon|E_1|^2} \qquad \ldots(5)$$

$$G_2 = \frac{g(N_2 - N_t)}{1+\epsilon|E_2|^2} \qquad \ldots(6)$$

where g is the differential gain, N_t is the carrier value at transparency and ϵ is the gain saturation parameter. The coupling delay terms $kE_2(t - \tau)$ and $kE_1(t - \tau)$ are added to equations (1) and (2) respectively.

The dot over E_1, E_2, N_1, N_2 represent differentiation with time.

In the case of injection current modulation, we have used the sinusoidal form of modulation as follows:

$$\text{For laser 1: } I_1 = I_{1dc} + m_1 . \sin(2\pi f t) \qquad \ldots(7)$$

$$\text{For laser 2: } I_2 = I_{2dc} + m_2 . \sin(2\pi f t) \qquad \ldots(8)$$

where $I_{1,2dc}$ are the constant parts of the injection current in laser (1) and (2) respectively, m_1 and m_2 are the ac parts or modulation depth of both lasers injection currents respectively and f is the modulation frequency.

Simulation results:

To obtain results we have used the fourth order Runge- Kutta method together with Matlab system making use of parameter values given in table (1) for lasers parameters and table (2) for the injection current (I) and solved the set of equations (1-4).Pulse shape is taken as:

$$I = I_o e^{(\frac{t-a}{b})^c} \qquad \ldots(9)$$

where I_o is the injection current, a,b and c are positive numbers.

Table (1): Parameters values used in the simulation.

Description	Parameter	Value	Units
linewidth enhancement factor	α	3.5	-
cavity loss	γ	288	ns^{-1}
differential gain	g	3.2×10^{-6}	ns^{-1}
coupling rate	k	23	ns^{-1}
carrier decay rate	γ_e	1.66	ns^{-1}
carrier value at transparency	N_t	1.5×10^{8}	-
gain saturation parameter	ϵ	5×10^{-7}	-
electronic charge	q	1.6×10^{-19}	Coul
delay time	τ	4.75	ns

Table (2): Modulation of injection current parameters.

I_{dc}	0.065	0.15	0.65					
m	0.01	0.1						
f(Hz)	10^{6}	10^{7}	10^{8}	10^{9}	10^{10}	10^{11}	10^{12}	10^{13}

The resultes are devided into two parts, in the first the effect of pulse shape on the dynamics of intensity produced from the two lasers are studied and in the second the effects of injection current modulation on the intensity from both lasers are studied too.

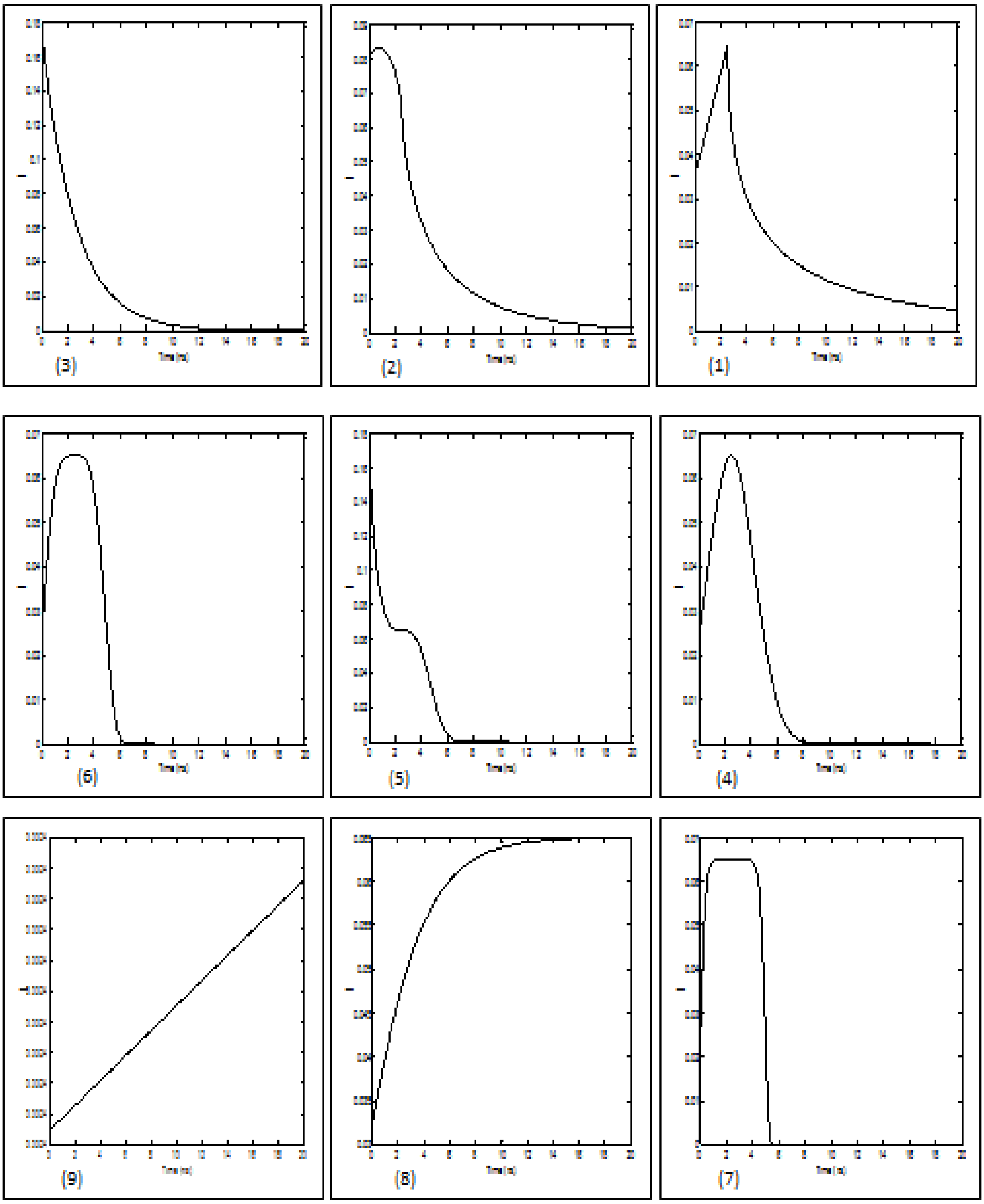
Part one: input pulse shapes are presented in fig.(2) where it can be seen the varieties of injection pulses that can be produced electronically depending on the parameters (a) and (b) which represents time in unit of nanosecond and the third parameter c wich is dimensionless.

These pulses were used to represents the injection current of both lasers, to laser 1 first only then to laser 2 only, the results of both are shown in fig.(3) and fig.(4)

respectively. The application of these pulses have led to varieties of laser signals in comparison to the case of dc injection current to both lasers (not shown). This happen to laser 1 only then to laser 2.

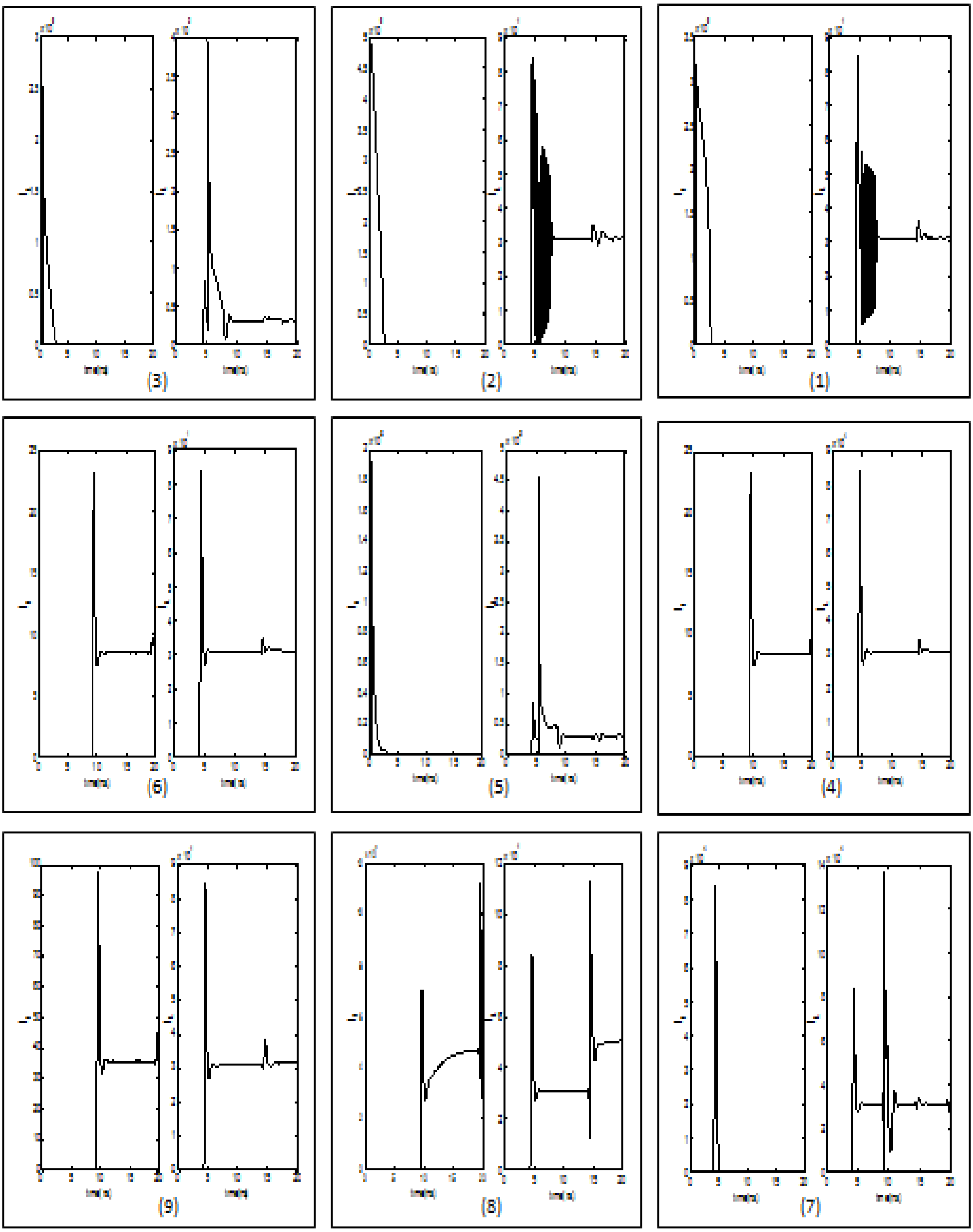
When this method is applied to both lasers at the same time should lead to new complexsignals, which can be used in various applications especially in communications.

Part two: the dynamics of the two lasers are investigated under the injection current modulation given in equations (7) and (8). Each injection current which vary with time since the ac part of it is written in a sinusoidal form. Figs.(5-7) shows varieties of dynemics by modulating the injection current of laser 1 only while figs. (8-11) are for the modulating of laser 2 current only. Even for low dc current and ac one both lasers intensity shows chaos in the frequency range $10^{12} - 10^{14} Hz$ (fig 5(c,d,e)). Another forms of laser intensity appears for high I_{ac} values and frequncy range ($10^{7} - 10^{14} Hz$) and even for higher I_{dc} and I_{ac}. All this occurs for both lasers signals. Self-pulsing occurs too (fig 5(a), fig6(a), fig7(c and d) and so on in all figures). In the two modulation cases i.e for laser 1 or laser 2 alone each times both lasers signal affected alot by the modulation of the injection current in comparison with no modulation case.

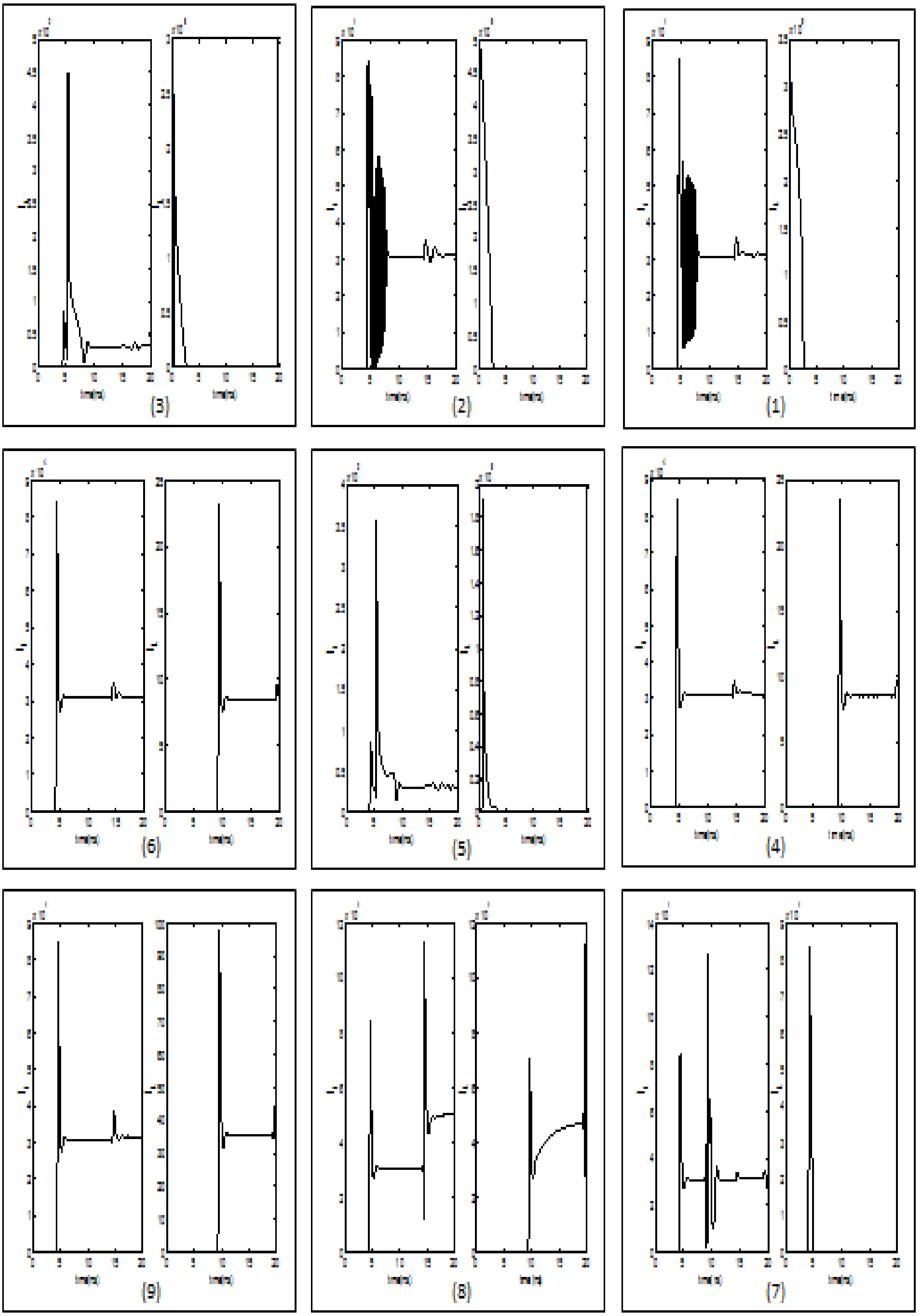


Fig(2): Injection pulse shape for the combination(a,b,c):

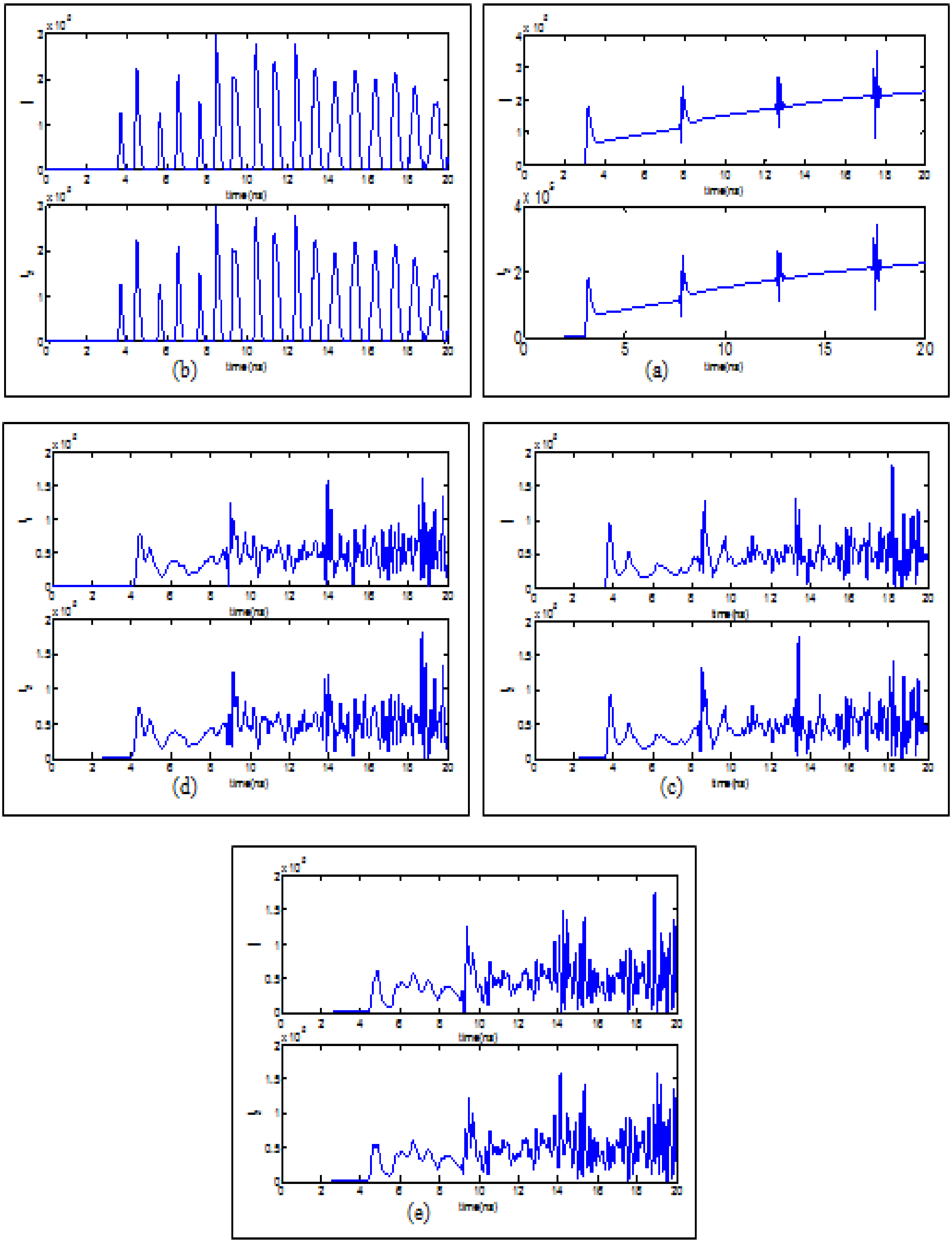
(1): $(2.49 \times 10^{-9}, 2.5 \times 10^{-9}, 0.5)$, (2): $(2.49 \times 10^{-9}, 2.5 \times 10^{-9}, 0.7)$, (3): $(2.49 \times 10^{-9}, 2.5 \times 10^{-9}, 1)$, (4): $(2.49 \times 10^{-9}, 2.5 \times 10^{-9}, 2)$, (5): $(2.49 \times 10^{-9}, 2.5 \times 10^{-9}, 3)$, (6): $(2.49 \times 10^{-9}, 2.5 \times 10^{-9}, 4)$, (7): $(2.49 \times 10^{-9}, 2.5 \times 10^{-9}, 30)$, (8): $(2.49 \times 10^{-7}, 2.5 \times 10^{-7}, 90)$, (9): $(2.49 \times 10^{-1}, 2.5 \times 10^{-1}, 90)$.



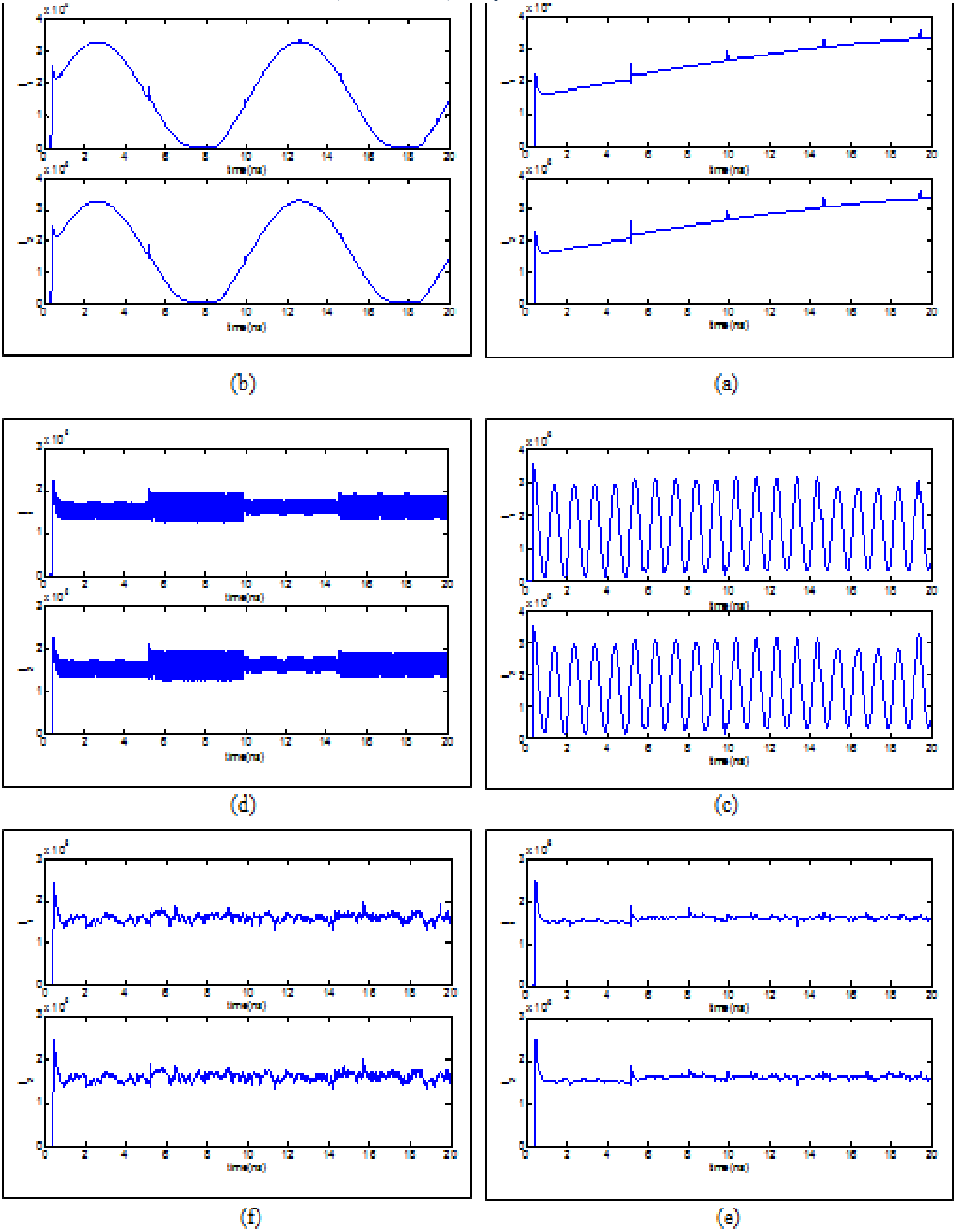
Fig(3): In each figure(1-9), left coloum is the, laser(1) signal, right coloum, laser (2) signal for parameters values given table (1) with injection signal shown in fig.(2) in same sequence as the input current signal. In injection current given in eq(3) only.



Fig(4): Same as in fig.(3) but injection current of laser 2 given in eq(4) only.

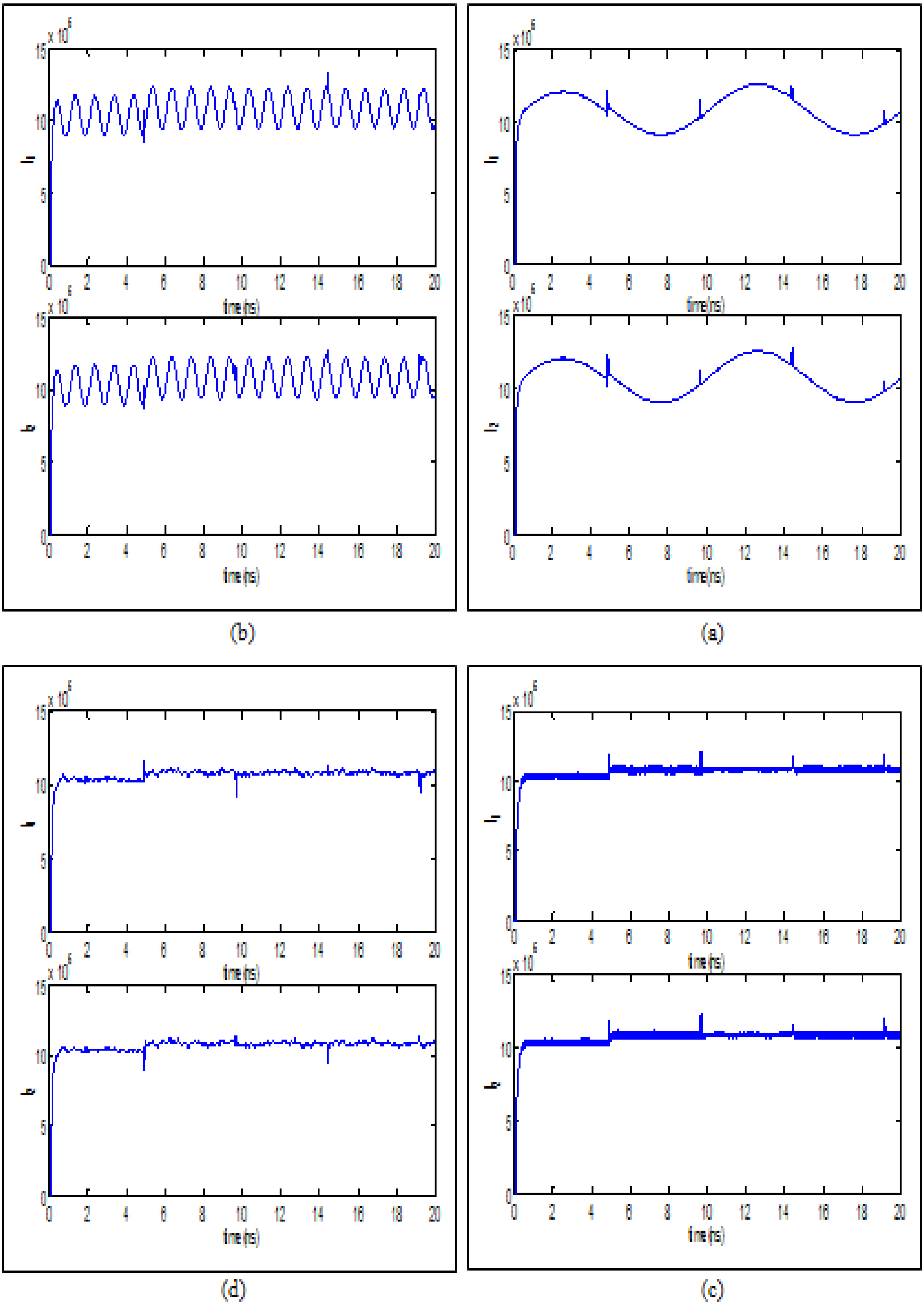


Fig(5) : In each figure, top is the laser 1 signal, botton is laser 2 signal as a result of frequency modulating the current in equation(3) for constant dc injection current=0.065 and injection depth m=0.01 and (a) $f(H_z)=10^7$, (b) $f(H_z)=10^9$, (c) $f(H_z)=10^{12}$, (d) $f(H_z)=10^{13}$, (e) $f(H_z)=10^{14}$.

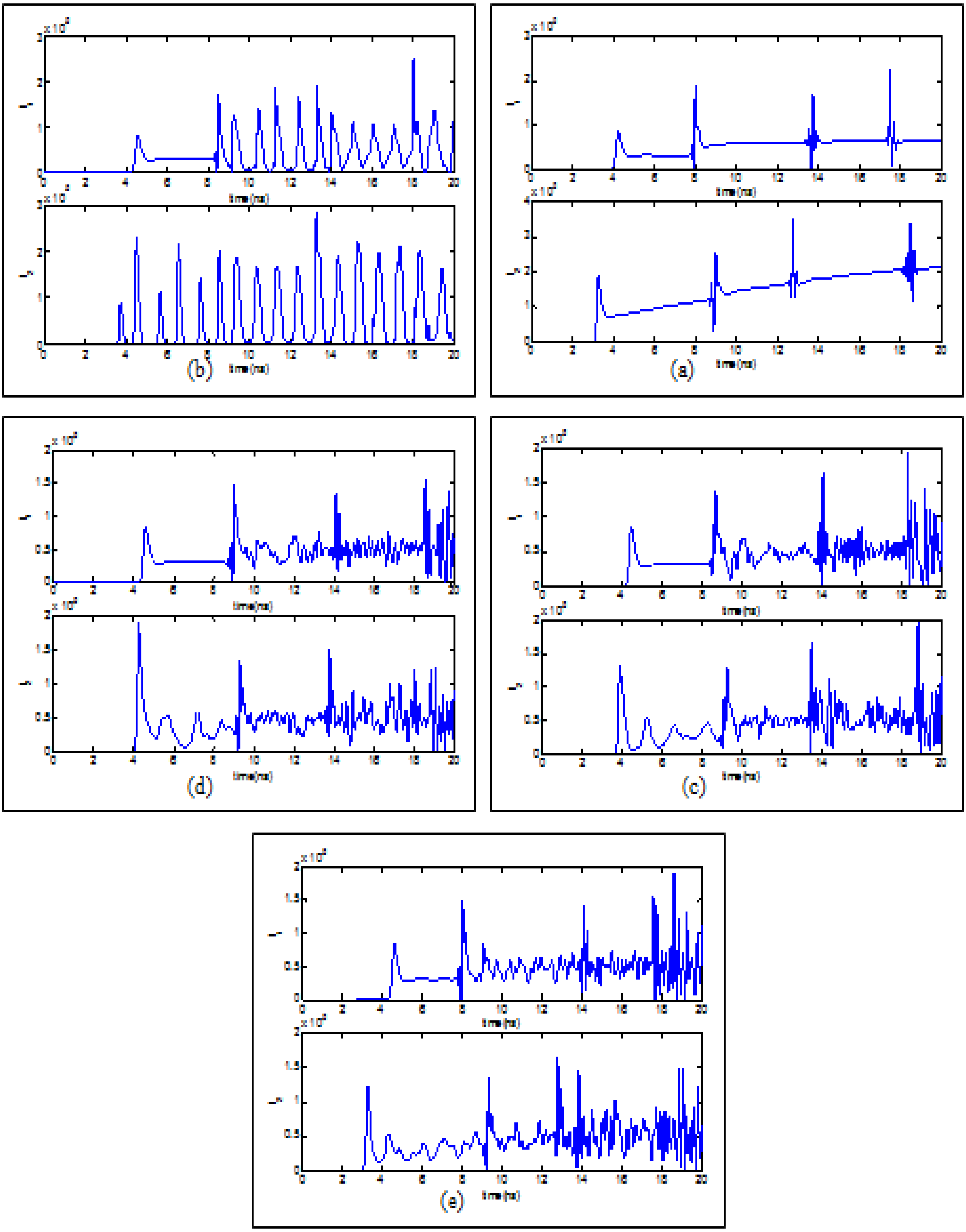


Fig(6) : The same as in fig.(5) but for dc current $I = 0.15$ and m=0.1 and (a) f(H_z)=10^7 , (b) f(H_z)=10^8 , (c) f(H_z)=10^9 , (d) f(H_z)=10^{10} , (e) f(H_z)=10^{12} , (f) f(H_z)=10^{14}.

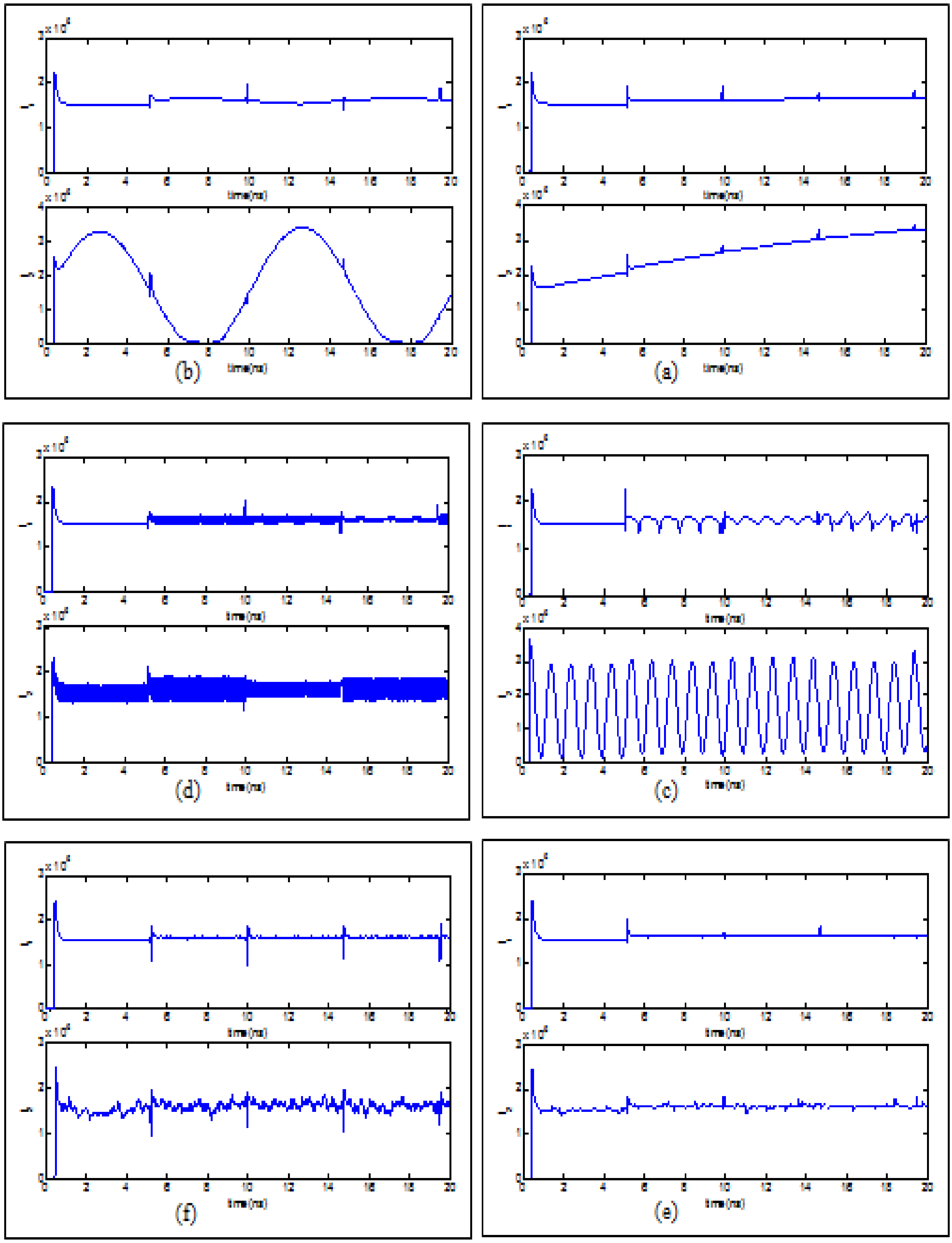
Journal of College of Education for pure sciences(JCEPS)
Web Site: http://eps.utq.edu.iq/ Email: eps_tqr@yahoo.com
Volume 7, Number 2, May 2017



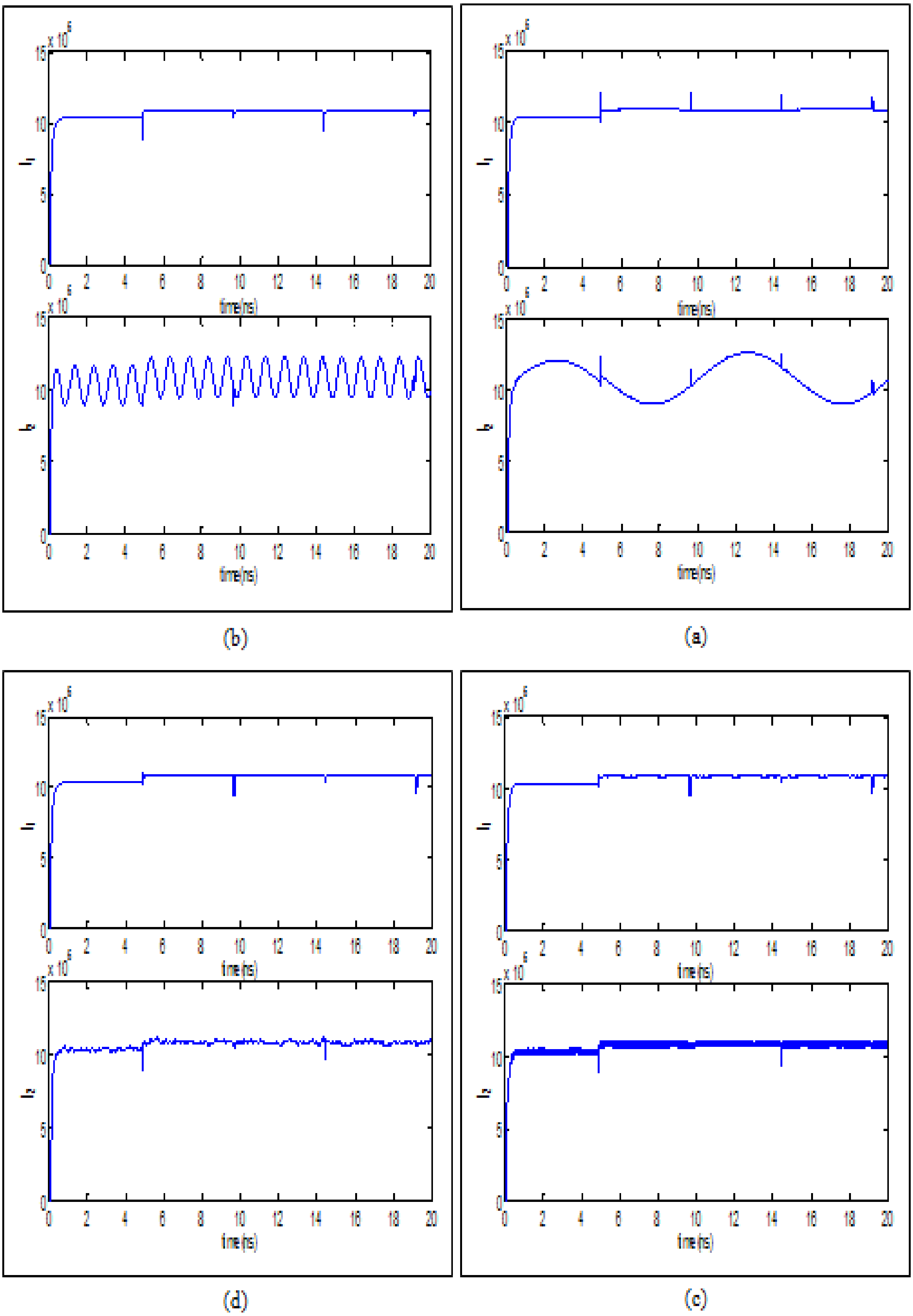
Fig(7) : Same as in fig.(5) but dc current I = 0.65 and m=0.1 and (a) f(H_z)=10^8 , (b) f(H_z)=10^9 , (c) f(H_z)=10^{10} , (d) f(H_z)=10^{14}.



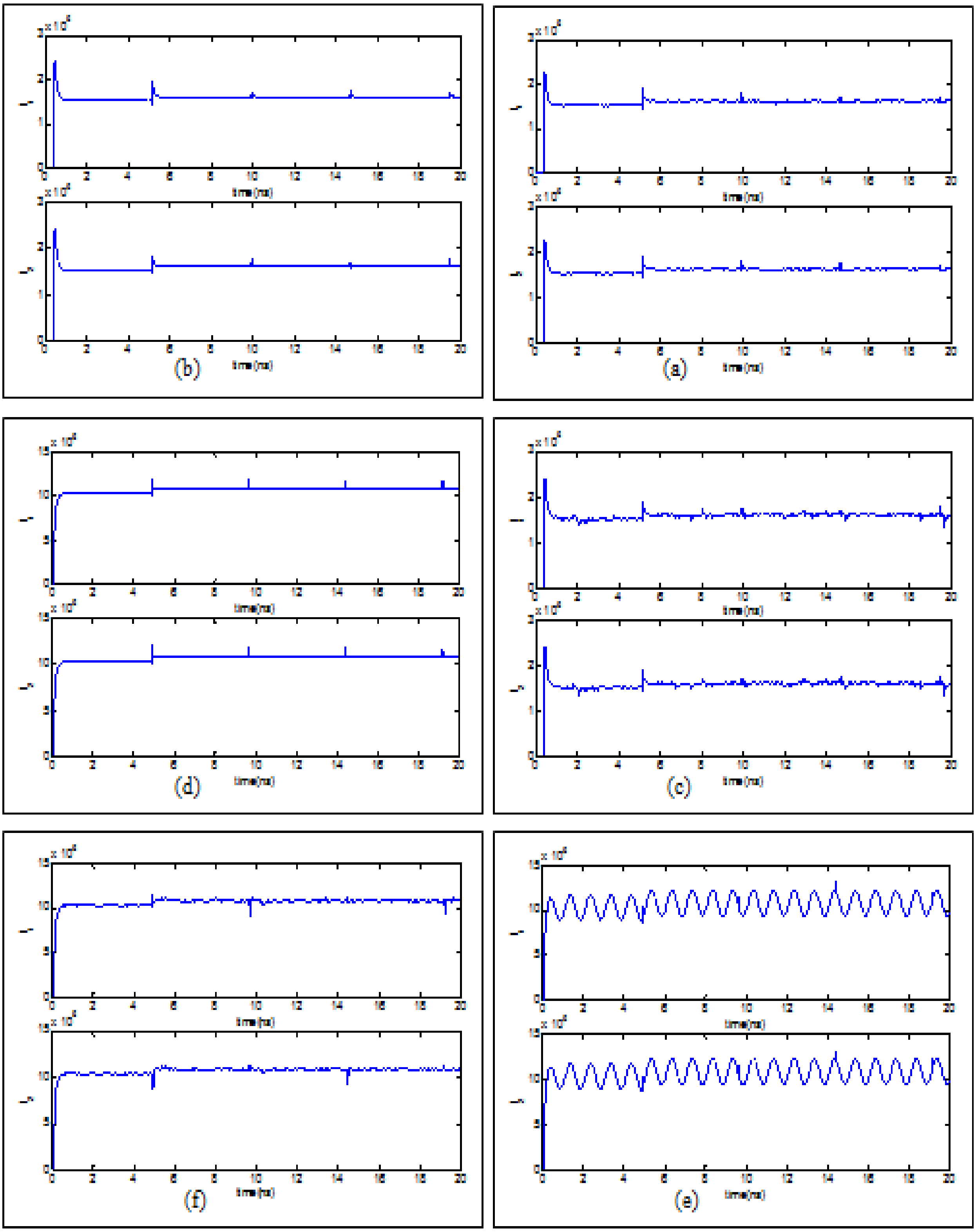
Fig(8) : Same as in fig.(5) but modulating the injection current for laser 2 in equation(4) only and $I = 0.065$, m=0.01 and (a) f(H_r)=10^7 , (b) f(H_r)=10^9 , (c) f(H_r)=10^{12} , (d) f(H_r)=10^{13} , (e) f(H_r)=10^{14} .



Fig(9) : Same as in fig.(8) for $I_{dc} = 0.15$, m=0.1 and (a) $f(H_z)=10^7$, (b) $f(H_z)=10^8$, (c) $f(H_z)=10^9$, (d) $f(H_z)=10^{10}$, (e) $f(H_z)=10^{12}$, (f) $f(H_z)=10^{14}$.



Fig(10) : Same as in fig.(9) but for $I_{dc} = 0.65$, m=0. 1 and (a) f(H_z)=10^{8} , (b) f(H_z)=10^{9} , (c) f(H_z)=10^{10} , (d) f(H_z)=10^{14}.



Fig(11) : Same as in fig.(10)but for I_{dc} = 0.15 , m=0. 01 and (a) f(H_z)=10^{11} , (b) f(H_z)=10^{12} and for I_{dc} = 0.15 and m=0. 1 (c) f(H_z)=10^{11} , (d) f(H_z)=10^{12} and for I_{dc} = 0.65 , m=0. 01 and (e) f(H_z)=10^{11} , (f) f(H_z)=10^{12}.

Conclusions:

Introducing of various types of injection current signal to two mutually coupled semiconductor lasers leds to new dynamics of the high intensity extracted from both lasers. Modulating the injection current of each laser alone leds to dynamics in the shape of self-pulsing or breathing and chaos.

References:

1. Ung ChoeC., DahmsT., HovelP. and SchollE., (2011), "Control of synchrony by delay coupling in complex networks", Disc. and Dyna. Syst.,292-301.
2. Jian-PingL., Lian- ChunY., Mei- ChenY. and YongC., (2012), "Zero- lag synchronization in spatiotemporal systems with long range delay couplings", Chin. Phys. Lett., 24, 050501- 1.
3. GalloL. L., MirassoC. R., AtienzaM., Crespo- GarciaM., and CanteroJ. L., (2011), "Theta band zero- lag long- range cortical, synchronization via Hippocampal dynamical Relaying", PLOS OVE e 17756, 6, 1- 9, e17756.
4. Sui LiS. and Chun ChanS., (2015), "Chaotic delay signature suppression in a semiconductor laser with frequency-detuned grating feedback", IEEE Sel. Top. Quant. Electron. , 21, 1800812.
5. AgrawalG. P. and BowdenC. M., (1993), "Concept of linewidth enhancement factor in semiconductor lasers: Its usefulness and limitations", IEEE Photon Techn. Lett, 5, 640-642.
6. ThornburgK. S., Jr, MollerM., RoyR., CarrT. W., LiR. –D and ErneuxT., (1997), "Chaos and coherence in coupled lasers", Phys. Rev. E, 55, 3865-3869.
7. HeilT., FisherI., ElsasserW., MuletJ. and MirassoC. R., (2001), "Chaos synchronization and spontaneous symmetry- breaking in symmetrically delay-coupled semiconductor lasers", Phys.Rev. Lett., 86, 795- 797.
8. LocquetA., MasollerC., MegretP. and BlondelM., (2002), "Comparison of two types of synchronization of external- cavity semiconductor lasers", Opt. Lett., 27, 31- 33.
9. ErzgraberH., LenstraD., KranskopfB., WilleE., PeilM., FischerI. and ElsasserW., (2005), "Pure frequency oscillations of semiconductor lasers with filtered optical feedback", Opt. Commun., 255, 286- 296.

10. JiangN., panj W. L. Yan, LuoB., ZhangW., XiangS., YangL. and ZhengD., (2010), “Chaos synchronization in mutually coupled semiconductor lasers driven by a third laser”, J. Lightwave Techno., 28, 1978- 1985.
11. Zamora- MuntJ., MasollerC. and Garcia- OjalvoJ., RoyR., (2010), “Crowd synchrony and quorum sensing in delay- coupled lasers”, Phys. Rev. Lett., 105, 264101-1.
12. Sultan H. A., Al- TamimiK. A., AhmedA. R. and EmsharyC. A., (2013), “The output dynamics of mutually coupled semiconductor face to face laser system under noise effect”, J. Bas. Res. (Science), 39, 13- 27.
13. ImranS. M. S., YamadaM., KuwamuraY., (2012), “A theretical analysis of the optical feedback noise based on multimode model of semiconductor lasers”,IEEE J. Quan Elect. 48, 521-527.