Chaos Modulation Using Synchronization in Quantum Dot Light Emitting Diode with Optoelectronic Feedback

Hussein B. Al Husseini[1*], Mustapha A.A Jebar[2], Salam K. Mousa[3]

Abstract

In this research, a communication scheme of chaos modulation (CMO) that depending on two chaotic quantum dot light emitting diodes (QDLEDs) synchronization was evaluated using theoretical model. The perturbation in behavior of the QDLED can be significantly increased by optoelectronic feedback. Changing the coupling strength between the transmitter and receiver in unidirectional coupling greatly contributes to creating a state of total synchronization between the two systems. Furthermore, the proposed communication model was successful by effectively receiving messages.

Key Words: QDLED, Optoelectronic Feedback, Synchronization, Chaos Communication.

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Introduction

QDLED has been used as a next technology after organic light emitting diodes (OLED). Recently, QDLED has been classified as a short distances source of light emitting that can provide an alternative for applications such as communication. Due to QDLEDs, have different advantages like tunable emission wavelength with varying particle size and narrow spectrum of the emission (described by the full width at the half maximum value) [1]. Development in the conception of the controlled generation mechanisms of nonlinear dynamics in QDLEDs has enhanced an effort to use their output in the telecommunication methods [2].
Chaotic synchronization has been investigated and validated as a topic of research in the past few decades, due to its application in physics, chemistry, biology as well as in the technological areas [3-8]. Many studies have paid more attention for synchronization of chaotic dynamics of systems in the last two decades because of its various uses in secure communication [9-14].
Communications have been employing chaotic signals as "carriers" of information that have quality over conventional communications designing in the performance of high qualification outcome and good use of broadband strength.

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The communication under chaotic systems synchronized by using optoelectronic feedback is controlled for a clear slow data rang with chaotic wave length variations [15]. In fiber ring lasers and a rare earth fiber piece as an active part [16-18], has been obtained the first high speed chaotic optical communication. For experimental applications, preferably use small gigabits rates per second, and a different active stuff of the laser cavity it has to consider, which a high level of fast chaos. In the following, first, this research will provide analysis of a rate equation that represents the fundamental appearance the transitions of electronic. In addition, it has done an analysis to suggest a novel approach as series of levels states in the dimensionless forms. These forms that show a complicated conduct and modulation range of QDLEDs, take the photon reabsorption and non-radiative recombination processes in consideration. secondly, QDLED with OEFB will be investigated. That is one method to produce chaos of high frequency and has a simile to electro-optical and optical feedback the feature of being insensitive optical-phase. Thus, the performance of a communication system will be improved significantly.

QD-LED Model with OEFB

The effect of OEFB is represented by an added terms to the pumping in the rate of these equations system. In this system, the electrons were captured by the QDs after being injected into WL. The equations show the processes of the carrier's transition in the QD as active layer and WL. n_{QD} is the number of carriers in the ground state of QD, n_{wl} WL, and (S) is the photons numbers in the optical mode, are shown using the following:

$$S = Wn_{QD}^2 - Wn_{QD}S - \gamma_s S,$$

$$n_{QD} = \gamma_c n_{wl}\left(1 - \frac{n_{QD}}{2N_d}\right) - \gamma_{r_{QD}} n_{QD} - \left(Wn_{QD}^2 - Wn_{QD}S\right)$$

$$n_{wl} = \frac{I}{e}\left(1 + \frac{k\,S(t-\tau_s)}{S_o}\right) - \gamma_{r_{wl}} n_{wl} - \gamma_c n_{wl}\left(1 - \frac{n_{QD}}{2N_d}\right) \quad (1)$$

In this system, the photon number $S(t-\tau_S)$ is fed from the external OEFB circuit to the QD-LED that is added to pumping in the third equation of system. In fist equation k is the optoelectronic feedback strength. The that has a positive feedback system, is related to a positive value of k, while The that has a negative feedback system, is related to a negative value of k. τ_s is the delay time that was taken by the feedback signal. the spontaneous emission and the reabsorption photon are processes in the QDs layer are approached using the first and second terms of the equation(1), the Einstein coefficient is known as $W = \left[\left(|\mu|^2\sqrt{\varepsilon_{bg}}\right)/\left(3\pi\varepsilon_o\hbar\right)\right]/\left(w/c\right)^3$, where ε_{bg} and ε_o are the background medium permittivity and the vacuum permittivity respectively, c is the speed of light in vacuum, and μ is the momentum of dipole of the QDs. The rate of capture from WL into the dot is γ_c, while the rate of output coupling of photons in the optical mode is γ_s. $\gamma_{r_{QD}}$ and $\gamma_{r_{wl}}$ are rates of the non-radioactive decayed of the carriers in the QD and WL, N_d is the total QDs number, and I is the current of bias, e is electron charge. The coefficient of spontaneous emission and the coefficient of absorption possess identical line-shapes. Both the QD and WL states can be in homogenously broadened for QD material system. In order to determine the true relation between reabsorption and spectra of spontaneous emission, the population distributions in both WL and QD are taken into account explicitly. Fig. 1 shows a diagram of OEFB in a QDLED.

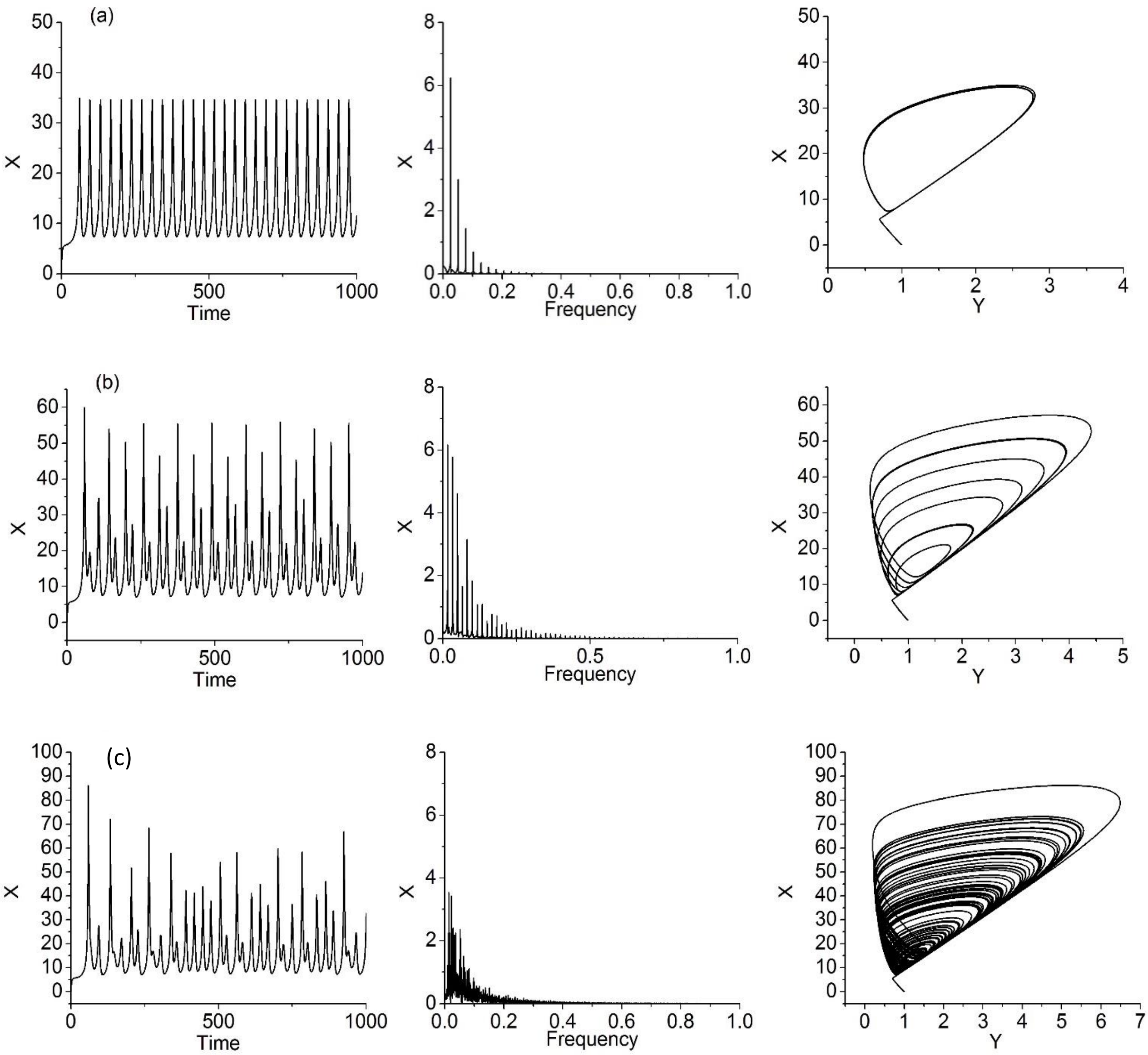

Figure 1. Schematic diagrams of scheme for the two chaotic systems synchronization with optoelectronic feedback. QD-LED: quantum dot light emitted diode; τ: feedback delay time; τc: transmission time.

When OEFB term has been applied QDLEDs equations system, it also has studied as dimensionless equations. The dimensionless parameters have been taken by using new variables.

$$x = S, \quad y = \frac{W}{\gamma_s} n_{QD}, \; z = \frac{n_{wl}\gamma_c}{W},$$

$$\gamma = \frac{\gamma_s}{\gamma_{r_{wl}}}, \;\; \gamma_1 = \frac{W}{\gamma_s}, \; \gamma_2 = \frac{W}{\gamma_{r_{wl}}},$$

$$\gamma_3 = \frac{\gamma_{r_{QD}}}{\gamma_{r_{wl}}}, \; \gamma_4 = \frac{\gamma_c}{\gamma_{r_{wl}}},$$

$N_d \equiv a, \;\; \delta_o = \frac{I}{We}$, and the time scale $t' = \gamma_{r_{wl}} t$.

After mathematical substitutions, the Eqs.(1) look like this:

$$\gamma_1 x = \gamma(y^2 - \gamma_1 x(y+1))\,,$$

$$y = \gamma_2 z(\gamma_1 - y/2a) - y(\gamma_3 + \gamma y) + \gamma_2 xy$$

$$z = \gamma_4(\delta_o(1+\frac{k\,x_\tau}{x_o}) - z + yz/2\gamma_1 \mathrm{a}) - z \tag{2}$$

The differential derivative by ( ) is expressed with respect to (t'), and for the bias current as (δ_0).

Results of QDLED Dynamic with OEFB

Here, chaotic evolution in negative OEFB system has been addressed. The rate equations system (2) is calculated by using the Matlab and Berkeley Madonna programs and using Runge-Kutta fourth-order method. All parameter values and initial values are mentioned in Table (1) unless otherwise indicated.

Fig. 2 shows the time series of the QDLED output. The corresponding Fourier transformation of the output spectrum, are shown in mid and the left columns, respectively while their attractors at different time delays. These figures were plotted at δ_o=0.006 for bias current and (k=-3× 10^{-3}) for feedback strength. The attractor was obtained in a delay-embedding space of photon versus carrier numbers using the theoretical time series. Fig. 2 (a)-(c) are plotted at the τ =39, 33 and 22, respectively. Figs. 2(a)-(c) show the time series and it are a clear transition from periodic behaviors (Fig. 2 (a)), a quasi periodic behaviors with power amplitudes modulated at a specific frequency (Fig. 2 (b)), and the dynamics finally goes to chaos behaviors where irregular dynamic of the intensities as seen in (Fig. 2 (c)). The numerical and experimental results for bulk LED [19] shows a good agreement with chaotic case, Fig. 2 (c). For FFT plotting, it is obvious from Fig. 2(a) there are only few original frequencies. The little peaks in the output point to that there is undersized QDLED instability. In Fig. 2 (b), additional frequencies agree to quasi periodic state. Lastly at Fig. 2(c), the output is wide and a intenssive sharp spectral peaks are appear as a system enters a chaotic state. For the column evidenced our results; the big cycle in Fig. 2 (a) corresponds to double periodic oscillations, several attractor cycles at Fig. 2 (b), and the extend of the attractor scheme shows a move to chaotic state in Fig. 2(c). for these cases, the attractors have a toroidal attractor nature. Also, they have the same size of the big cycle due to the same used OEFB. This also refers that the delayed time controls the dynamic states not the intensity. High dynamics case for short delays are also shown in QD laser with OEFB circuit and related to fast inter dot dynamics [20].

Table 1. Numerical parameters used in the simulation unless stated otherwise.

Parameters	value	Parameters	value
x_{oT}	0.066	γ	0.158
y_{oT}	0.99	γ_1	0.04
z_{oT}	0.0049	γ_2	0.025
x_{oR}	0.022	γ_3	0.03
y_{oR}	1	γ_4	0.078
z_{oR}	0.01	a	0.891

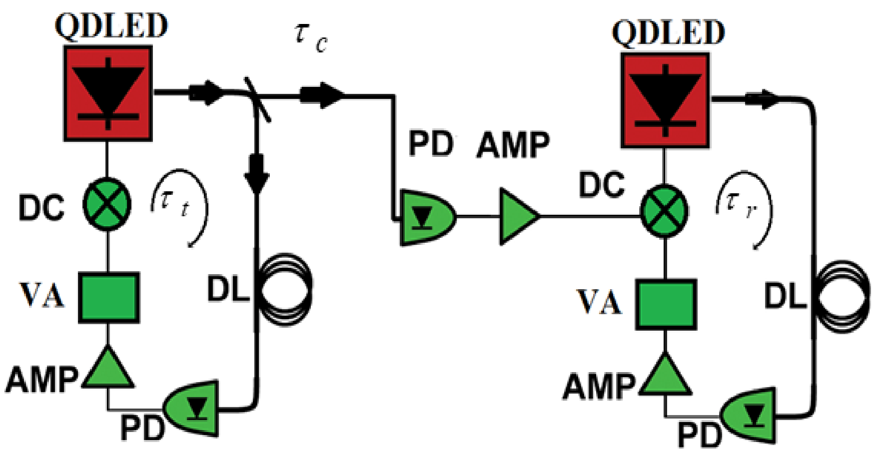

Figure 2. Time series (column 1), FFT (column 2) and attractor sections (column 3) with delay times at different values. From top to bottom: (a) periodic state, at τ =39; (b) quasi periodicity as two frequency, at τ = 33; (c) chaotic state, at τ =22. The results show the broadband background in (c) is a great deal than in (b). The parameters measured are δo=0.006 and k=-3× 10-3.

Synchronization in QDLED

Coupled chaotic systems synchronization has a major advantage and interest, in theoretical and additional several applications area, like neuroscience and communication encryption. Lately, base on theory of stability, coupled chaotic systems synchronization by purpose suitable coupling has been exceedingly classified and estimated. Therefore, synchronization is mainly investigated in regular (periodic) and complex (chaotic or quasi-periodic) self-feedback QDLED in dissipative dynamical systems.

This research has discussed chaotic oscillations in OEFB in QDLED in section III. In this section the chaotic synchronization of coupling unidirectional system with OEFB was studied. In OEFB method, the equations of rate for carriers and photons number are adequate for explaining the model. The system of OEFB in laser has a benefit of outstanding synchronization more than other systems. Time scale of carrier is larger than lifetime of the photon about three times [8]. Synchronization is studied briefly in bulk LED [19]. There are no work deals with it in QD-LED. The rate equations for the photon and carrier number in QD and WL in a T and R of OEFB are written by

$$\gamma_1 x_{T,R} = \gamma(y_{T,R}^2 - \gamma_1 x_{T,R}(y_{T,R}+1)),$$

$$y_{T,R} = \gamma_2 z_{T,R}(\gamma_1 - y_{T,R}/2a) - y_{T,R}(\gamma_3 + \gamma y_{T,R}) + \gamma_2 x_{T,R} y_{T,R}$$

$$z_{T,R} = \gamma_4(\delta_o(1 + k_{T,R} x_{\tau_{T,R}} + \delta k_c x_{\tau_T}) - z_{T,R} + y_{T,R} z_{T,R}/2\gamma_1 a) - z_{T,R} \quad (3)$$

Where $k_{T,R}$ is the coefficient of the OEFB strength in the T and R. $\delta = 0$ in T rate equations and $\delta = 1$ in R rate equations system. Fig. 6 (a) is shown the diagram arrangement of the synchronization.

In the synchronization model of QD-LED, this research has included the k_c factor, at $0 \le k_c \le 1$, in order to point to the full coupling output strength of the R from the T. When k_c =0 there is no coupling in the R and it is called open loop. When k_c =1 the T and R are completely coupled. The time of transmission signal noted by τ_c (the time related to the signal transmission from T to the R system). Complete synchronization state is was achieved in case of correspond between T and R systems, with the equal dynamical variables. Thus, the case of correspond systems was not discussed in this work.

Residual Chaos and Entropy

Some mathematical properties can be used to determine residual chaos synchrony with the following relationship:

$$R_{chaos} = \left| \frac{x_{T_{max}} - x_{R_{max}}}{x_{T_{max}}} \right| \quad (4)$$

Where x_T and x_R are the maximum intensities of the T and R QD-LED systems. To imply more details about the synchronization, a different feedback cases were taken with negative and positive feedback strengths for both of these two systems. In this research, Residual chaos attractor has been introduced for the first time.

In this sudden transition between synchronization and non-synchronous cases study, the degree of ordering in the system by means of the entropy (S), has been characterized in order to display. By extracting the S value in synchronization and non-synchronization states. S is calculated from the distribution of the response times t_r in the time series using the relation [21]:

$$S_i = \sum_j \left[x_i(t_r) \ln \frac{x_j(t_r)}{x_i(t_r)} \right] \quad (5)$$

Results of Residual Chaos and Entropy

Residual chaotic and entropy are a measure of the synchronization in bidirectional QD-LED systems. Several results are shown in Fig. 3 and 4 for the parameter values systems $\tau_t = \tau_r = \tau_c$ =30, k_t = 0.0231, $k_r = 5\times 10^{-3}$ and δ_o =0.013 used as a control parameters to select different dynamical behaviors. Fig. 3 shows residual chaos plots (left panel) and entropy (right panel). In Fig. 3 (a) for positive feedback strength of T and R, a stable solution is obtained when k_c = 0.032 where the photon and carrier numbers synchronization in T and R is talented. For negative OEFB for both T and R, Fig. 3 (b) shows that the completely synchronization is obtained when k_c = -0.03 and very close of the synchronization status at k_c = -0.008, -0.025 and -0.04. In Fig. 4 (a) the residual of positive (T) and negative (R) have the same synchronization case in Fig. 3 (a). Fig. 4 (c) shows the residual for negative T and positive R, the synchronization is obtained at k_c = -0.04. Several cases can be determined in these figures, the lack of symmetry in dynamic system when $k_c \approx 0$, where the rapid change of the system behavior when k_c values is negative while the change in behavior is slow when values as positive (this continues disappear with negative values of k_T. in addition, it is obvious from the Fig. 3 and 4, synchronization occurs at negative and positive values of k_c follow the polarity transmitter system (T).

Fig. 3 and 4 (right panel) shows S location which is shifted according to synchronization points that shown in the left panel. Moreover, the T output is still fixed while the R output is shifting since the T is demonstrated.

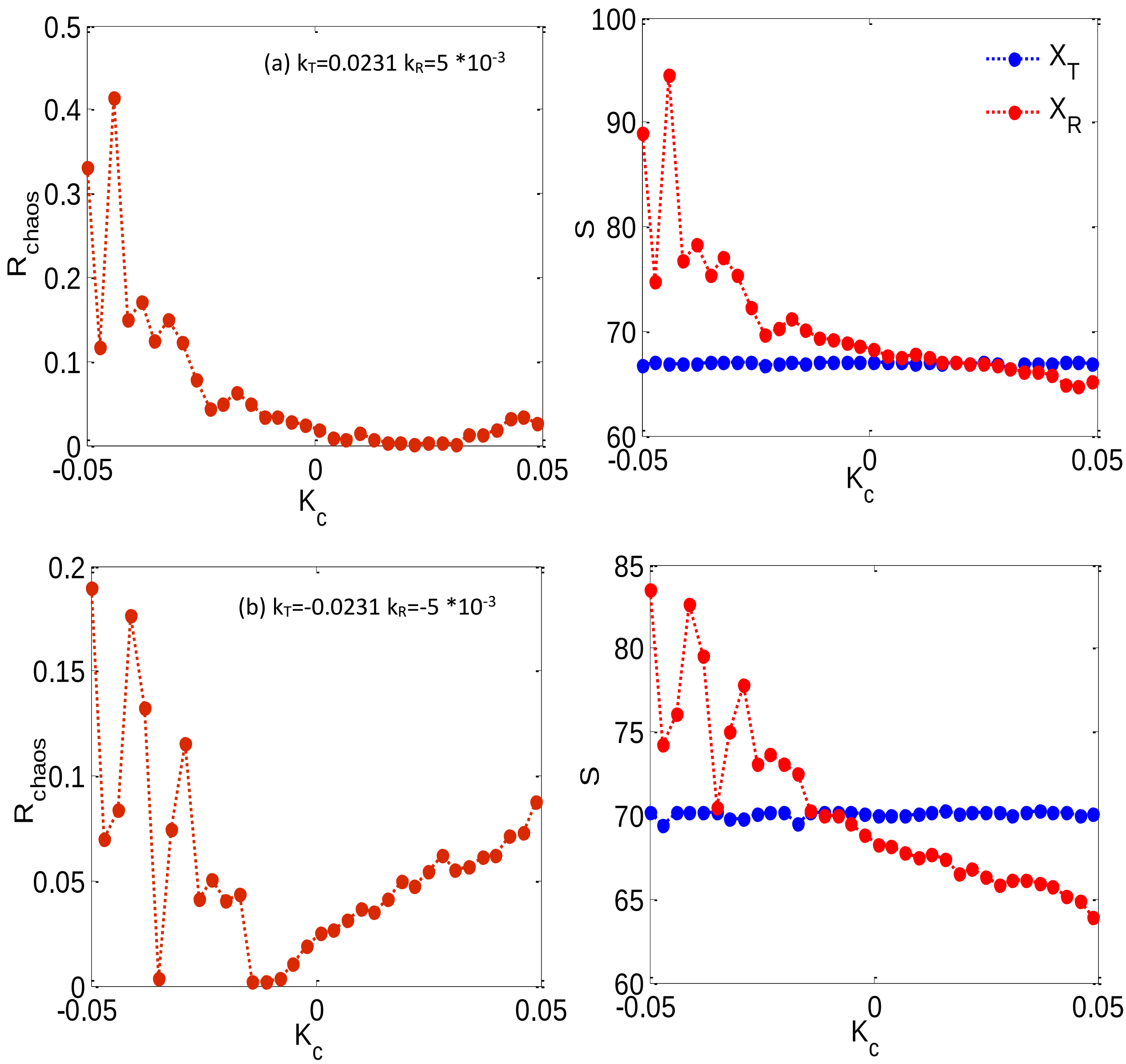

Figure 3. Calculated residual chaos and the entropy of two chaotic systems as a function of coupling strength. The chaotic systems unidirectional synchronization is done with two different cases of feedback signal strength in the R and T. The parameters are used in Table 1.

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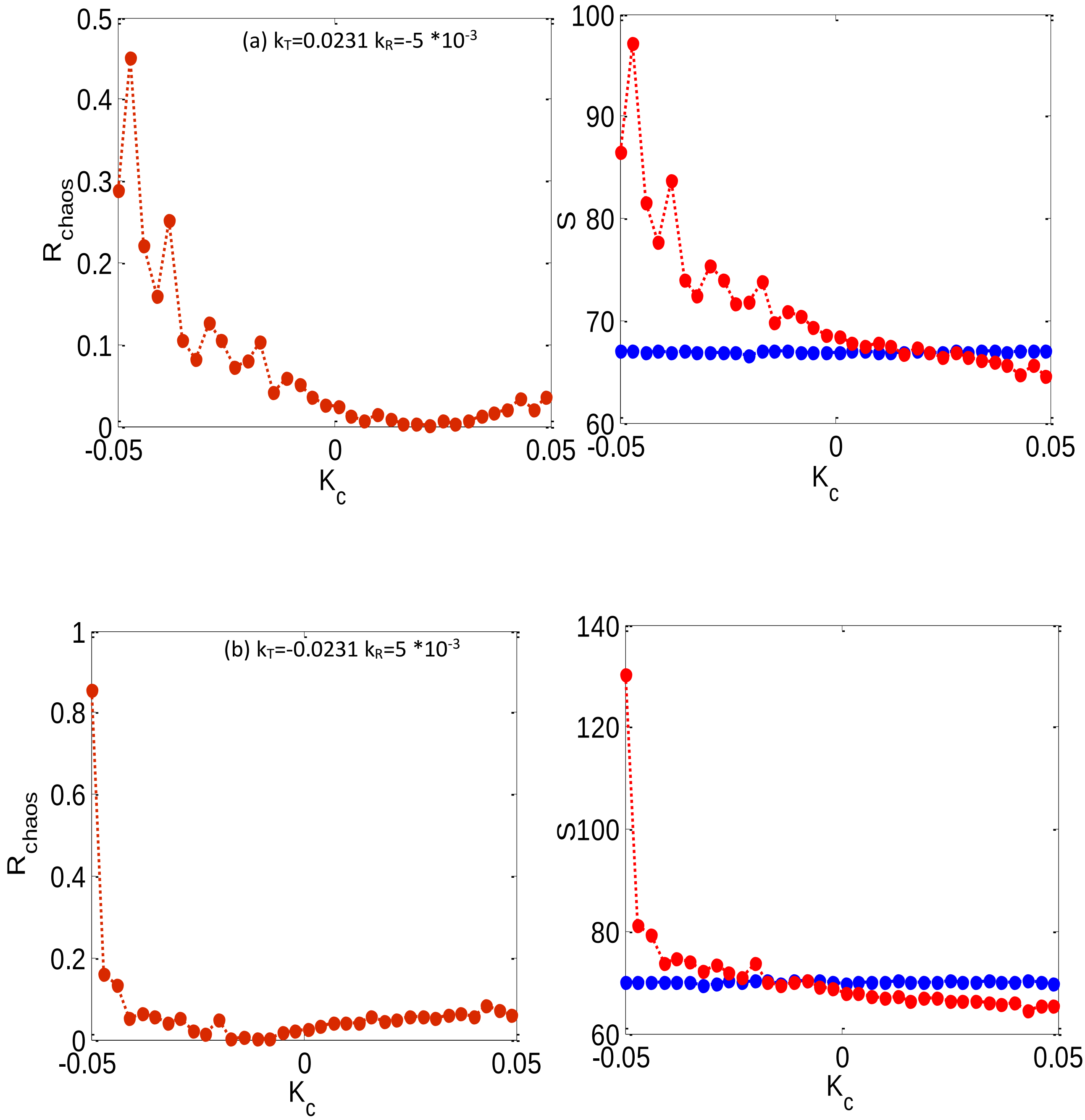


Figure 4. Calculated residual chaos and the entropy of two chaotic systems as a function of coupling strength. The chaotic systems unidirectional synchronization is done with two different cases of feedback signal strength in the R and T.

QDLED Model of Chaos Communication

Fig. 5 is illustrated the diagram for chaos based of secure communication by using QDLED model. Now communication diagram has been suggested for encoding the information; attainments of the third equation of system (3) can be modeled by,

$$\gamma_1 x_T = \gamma(y_T^2 - \gamma_1 x_T (y_T + 1)) + \eta_{CMO}\, m_{CMO}(t)$$

$$z_R = \gamma_4(\delta_o(1 + k_R x_{\tau_R} + k_c x_{\tau_T} + \eta_{CMO}\, m_{CMO}(t-\tau)) - z_T + y_T z_T / 2\gamma_1 a) - z_T \qquad (6)$$

Here the components m_{CMO} communicate to the modulation messages applied in the chaos modulation (CMO) systems, and η_{CMO} are the modulation coefficients for system. The transaction for get back messages includes setting for optimal synchronization and then under comparing the received signal and the output of the receiver QDLED extracting the message.

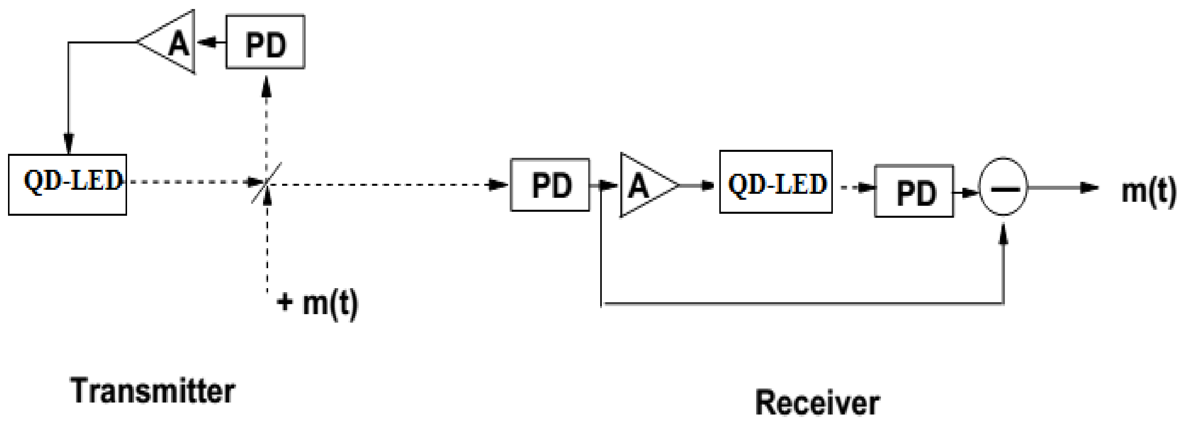


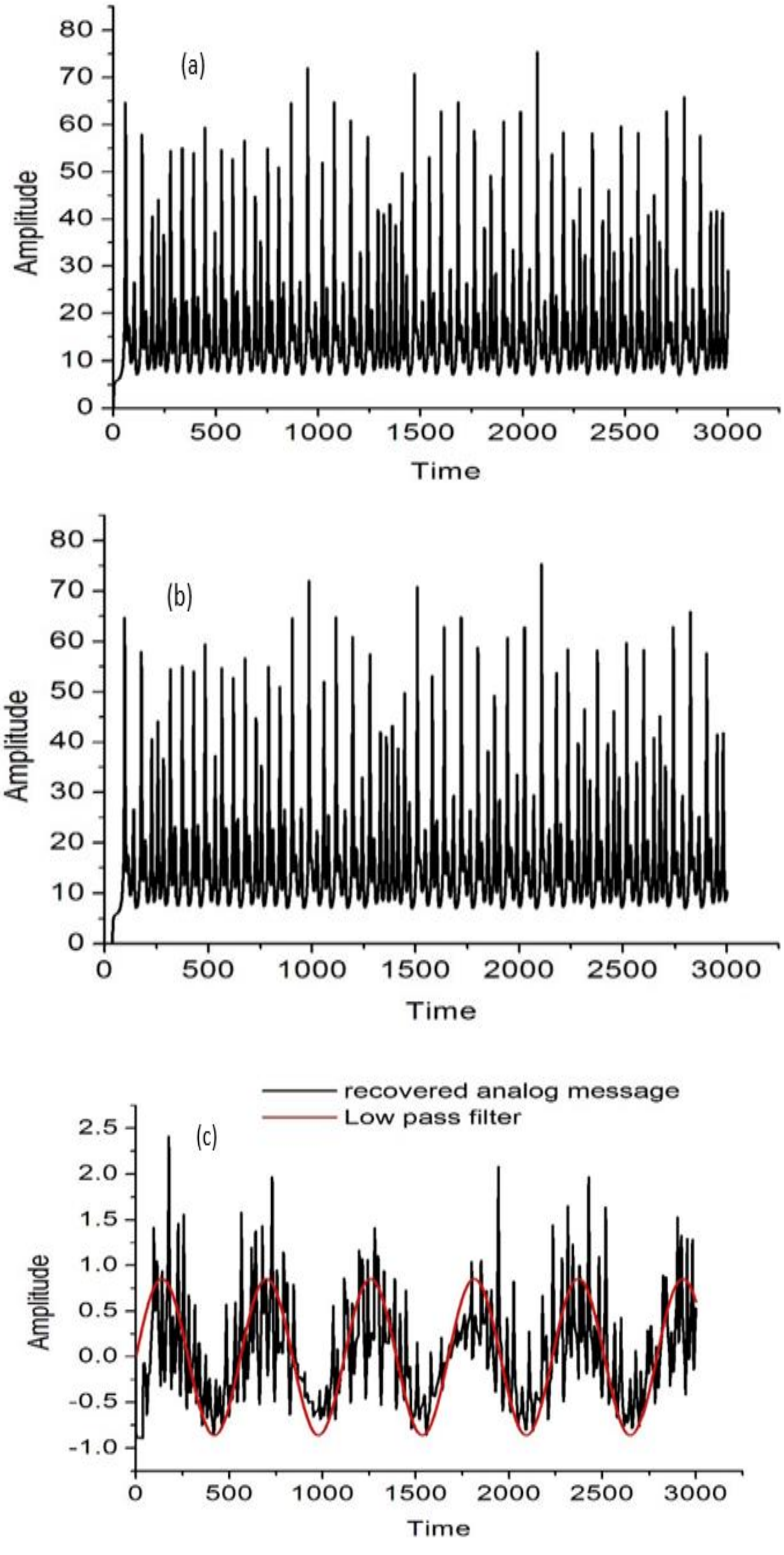
Figure 5. Diagrams of scheme for communications and chaotic synchronization by using QDLEDs with OPEFB. Method of Chaos modulation (CMO).

Chaos Modulation Communication

In two QDLEDs under optoelectronic feedback, the realization of chaotic synchronization allows us to appoint diagram of communication as a message that one set at the dynamics of transmitter by a reversible process, like multiplication or an addition. When the signal is transmitted, it is an incorporation of the output of the QDLED transmitter and the message. Because of the predictable transmitter on dynamics output is known for the receiver hand, due to the corresponding synchronization, from the received signal the predictable output can be utilized to excerption the message. The performances of a QDLED communication scheme have been evaluated and for a wide range of the k_c factor, it is found some appropriate bit of error rates.

Fig. 5 shows the diagrams of CMO scheme with open loop order at the k_c=0.032. It is significant to observe that the signal of message m (t) gets in the transmitter dynamics by the loop of feedback. Thus, the concerted signal of output with additional message gets in symmetrically to both the receiver R and transmitter T, which secures which synchronization is preserved when the information is transmitted.

We are considered In Fig.6 an examination the transmission of data depends on CMO. And Fig.6 represents the outcomes of the decoding got in our numerical methods of narrow pulses. The signal decoding time series was presented as seen of Figure. 6. A first path represents the signal message encoded of the transmitter (Fig. 6 (a)). The local receiver output was the second trace (Fig. 6 (b)), that was because the synchronization was the output of the transmitter previously adding the message. Therefore, a message was recovered by the third trace (subtracting the receiver output) from the output received, (Fig. 6 (c)). The recovered signal gives a reasonable decoding of quality as investigated via the recovered signal and the trace tertiary, which was compared with the original 'message', in Fig. 6.


(a)
Amplitude
Time
(b)
Amplitude
Time
recovered analog message
Low pass filter
(c)
Amplitude
Time

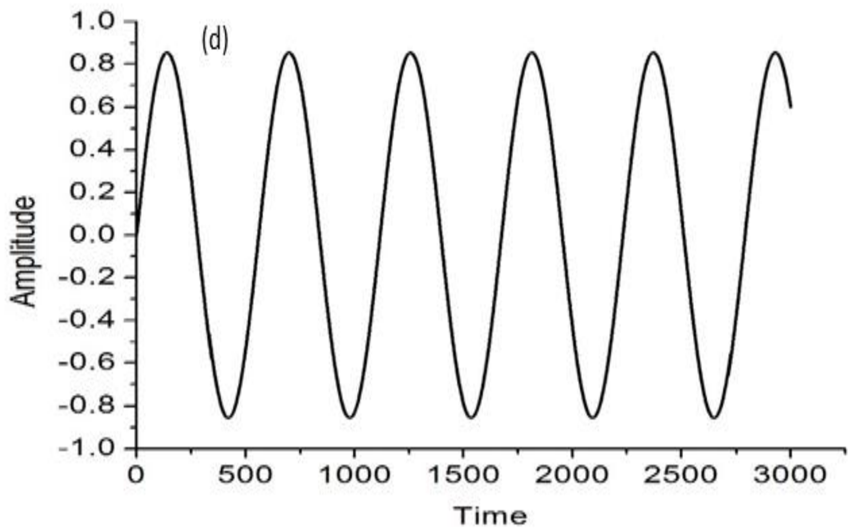


Figure 6. CMO method of of analog message communication decoding using unidirectional coupling system with: (a) Signal of chaotic output is transmitted simultaneously with a message. (b) Chaotic signal is synchronized in the receiver. (c) Analog message is recovered (black line) and decoded message after filtering (red line). (d) Original message of amplitude 0.855.

Conclusion

In conclusion, this research has demonstrated that OEFB in QDLEDs presentation chaotic dynamics as a quasi periodic behavior. In addition, it has carried out synchronization of two chaotic systems. Over and above, a message with frequency at high speed is encoded and decoded successfully. A message is transmitted under the encoded case can be possibly as the repetition rate of the chaotic frequency because of the transmitter and receiver remain synchronized.

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