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Frequency-Frequency Interactions in Chaos Communications

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Abstract

In this research, the frequency-frequency interactions in chaotic systems has been experimentally and numerically studied. We have injected two frequencies on chaotic system where one of these frequencies is modulated with chaotic waveform and the other is untiled as a scanning frequency to find modulating frequency. It is observed that the Fast Fourier Transformation (FFT) peaks amplitude increased when the value of the two frequencies are matched. Thus, the modulating frequency could be observed, this leads to discover a new method to detect the modulating frequency without synchronization.

Keyword: chaotic spiking, chaos communication, frequency-frequency interactions, without synchronization.

تفاعل تردد-تردد في الاتصالات الفوضوية

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الخلاصة

في هذا البحث، تمت دراسة تفاعل التردد-التردد في الأنظمة الفوضوية. لقد قمنا بحقن ترددين على نظام فوضوي حيث أن أحدهما يكون مضمن مع شكل الموجة الفوضوية، والآخر في شكل تردد ماسح للعثور على تردد المضمن. يزداد ارتفاع سعة (Fast Fourier Transformation FFT) عندما تتم مطابقة قيمة التردد. وبالتالي، يمكن ملاحظة تردد المضمن، وهذا يؤدي إلى إيجاد طريقة جديدة لاكتشاف تردد المضمن بدون التزامن.

Introduction

Chaos theory is a branch of mathematics focusing on the dynamical systems behavior which are highly sensitive to initial conditions [1]. Chaotic communication is the application of chaos theory, which aims to provide security in transfer of the information that is made through the telecommunications technologies [2]. Currently, the secure communication is most widespread

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application which used the chaotic waves (as carriers) of information are potentially advantageous compared to traditional communications strategies [3, 4].

The chaotic security is depending on the complex dynamical behaviors which provide by chaotic systems [5-7]. Several characteristics of chaotic dynamical behavior like as complex behavior [8], dynamics like noise has spread spectrum, are using for data encryption [5]. The chaotic waveform shape that works as an information carrier (traditional sinusoidal carrier), provides the possibility of enhancing privacy in communications [9, 10]. Recently, the chaotic synchronization and the chaotic secure communication have received increasing attention [11-15]. The synchronization of chaotic laser systems plays an important role in chaotic communications [16-20]. As in ordinary communication, the specific frequency carrier is modulated with the message and transmitted. The radio receiver must be tuned to the particular frequency of the carrier to recover the message, the same way in the optical communication, the received information can be recovered from an optical chaotic carrier by synchronization or tuning to chaotic dynamics of the transmitter [21-23].

The aim of this research is to enhance the chaotic communication security using two frequencies coupled with the carrier without synchronization. While, most of researches are concentrated on chaotic synchronization in the secure communication where these systems need to two chaotic oscillators as a transmitter (i.e. master) and receiver (i.e. slave), the purpose of synchronization is the detection of the message sent through the chaotic waveforms.

Physical model

The ac-coupled opto-electronic feedback method is introduced two benefits, firstly, adds the third much slower time-scale to create the third degree at freedom. The intensity of photons S and the population inversion N are evolving according to the rate equations of semiconductor laser this is usual signal-mode [3] are modified by S.F Abdalah [9]:

$$\frac{\partial x}{\partial t} = x(y - 1) + \gamma y \quad (1)$$

$$\frac{\partial y}{\partial t} = \gamma(\delta_0 - y + \omega/(1 + s\omega) - xy) \quad (2)$$

$$\frac{\partial \omega}{\partial t} = -\varepsilon(\omega + x) \quad (3)$$

where equation 1 represents the intensity of photons, equation 2 represent the population inversion and equation 3 represent the feedback strength. The equations above are identical to that characterizing the dimensionless form (i.e. three differential equations of models dimensionless), and for the dynamical mechanism basic for chaotic spiking behavior. Secondly, additional a new term for equation 3 (which is $(1+K)$) where K represent two periodic external perturbations, therefore equation 3 becomes:

$$\frac{\partial \omega}{\partial t} = -\varepsilon(\omega + x)(1 + K) \quad (4)$$

where $K = (1 + g \sin(2\pi m f_1 t + \Phi)) \sin(2\pi f_2 t)$ represent the modulation parameter, g is a perturbation strength, m is the frequency ratio, f_1 and f_2 are periodic external perturbations (once of frequency is modulated with chaotic spiking and another is used as a scan for finding the modulation frequency), and Φ is a phase difference between the periodic external perturbations [24]. The system parameters are $\delta_0 = 2.75$, $\varepsilon = 5 \times 10^{-4}$, $a=1$, $s=0.2$, $\gamma=0.01$, $g=1$, $\omega=1$, $m=1$, $f_1=0.0001$, $f_2=0.00015$ and the initial values of parameter $x_1=1$, $y_1=1$ and $z_1=0.005$.

The numerical results

Figure-1 shows the chaotic spiking and there is no frequency-frequency interactions because the amplitude of both perturbations are zero, where Figure-1a is represents the time-series of chaotic spiking state and Figure-1b represents the FFT of this state. With increasing the parameters to $g=1.5$, and $f_1=1.1 \times 10^{-4}$ (which is frequency modulation with chaotic spiking) and $f_2=1.2 \times 10^{-4}$ (which is scanning frequency), the frequency-frequency interactions is not occurred because the two frequencies are non-matched as in Figure-2a and the corresponding FFT of this case is demonstrated in Figure-2b. When the two frequencies of perturbations are matched, the frequency-frequency interactions is occurred as shown in Figure-3a and corresponding FFT of this case is demonstrated in Figure-3b, where the value of FFT peak amplitude has been increased.

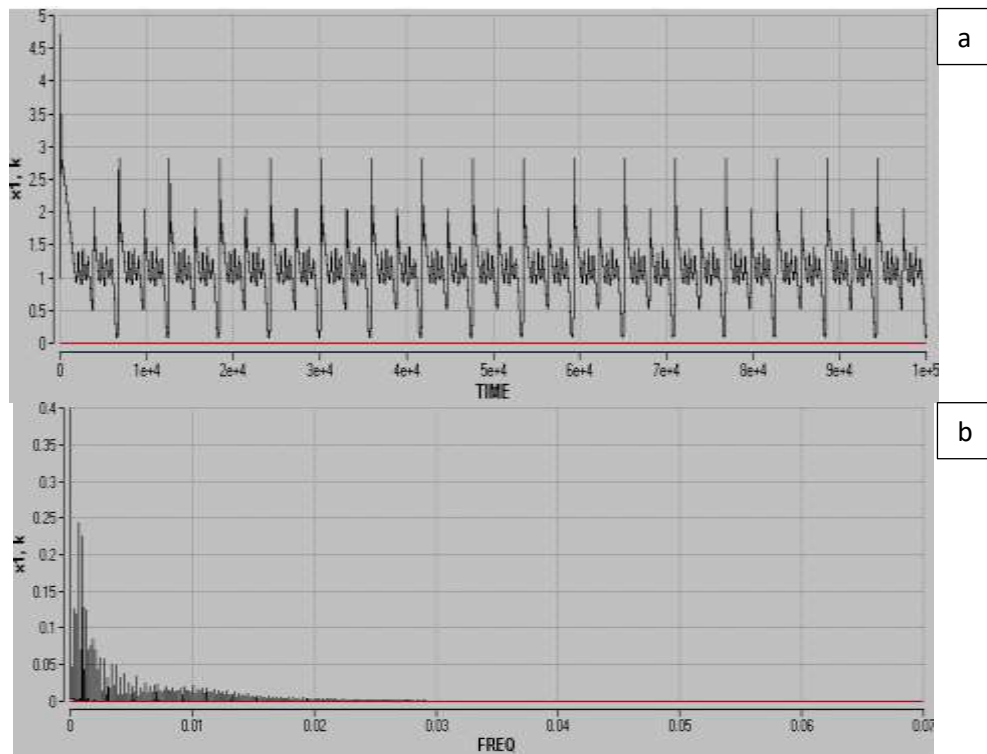


Figure1 (a)-the time series chaotic spiking for dynamical model when $\delta = 2.09$, (b) the FFT chaotic spiking for dynamical model at the same value of δ .

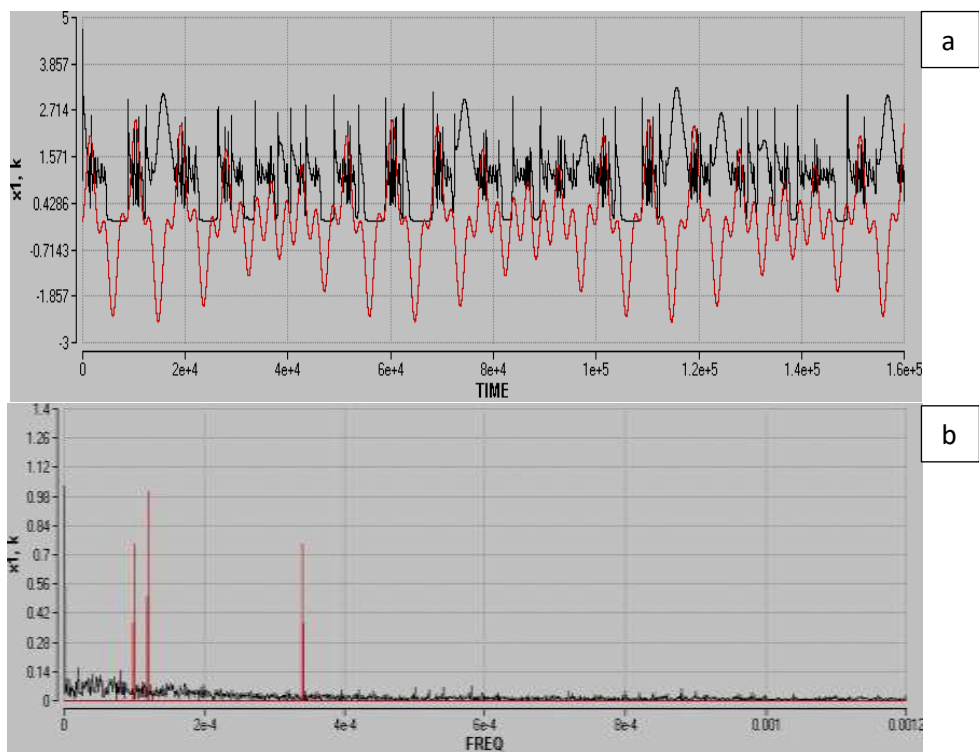


Figure 2-The numerical result demonstrates that two frequencies are not identified, (a) time series (b) FFT.

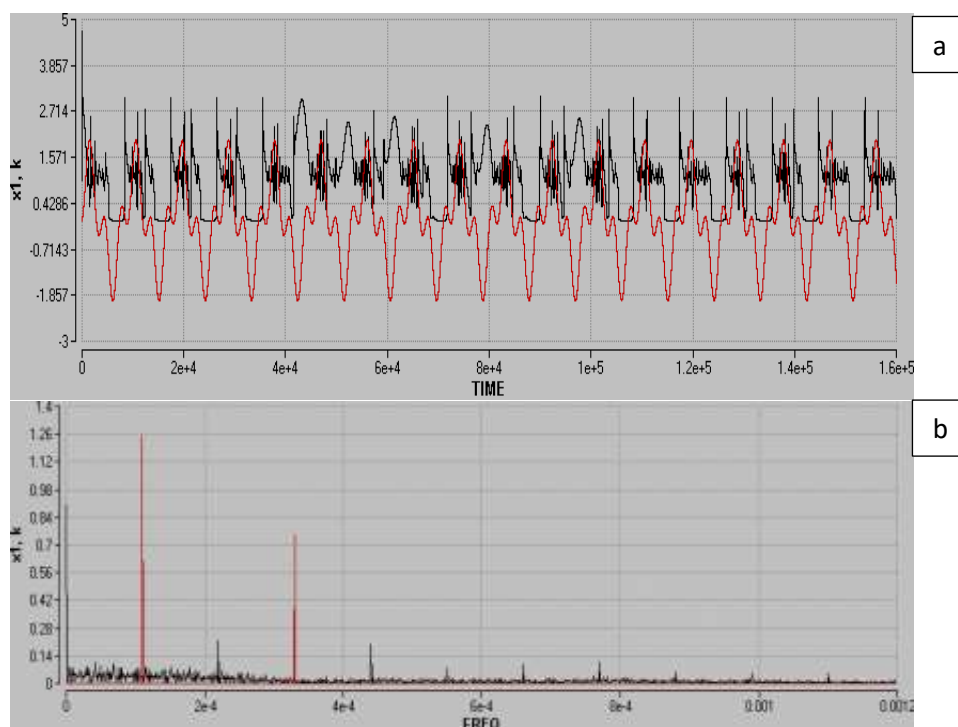


Figure 3-The numerical result demonstrates that two frequencies are identified, (a) time series (b) FFT.

The experimental method

The system here considered is the semiconductor laser (GaAs is working in the first optical telecommunication window and a controllable power range of 1 nW to 2 mW and the operating wavelength of laser is 850nm) with ac-coupled nonlinear opto-electronic feedback (OEFB). The emitted laser light is transmitted to the photodetector using a signal-mode optical fiber. The laser light is converted to the electrical current by a photodetector. The output electrical current is amplified by a variable gain amplifier which is used to achieve the feedback strength and then the corresponding current is fed back to the injection current of the semiconductor laser as shown in Figure-4.

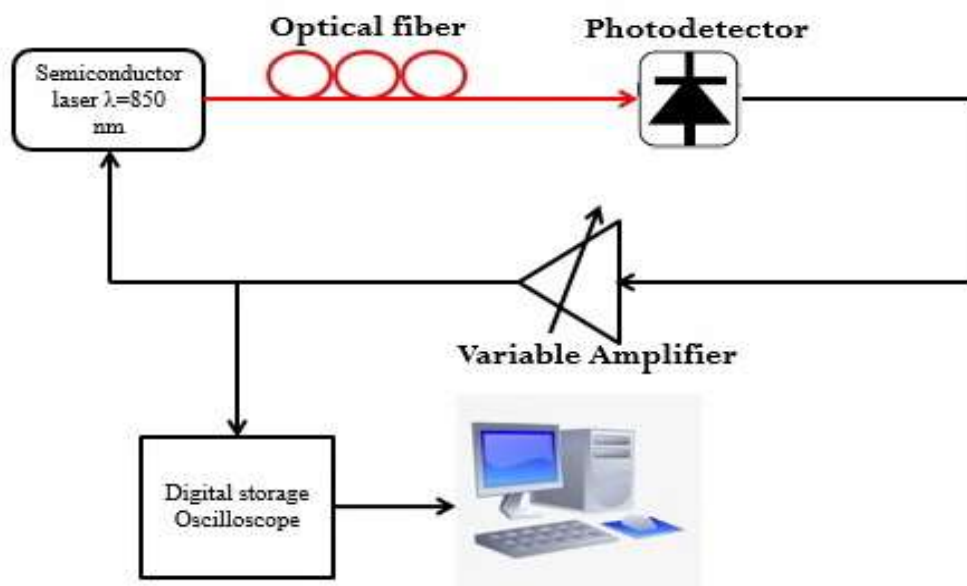


Figure 4-the configuration of optoelectronic feedback system.

The frequency-frequency interactions, after the generation of chaotic spiking and the chaotic spiking has been modulated. The modulation might be hidden or visible. Thus, the discovery of this modulation (frequency) from the other frequencies using the second external perturbation of the

function generator. The two external perturbations have been coupled with configuration of the OEFB devices without synchronization by using differential gain amplifier as shown in Figure-5. One of the frequencies has been modulated with chaotic spiking in which the amplitude and frequency have been fixed.

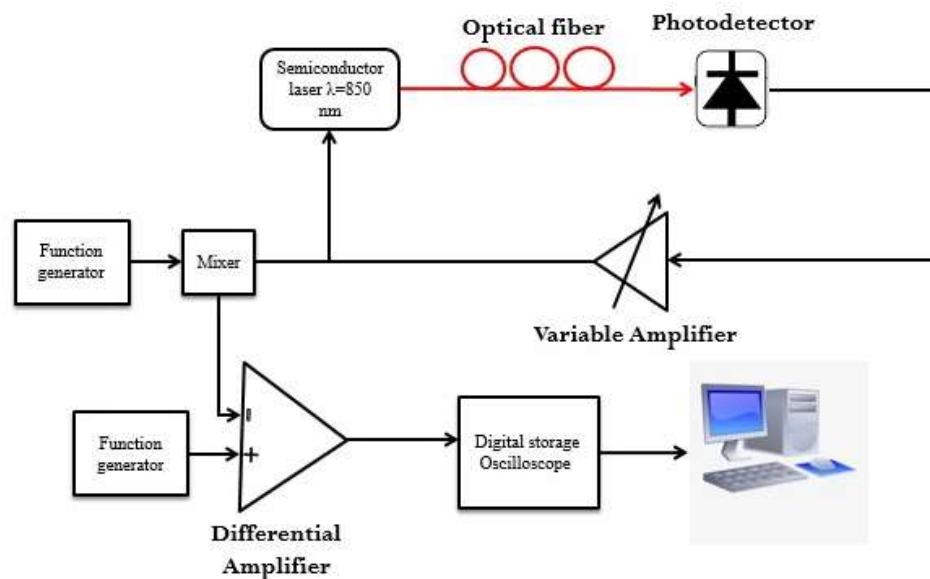


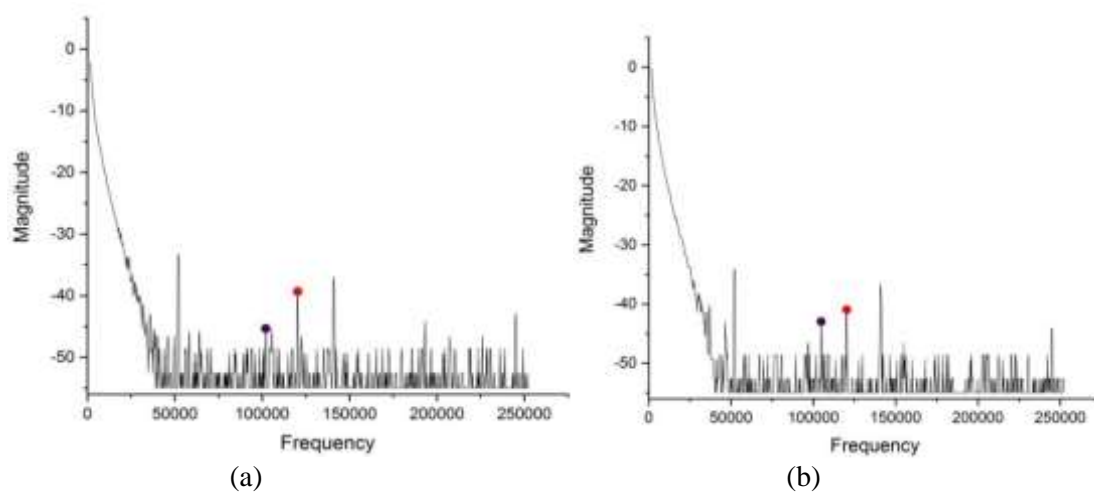
Figure 5-Configuration of the frequency-frequency interactions.

The aim of usage of the other frequency is scanning and searching for the modulated frequency. When two frequencies have been comparable, the interactions between them has been observed on the digital oscilloscope.

The experimental results

Firstly, the chaotic spiking behavior is evaluated by varying the laser bias current as a control parameter and feedback strength is fixed [25].

Secondly, once of perturbations (which consider the modulation with chaotic spiking) is fixed at frequency (120KHz) and amplitude (0.6V) and the second perturbation (which consider the scanning for the frequency modulation) is fixed at amplitude (0.005V) and the frequency is changed from (100-130 KHz). If two frequencies have been equal, interactions between them has been occurred. The values of FFT peaks amplitude have been changed from (-33.477 dB to -43.928 dB) as shown in Figure-6.



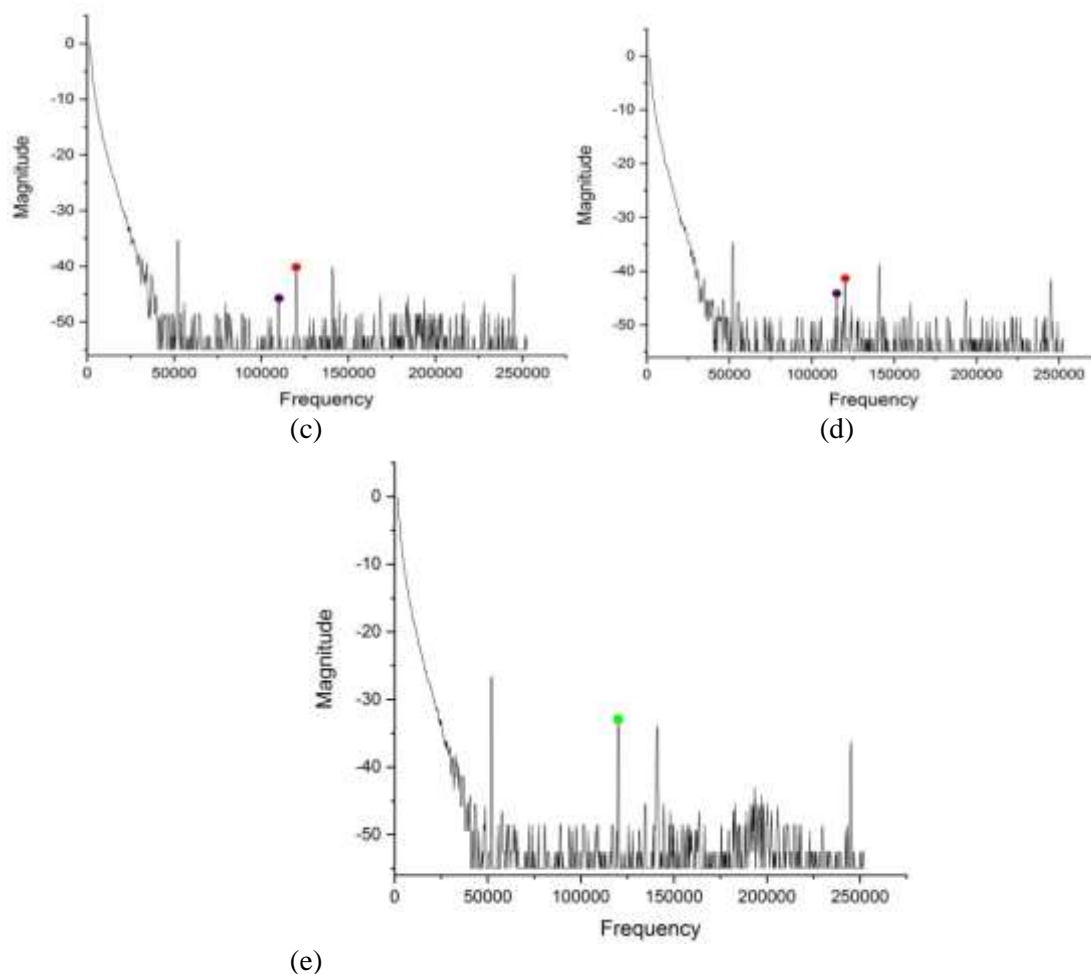
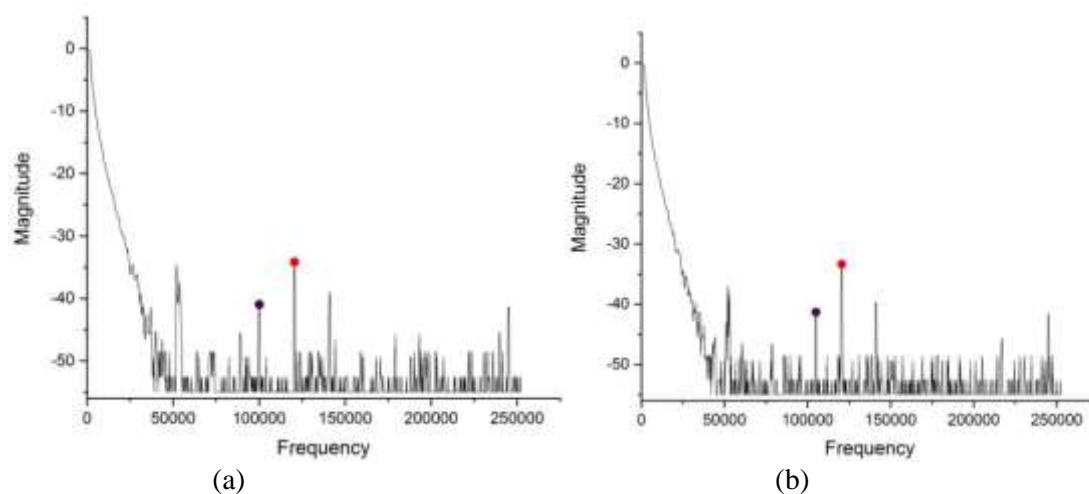


Figure 6-FFT of the experimental part of frequency-frequency interactions, when the scanning frequency at (a) 100KHz, (b) 105KHz, (c) 110KHz, (d) 115KHz, (e) 120KHz which is represented frequency-frequency interactions.

Second experiment is related to the amplitude and frequency. Values of the amplitude and frequency of first perturbation are (1V, 120KHz). The interactions between the frequencies has been occurred when they are equal and the FFT peaks amplitude have been changed from (-38.590 dB to -29.688 dB) as shown in Figure-7.



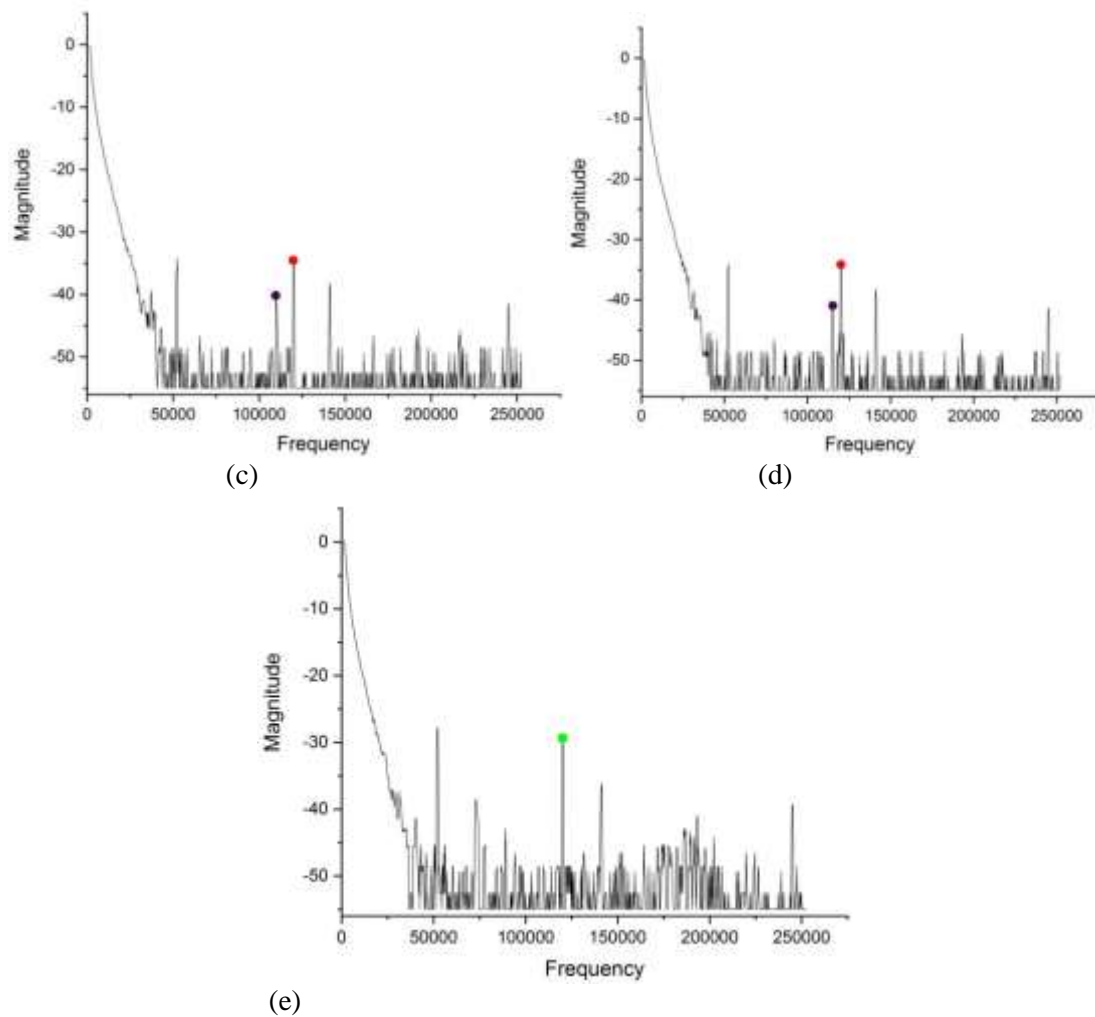
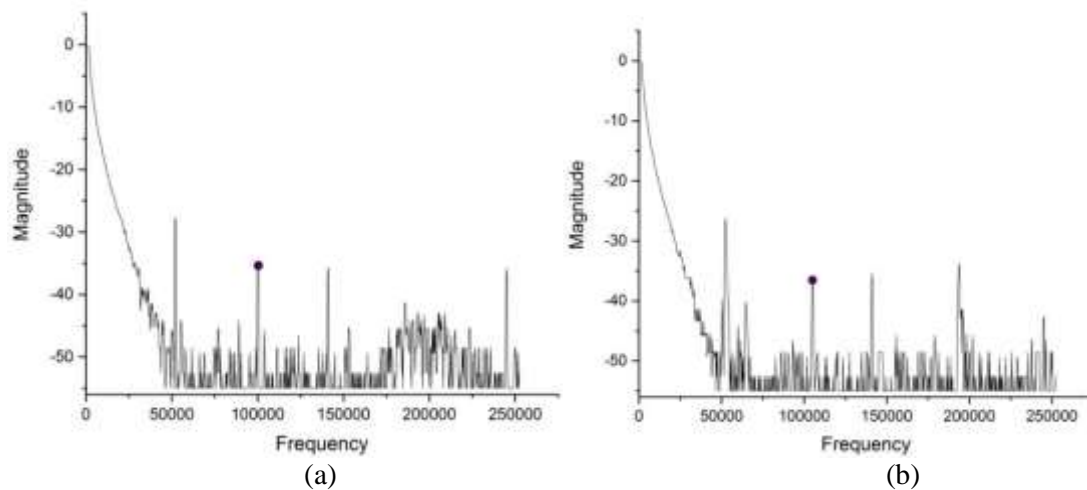


Figure 7-FFT of the experimental part of frequency-frequency interactions, when the scanning frequency at (a) 100KHz, (b) 105KHz, (c) 110KHz, (d) 115KHz, (e) 120KHz which is represented frequency-frequency interactions.

In the third experiment, the values of the amplitude and frequency of the first perturbation (0.055V, 120KHz) respectively; while the value of amplitude (0.01V) and frequency changed from (100 to 130KHz) for the second perturbation. It has been observed that the interactions is taken place when the frequency is equal of both perturbations and the FFT peaks amplitude have been changed from (-32.234 dB to -28.134 dB) as shown in Figure-8.



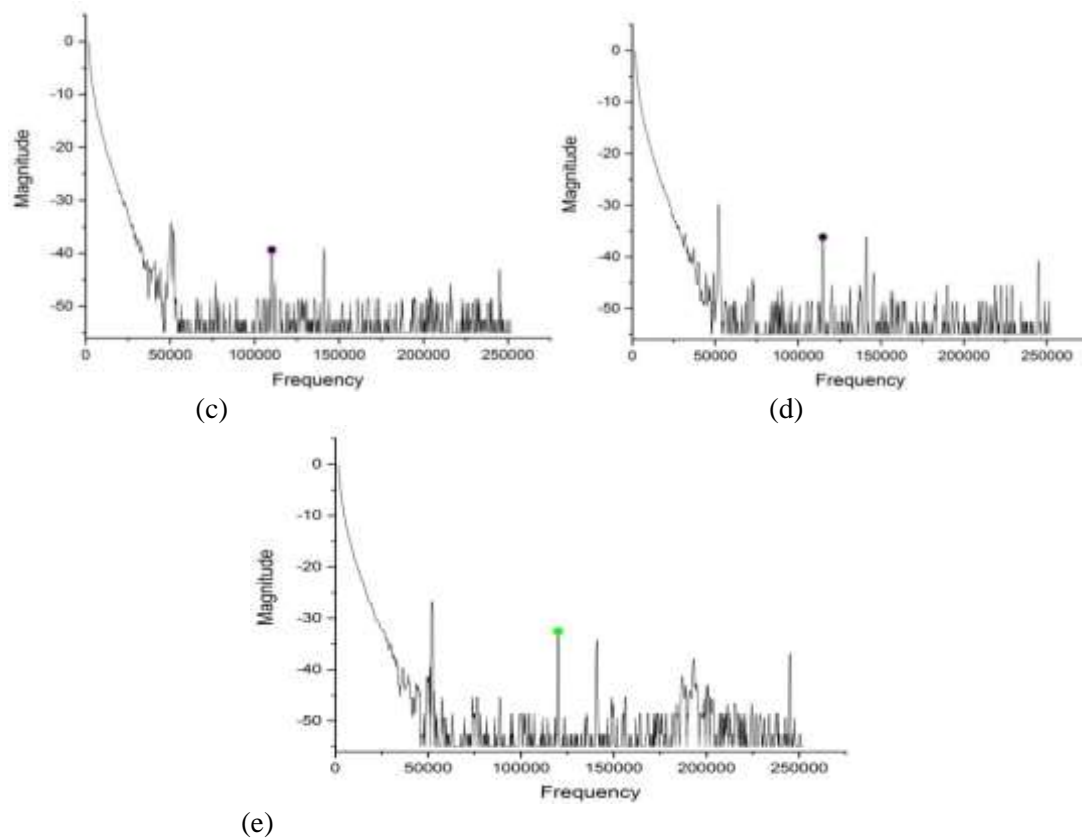


Figure 8-FFT of the experimental part of frequency-frequency interactions, when the scanning frequency at (a) 100KHz, (b) 105KHz, (c) 110KHz, (d) 115KHz, (e) 120KHz which is represented frequency-frequency interactions.

Conclusions

In conclusions, we reported the experimental proof of chaotic spiking and chaotic communication without synchronization: frequency-frequency interactions in semiconductor laser with ac-coupled optoelectronic feedback. When the two frequencies identified at a certain value of frequency, the value of FFT amplitude changes until it reaches the highest value (or twice the value) then decreases to lowest value as shown in figures of FFT. This highest value (or twice the value) indicates that the value of second frequency (or scanned frequency) is corresponded with the value of the modulating frequency in chaotic signal. The experimental results are identical with physical model of the system showing that the frequency-frequency interactions without synchronization is observed.

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