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The Dynamics of Semiconductor Laser under Optical Feedback

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Abstract:

The dynamical behavior of semiconductor laser in the present of optical feedback is studied by varying number of control parameters that appeared in the adopted theoretical model viz, linewidth enhancement factor , pump level , delay time and feedback level . Various dynamics seen to occur such as steady state, periodic, aperiodic and chaotic in the output of the semiconductor laser.

Keywords: Semiconductor laser, Optical feedback, Periodics, Chaos

حركيات ليزر شبه الموصل تحت تأثير التغذية العكسية البصرية

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الخلاصة

درس التصرف الحركي لليزر شبه الموصل بوجود التغذية العكسية البصرية عن طريق تغيير عدد من عوامل السيطرة الواردة في الأنموذج النظري المقتبس وهي معامل تعزيز عرض الخط و مستوى الضخ وزمن التأخير ومستوى التغذية العكسية . لوحظت حركيات مختلفة في خرج ليزر شبه الموصل مثل التصرف المستقر والدوري واللا دوري والفوضوي .

Introduction

In 1980, Lang and Kobayashi [1] presented a theoretical model that describe the dynamics of a single mode semiconductor lasers (SCLs) under the effect of coherent optical feedback (OFB). Various types of feedback techniques have been applied into SCLs, such weak OFB [2], dispersive OFB [3], filtered OFB [4], optoelectronic FB[5], phase-conjugated FB[6], distributed FB [7], active OFB [8], nonlinear OFB [9] and negative optoelectronic feedback [10]. These techniques were applied for various objectives such as controlling nonlinear dynamics, enhancing nonlinear dynamics, creating spectral as well as time phenomena, stabilization, noise amplitude reduction, enhancing chaos, etc, in types of semiconductor lasers.In this article we study the dynamics of semiconductor lasers subjected to optical feedback based on a dimensionless model by varying the line-width enhancement factor, α, pump above threshold, P , delay time, θ , and feedback rate, Γ .

Theoretical model

The laser equations derived by Erzgraber et al. [4,11] consisted of three equations describing the temporal behavior of the laser field in the cavity, E , the field feedback into the laser, F , and the inversion, N , which reads:

$$\dot{E} = (1 + i\alpha) NE + \Gamma F \quad ....(1a)$$

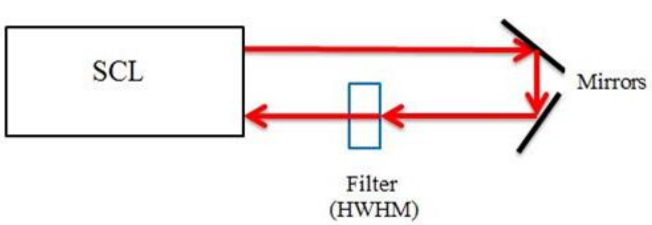
$$\dot{F} = \lambda[E^*(s-\theta) - F] \quad ....(1b)$$

$$\dot{N} = \frac{1}{T}[P - N - (1+2N)|E|^2] \quad ....(1c)$$

α is the line-width enhancement factor, λ is the filter width, half width at half maximum (HWHM) , added to the feedback circuit shown in fig.(1), θ is the normalized delay time, T is the ratio of carrier to photon life times, and P is proportional to the ratio $(\frac{J - J_{th}}{J_{th}})$ where J is the injection current of the semiconductor laser and J_{th} is its threshold injection current is the feedback rate.s is the normalized time , E* is the complex conjugate of E and i is the complex number. Generally SCLs have α values that vary between 2-7 . Table (1) gives the parameters values of the various parameters appeared in equations (1).

Table 1. Parameters values used in the simulations

Symbol	Parameter	Value
α	Line-width enhancement factor	2-6
T	Ratio of carrier to photon life times	100-200
P	Pump above threshold	3-5
θ	Delay time	50-200
Γ	Feedback rate	0.1-0.3
λ	Filter width	6.7×10^{-4}



Fig(1): Schematic of the semiconductor laser with external optical feedback

Results and discussion

To study the dynamics of the semiconductor laser under the effect of feedback the set of equations (1) was solved using the fourth order Runge-Kutta numerical method with the aid of MATLAB system, choosing certain initial conditions and the parameters values given in table 1.

The results are given in the form of variation of the field $|E|$ against the normalized time s, inversion , N , against the field $|E|$ to obtain attractors, and $|E|$ versus the field feedback to the laser cavity $|F|$.

Figs (2-4) shows the effect of pump above threshold, P , for $\alpha=2,\ \theta=50,\ \Gamma=0.1$ where it can be seen there is no effect occur for $P=3-5$.

Figs (5-7) shows the effect $\theta=100-200$ for $\alpha=2,\ P=3,\ \Gamma=0.1$, on the laser dynamics ,once again no effect appeared.

Figs (8-10) shows the effect of $\Gamma=0.1-0.3$ for $\alpha=2,\ P=3,\ \theta=50$. No effect can be noticed again.

Figs (11-13) shows the effect of $P=3-4,\ \alpha=4,\ \theta=50,\ \Gamma=0.1,$ it can be seen the effect of increasing the linewidth enhancement factor $\alpha=4$ which is believed to be responsible for the nonlinearities in all lasers especially semiconductor one. A transient region is followed by a steady state output which is followed by high frequency oscillation region of high amplitude oscillating above $|E|=2$ as can be seen in all (11-13) figures. As P increased from 3 to 5 the steady state part of the output delayed , i.e. the oscillatory behavior started at s=1000 for P=3, at s= 1100 for $P=4$ and s =1400 for P=5 .

As θ is varied through 100 – 200 and $\alpha=4,\ P=3$ and $\Gamma=0.1$ the output have the same shape as the previous case (figs (14-16)) but the oscillatory part of the output started at s = 1050 for the three values chosen of θ .

For $\alpha=4,\ P=3,\ \theta=50$ while $\Gamma=0.1-0.3$ shows a reduction in the steady state part of the output followed by sever and aperiodic oscillation of chaotic frequency and amplitude as can be seen in figs (17-19).

As α is increased to 6 keeping $\theta=50$ and $\Gamma=0.1$ and increasing P from 3 to 5 the chaotic state is reduced with the increased of steady state region which occurs at s=600 at P=3 ,s=750 at $P=4$ and s=1000 at $P=5$ respectively, as shown in figs (20-22).

As θ changed from 100 to 200 and $\alpha=6,\ P=3,\ \Gamma=0.1$ the output is in form of transient region and a steady one followed by an oscillatory part breaks into segments of different frequencies separated by short steady state parts as can be seen in figs (23-25). Such behavior is enhanced for $\alpha=6,\ P=3,\ \theta=50$ and $\Gamma=0.1-0.3,$ and the steady state part length is reduced as can be seen in figs (26-28). When comparing figs (2-4) with (11-13) and (20-22) we noticed that varying $P=3-5$ does not affect the behaviors very much. By comparison of figs (5-7) with (8-10) and (23-25) and varying $\theta=100-200,$ the effects are not the same i.e as θ increased the dynamics became complex. The same trend occurs when increasing Γ from 0.1 to 0.3 as one compares figs (8-10) with figs. (17-19) and figs. (26-28) except that the effect is more severer than the previous cases. Any semiconductor laser with delayed optical feedback generally believed to be one of the important systems used to study the nonlinear dynamics. Since it represents an example of delay systems extensively studied long time ago in different directions. The feedback with existence of nonlinearities as the case shown in the set of equations (1) can lead to a new direction in research where it have been proved the generation of low and high frequency oscillations and coherence collapse both experimentally and theoretically [12]. All the control parameters examined have from the physical point of view number of effects on the dynamics of semiconductor lasers viz, power drop-out, mode hoping [13], phase variation etc.

Conclusions

The semiconductor laser output under the effect of optical feedback shows various types of dynamics such as steady state , periodic , aperiodic and chaotic ones through the variation of linewidth enhancement factor , pump level ,delay time and feedback rate.

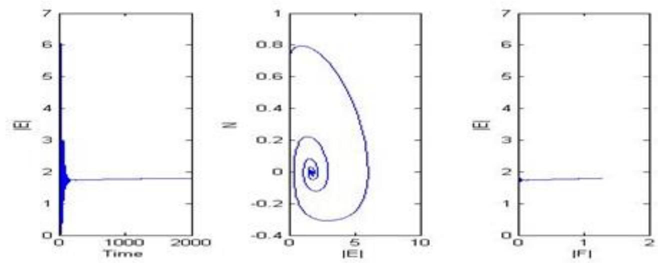


Fig.2: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.1$

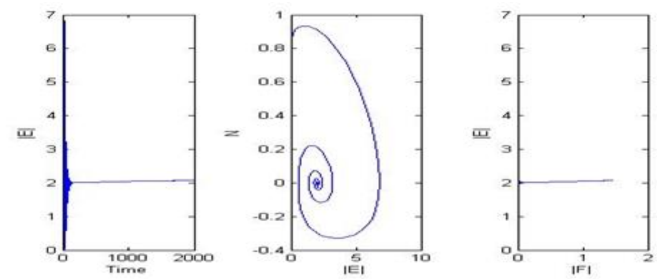


Fig.3: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 4$, $\theta = 50$ *and* $\Gamma = 0.1$

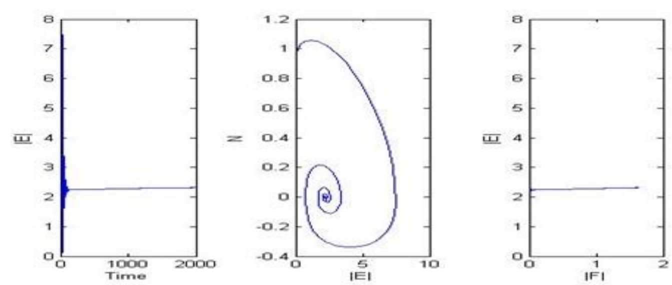


Fig.4: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 5$, $\theta = 50$ *and* $\Gamma = 0.1$

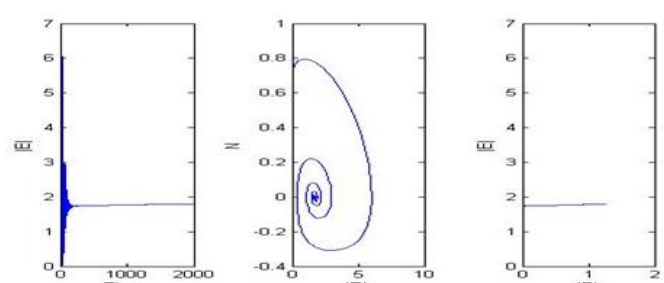


Fig.5: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 3$, $\theta = 100$ *and* $\Gamma = 0.1$

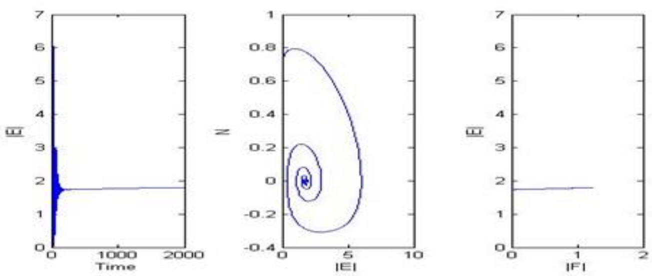


Fig.6: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 3$, $\theta = 150$ *and* $\Gamma = 0.1$

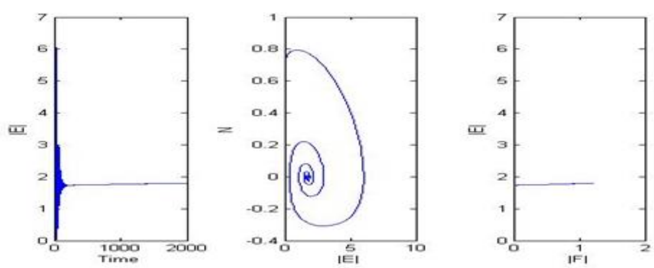


Fig.7: From left to right, E vs time(s), N vs $|E|$ and E vs $|F|$ for $\alpha = 2$, $P = 3$, $\theta = 200$ *and* $\Gamma = 0.1$

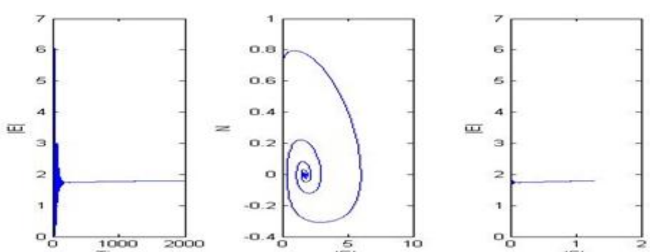


Fig.8: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.1$

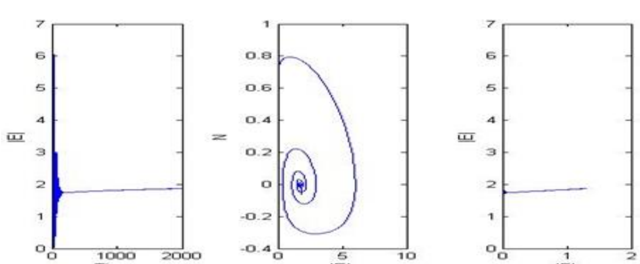


Fig.9: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.2$

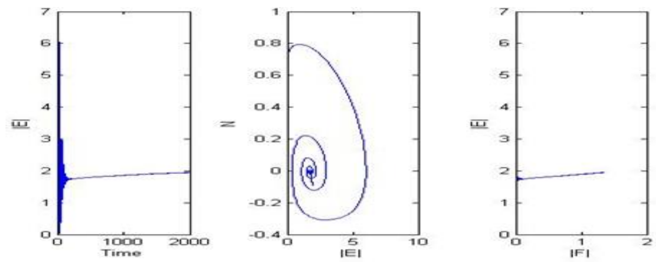


Fig.10: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.3$

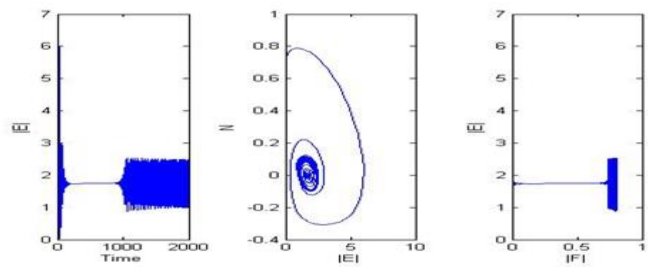


Fig.11: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 4$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.1$

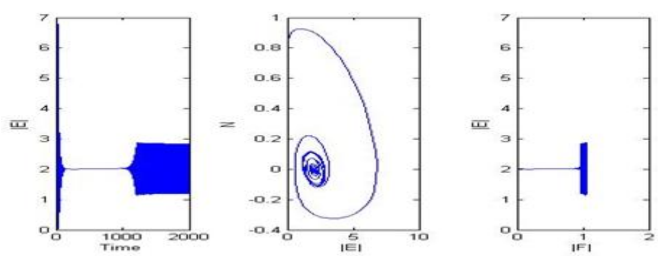


Fig.12: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 4$, $P = 4$, $\theta = 50$ *and* $\Gamma = 0.1$

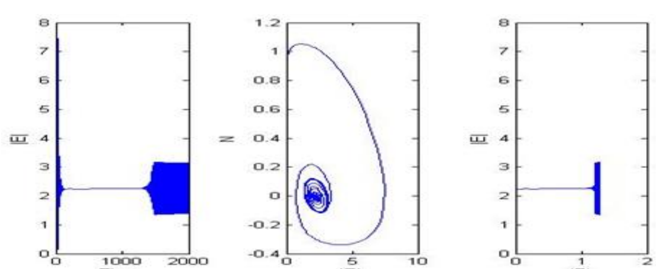


Fig.13: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 4$, $P = 5$, $\theta = 50$ *and* $\Gamma = 0.1$

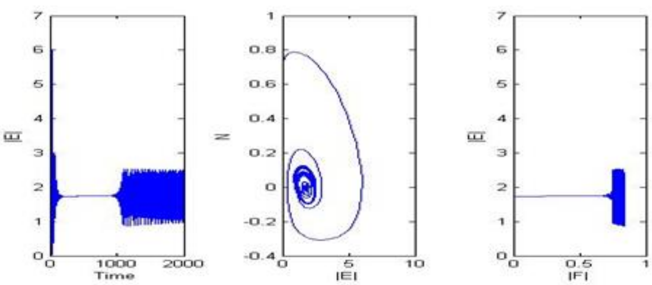


Fig.14:From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 4$, $P = 3$, $\theta = 100$ *and* $\Gamma = 0.1$

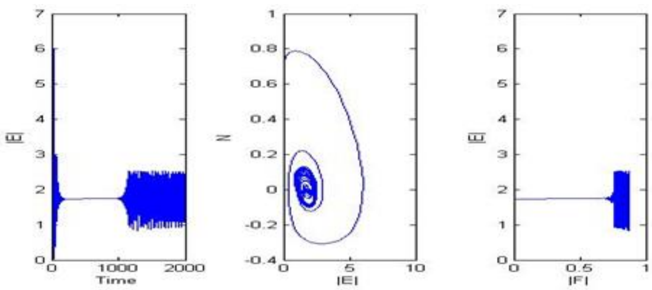


Fig.15: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 4$, $P = 3$, $\theta = 150$ *and* $\Gamma = 0.1$

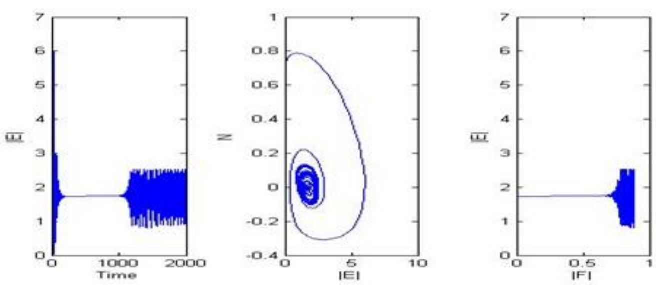


Fig.16: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 4$, $P = 3$, $\theta = 200$ *and* $\Gamma = 0.1$

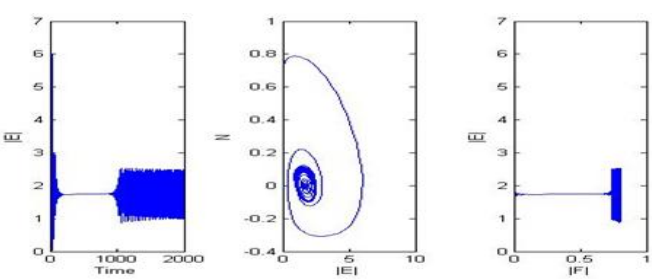


Fig.17: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 4$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.1$

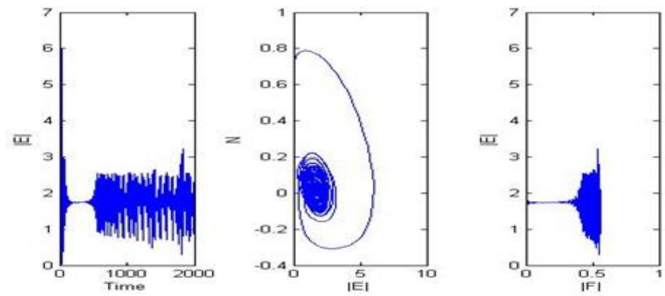


Fig.18: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 2$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.3$

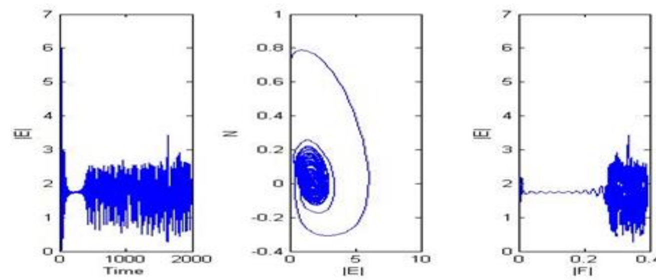


Fig.19: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 4$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.3$

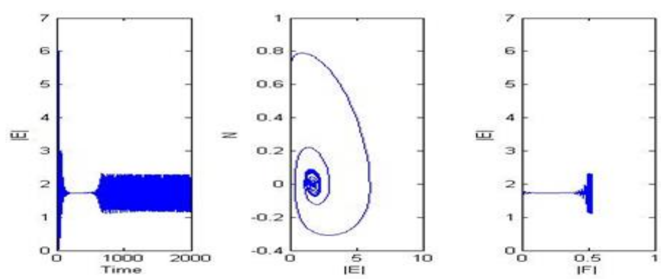


Fig20: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.1$

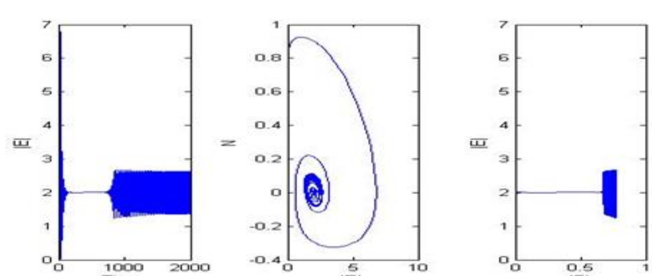


Fig.21: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 4$, $\theta = 50$ *and* $\Gamma = 0.1$

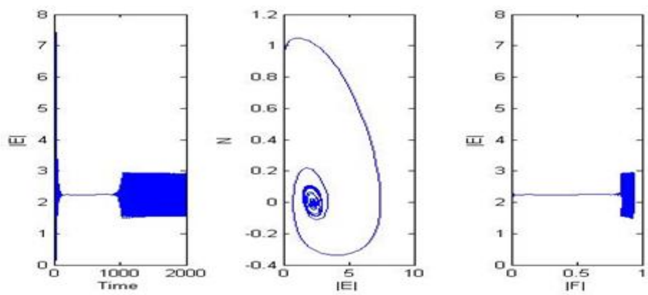


Fig.22: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 5$, $\theta = 50$ *and* $\Gamma = 0.1$

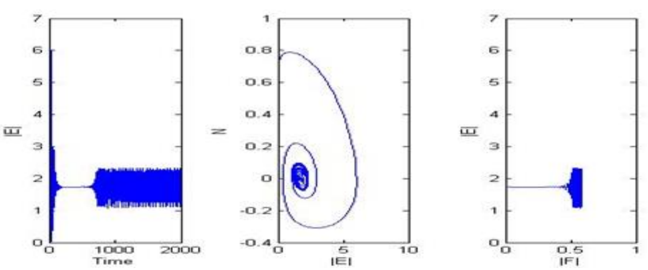


Fig.23: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 3$, $\theta = 100$ *and* $\Gamma = 0.1$

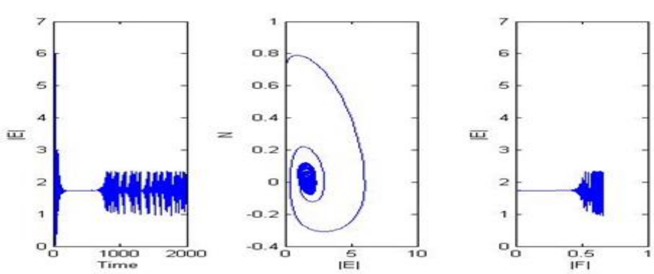


Fig.24: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 3$, $\theta = 150$ *and* $\Gamma = 0.1$

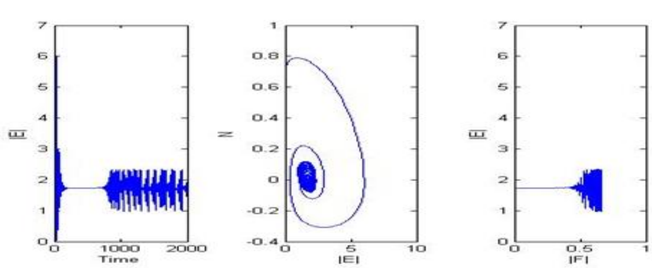


Fig25: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 3$, $\theta = 200$ *and* $\Gamma = 0.1$

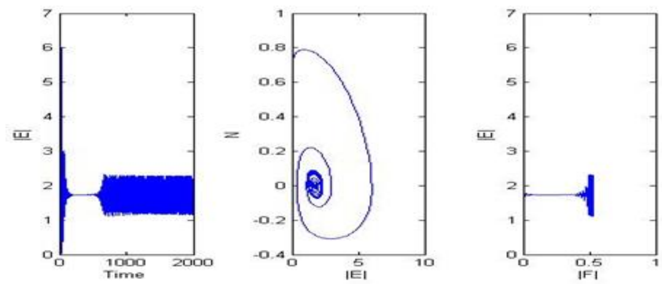


Fig.26: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.1$

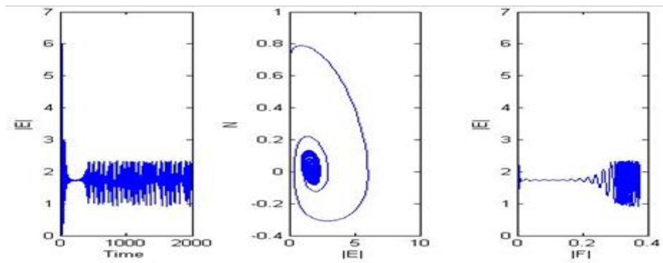


Fig.27: From left to right, $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.2$

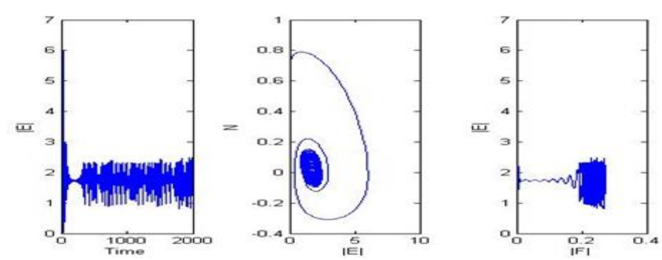


Fig.28: From left to right $|E|$ vs time(s), N vs $|E|$ and $|E|$ vs $|F|$ for $\alpha = 6$, $P = 3$, $\theta = 50$ *and* $\Gamma = 0.3$

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