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# Study the Effect of Spreading Factor value on the Performance of Chaotic Modulation Schemes

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**Abstract—** *High data rate and bandwidth efficiency are the requirements of modern wireless systems. Most studies introduce different ways to develop communication systems to meet these requirements. The researches in the last few years focused on the chaotic system as a chaotic modulation due to its nature. So that the performances of various chaotic modulation schemes (Initial Condition Modulation (ICM) and Chaotic Shift Keying (CSK)) in terms of bit error rate (BER), for different spreading factors are implemented in this article and simulated using MATLAB 2016b simulation. The main objective of this paper is to make a comparison of various chaotic modulation schemes under AWGN channel and study the effect of the spreading factor (β) on the performance of different chaotic modulation schemes, where the spreading factor (β) is the number of generated chaotic signal samples during the bit period (Tb). Different values of spreading factor (12, 16, 20, 40, 60, 80, and 100) samples are selected to implement various chaotic modulation schemes. The results show that the spreading factor value of (100) achieves good performance for all types of chaotic modulation schemes which are implemented here. Increasing the value of spreading factor over (100) such as (120, 140, and 180) will add a little bit enhancement to the system, whilst the processing time will increase dramatically.*

**Index Terms**—*Chaotic Signal. Chaotic Modulation. Chaos Shift Keying. Spreading Factor.*

## I. INTRODUCTION

In the modern communication system the attention turned to the use of chaos communications which is an application of the chaos theory that utilizes chaotic signals as information bearing signals. Chaotic modulation is a very important application of the chaotic sequences that have properties required for spread spectrum (SS), so a narrowband information signal can be modulated over a wideband carrier due to the broadband spectrum of chaos [1], [2].

Chaos Modulation systems can be classified as analog and digital systems according to the type of information to be transmitted. For analog chaotic communication systems, two modulation techniques have been introduced, chaotic masking in which the massage signal is combined to the chaotic signal to mask information data, then the overall signal is sent via RF to the receiver [3], [4].

In the second analog chaotic communication system, the information to be sent is used to change a parameter in the chaos generator. In this case the receiver will extract the data from the incoming signal according to the parameter using a correlation process as in Initial Condition Modulation (ICM) [1].

For digital chaotic communication systems, each symbol to be transmitted will be represented by a segment of chaotic sequence instead of sinusoidal as in conventional communication systems, as in Chaotic Shift Keying (CSK) [1], [5].

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## II. CHAOTIC MODULATION SCHEMES WITH FREQUENCY MODULATION

Because of the fact that the chaotic signal is non-periodic and cannot be repeated, the energy of each bit will be changed from one bit to another and this varying leads to a problem at the estimation as the output of the correlator is not constant instead of being distinct [5]. This problem can be reduced by increasing either the statistical bandwidth of the transmitted signal or the bit duration, or reduced by keeping the energy of each symbol constant. However, this solution can be provided by using Frequency Modulation (FM) [6], [7]. **Error! Reference source not found.**) represents a general block diagram of FM modulation based on several modulation schemes spatially (FM-DCSK, FM-CDSK, FM-QCSK, and FM-COOK).

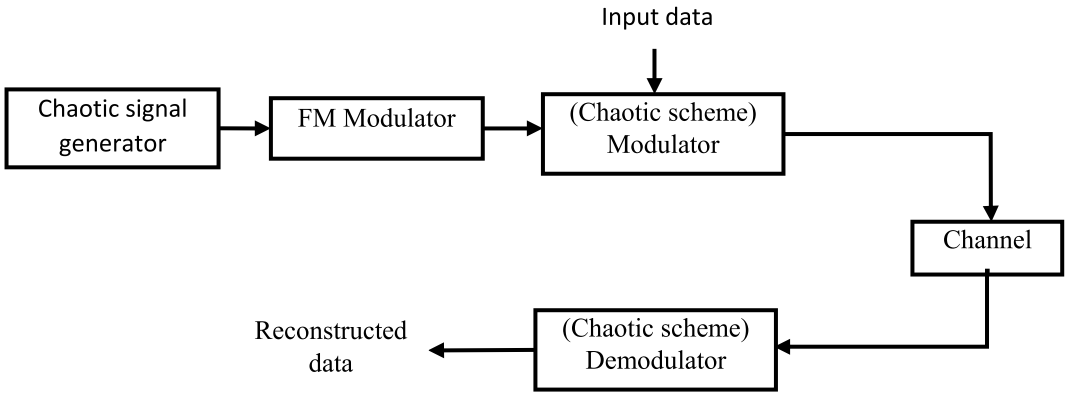

FIG. 1. COMMUNICATION SYSTEM OF FREQUENCY MODULATED-CHAOTIC MODULATION SCHEME [5].

## III. System Implementation

Two types of chaotic modulation have been discussed, which are Chaotic Shift Keying (CSK) and Initial Condition Modulation (ICM). The implementation details are described in the following subsections:

### A. Chaotic Shift Keying (CSK)

In this modulation technique each binary information data are replaced by a limited chaotic sec [illegible] mismatch of the chaotic generator parameters, the implementation simplicity, and more immunity to interception [4], [8].

The block diagram of the used chaotic shift keying system is shown in FIG). The CSK modulator shown in this figure can be one of different implemented chaotic modulation schemes which are (QCSK [9], CDSK [10], ACSK [11], [12], COOK [6], [8] DCSK [10], [13], [14], FM-CDSK [15], FM-QCSK [16], FM-COOK [6], and FM-DCSK [13, 14]. Each of them modulates the input signal message within a chaotic signal generated using a chaotic generator. The chaotic generator generates chaotic sequences of length (β). Logistic and Hénon maps [17] are used in chaotic generator, each of which is used for several modulation schemes as listed in

TABLE ).

The bifurcation parameters and initial values of chaotic generator are also listed in this table for different chaotic CSK modulations.

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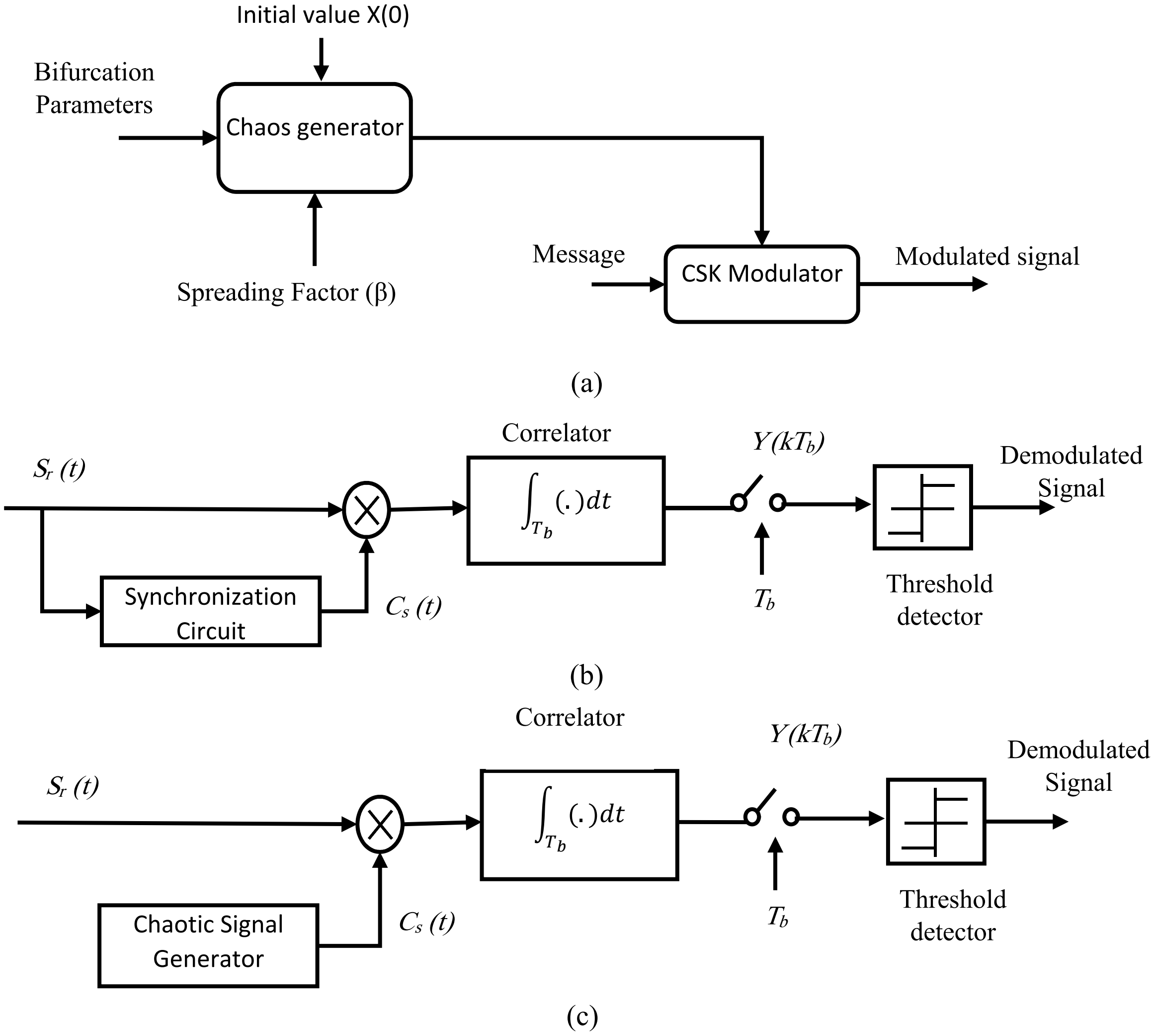

FIG. 2. BLOCK DIAGRAM OF CSK (a) MODULATOR, (b) DCSK DEMODULATOR, (c) DEMODULATOR OF THE REST SCHEMES

TABLE 1. DESIGN PARAMETERS OF CHAOTIC GENERATOR FOR DIFFERENT CHAOTIC SHIFT KEYING SCHEMES.

| **CSK Scheme** | **Map Type** | **Its equation** | **Initial value *x(0)*** | **Parameter *a, b, c*** |
|---|---|---|---|---|
| QCSK<br>ACSK<br>COOK<br>BCSK<br>FM-QCSK<br>FM-COOK | Hénon | $x_{n+1} = 1 - \boldsymbol{a} * x_n^2 + y_n$<br>$y_{n+1} = \boldsymbol{b} * x_n$ | 0 | $\boldsymbol{a}$ = 1.4<br>$\boldsymbol{b}$ = 0.3 |
| CDSK<br>DCSK<br>FM-CDSK<br>FM-DCSK | Logistic | $x_{n+1} = \boldsymbol{c} - {x_n}^2$ | 0.35 | $\boldsymbol{c}$ = 2 |
| ICM | Cubic | $x_{n+1} = \boldsymbol{a} * x_n^3 - (\boldsymbol{a} - 1) * x_n$ | Data | $\boldsymbol{M}$ = 16,<br>$\boldsymbol{a}1$ = 4<br>$\boldsymbol{a}2$ = 3.9 |

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### B. Initial Condition Modulation (ICM)

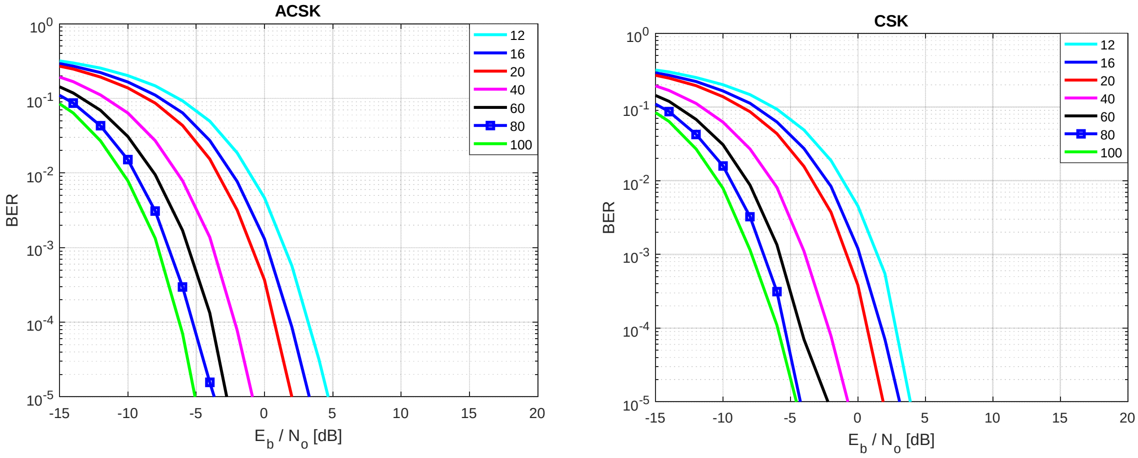
In this modulation scheme [18], 4 binary bits (16 QAM) are injected into the mapper in each symbol period. The in-phase and quadrature analog output signals are set as initial values of chaotic generators. Each output is set as an initial value for one chaotic generator. Starting with these initial conditions, each chaotic generator produces an $N$ samples sequence over a period of $T_b$. The two chaotic generators using cubic chaotic map and the bifurcating parameter for the first and second generators ($a1, a2$) are equal to 4, and 3.9, respectively. The values of bifurcating parameters are chosen to make synchronization error to be as minimum as possible. At the receiver side, only the type of chaotic map used (which is cubic map) and the bifurcating parameters ($a1$, $a2$) are known. The receiver will use these values to generate a chaotic sequence for each state of 16 QAM. Using the correlator to detect the correct sequence of the information, the original information can be retrieved accurately by demodulating this complex sequence in QAM constellation demapping.

## IV. Results and Discussion

A performance evaluation of various chaotic modulation schemes with considering the effect of selecting different values of spreading factor, are discussed in this article. The values of spreading factor ($\beta$) are varied from 12 to 100 samples. It is easy to show that the bit error rate decreases as the value of spreading factor increases; on the other hand, the processing time and hardware requirements will also increase. So, the appropriate value of spreading factor is a tradeoff between the performance of the system, its processing time and the complexity.

ACSK and CSK chaotic modulation schemes achieve superior performance compared to the other schemes even for low values of spreading factor and signal to noise ratio (SNR), see Figure (3). For example, the ACSK achieves a BER value equals to ($10^{-4}$) at a signal to noise ratio (SNR) value of about (-2 dB) when the value of spreading factor is (40), and it is almost the same for CSK. The similarity of results between these two chaotic modulation schemes is due to the likeness between their structures, where both techniques use two signals to represent bit 1, and bit 0.

Although increasing the spreading factor can enhance the performance of the system, the enhancement increment will decrease as the spreading factor increases, particularly above 80, as shown in Figure (3). According to this, the benefit of increasing the spreading factor value above 100 can be considered negligible.



(a) (b)

FIG. 3. BER PERFORMANCE OF (a) ACSK, AND (b) CSK.

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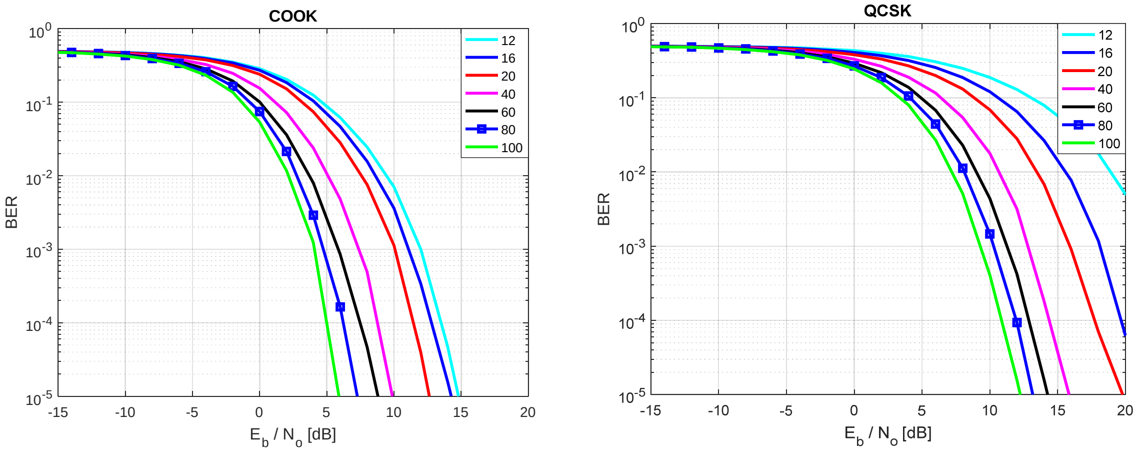
In spite of the simplicity of COOK modulation scheme, there is a degradation in its performance. It achieves a BER value equals to ($10^{-4}$) at a signal to noise ratio (SNR) value of about (8.5 dB) when the value of the spreading factor is (40), as shown in Figure (4-a). In addition to its simplicity, COOK modulation scheme has another advantage represented by less power consumption because it has no transmission when (bit 0) is sent. QCSK has also a severe degradation in its performance and it achieves a BER value equals to ($10^{-4}$) at a signal to noise ratio (SNR) value of about (14 dB) when the value of the spreading factor is (40), as shown in Figure (4-b).

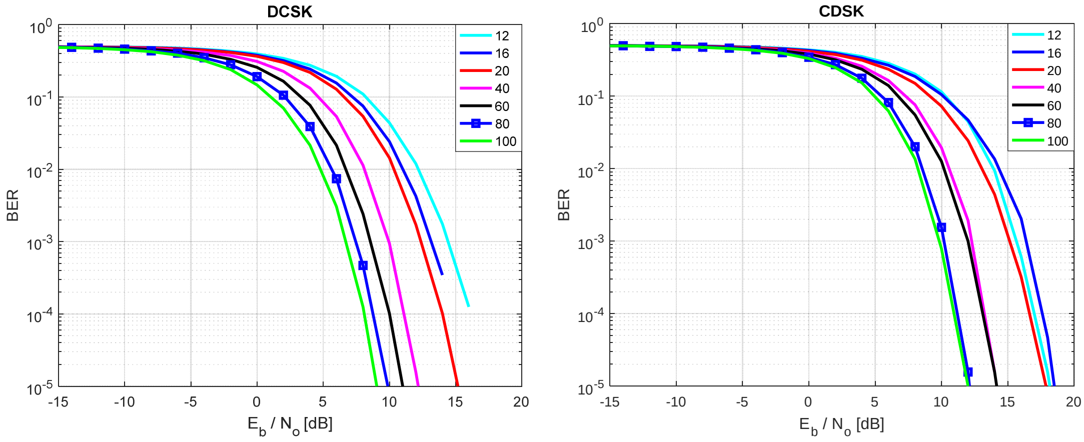


(a) (b)

FIG. 4. BER PERFORMANCE OF (a) COOK, (b) QCSK.

In contrast, the QCSK chaotic modulation scheme enhances the system bit rate by double the number of bits transmitted for the same transmission time (M=4, k=2);

As shown in Figure (5), the performance CDSK modulation scheme is lower than that of DCSK modulation scheme because of the uncertainty which is introduced due to the cross correlation between the chaotic signal and the delayed versions of it. DCSK achieves a bit error rate of ($10^{-4}$) at a SNR value of (11 dB) for the spreading factor value of (40), whilst the CDSK achieves the same value of BER at a SNR value of (13 dB). So, it is needed to increase the SNR by the two to obtain the same value of BER of DCSK, or it is also possible to double the spreading factor value to achieve the same BER value at (11 dB) SNR.



(a) (b)

FIG. 5. BER PERFORMANCE OF (a) DCSK, (b) CDSK.

The performance of COOK, QCSK, DCSK, and CDSK can be improved by using frequency modulation (FM) as described in section (II). Figures (6) and (7) show the performances of these schemes when using FM in their structures.

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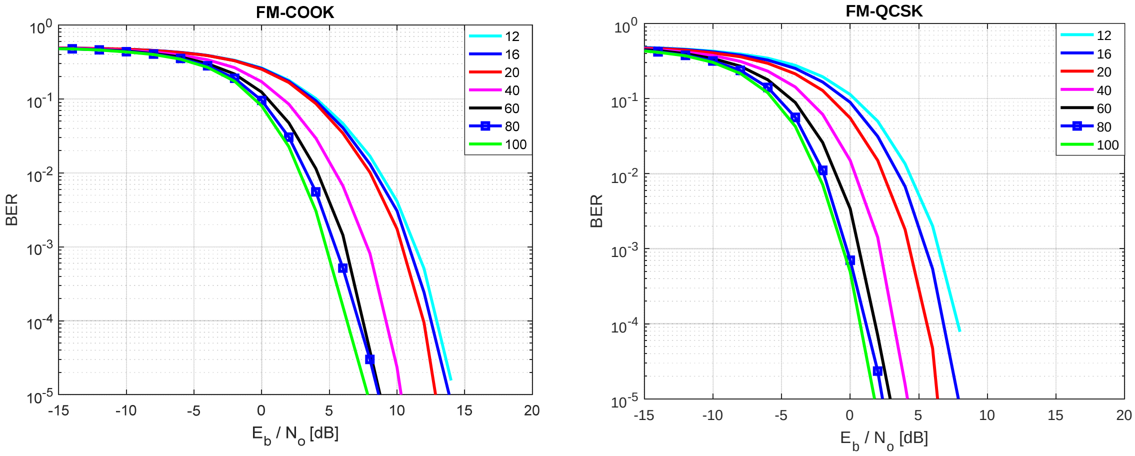
As seen in Figure (6), the required SNR value needed to achieve BER value of ($10^{-4}$) at spreading factor of (40) is decreased from (14 dB) to (3 dB) by using FM-QCSK. Almost the same reduction in the required value of SNR can be obtained when using FM-CDSK and FM-DCSK modulation schemes as compared with CDSK and DCSK, respectively. As shown in Figure (7), FM-CDSK eliminates symbol energy variation, which leads to reduce the bit error rate and duplicate the transmission rate in comparison with FM-DCSK. No noticeable enhancement was obtained from using FM-COOK in comparison with COOK.

According to TABLE (2), QCSK, COOK, DCSK, CDSK, and FM-COOK performances are less than the remaining chaotic modulation schemes so the performances of these schemes are evaluated again at spreading factor values of (120,140, and 180) and are shown in Figures (8, 9, and 10). In spite of increasing the spreading factor values from (100 to 180), the required value of SNR to obtain BER value of ($10^{-4}$) is reduced by two only and FM-DCSK shows no enhancement.

TABLE (2) THE REQUIRED $E_B/N_O$ TO ACHIEVE BER OF ($10^{-4}$) FOR VARIOUS CHAOTIC MODULATION SCHEMES

| | $E_b/N_o$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Scheme<br>β | ACSK | CSK | QCSK | FM-QCSK | COOK | FM-COOK | DCSK | FM-DCSK | CDSK | FM-CDSK | ICM |
| 40 | -2 | -2.1 | 14.3 | 3.2 | 8.7 | 9.1 | 11 | 4.2 | 13.2 | 1.4 | 4.2 |
| 100 | -6 | -5.9 | 10.8 | 0.7 | 5 | 6.2 | 8 | 5.4 | 11 | -0.2 | -0.45 |
| 180 | - | - | 8.5 | - | 3 | 4.2 | 6 | 4 | 9 | - | - |



(a) (b)

FIG. 6. BER PERFORMANCE OF (a) FM-COOK, (b) FM-QCSK.

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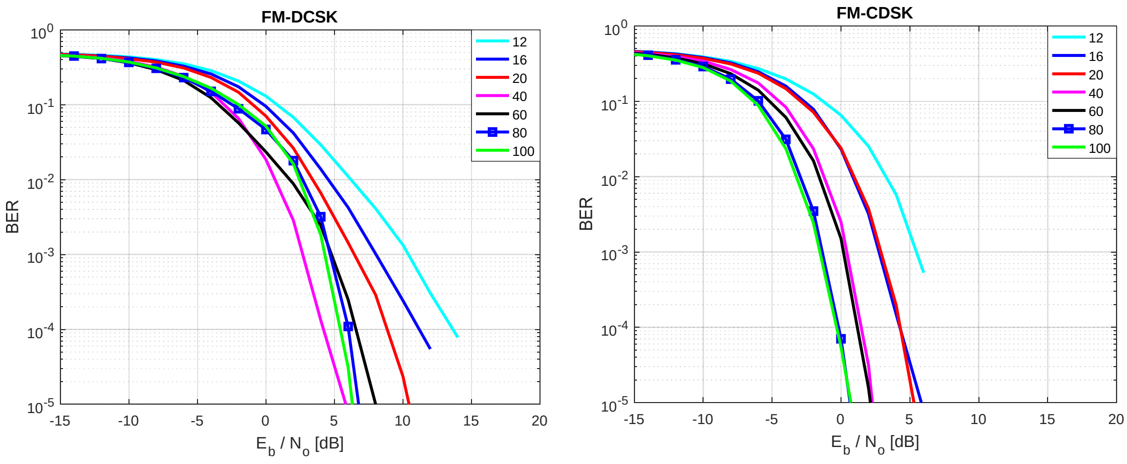
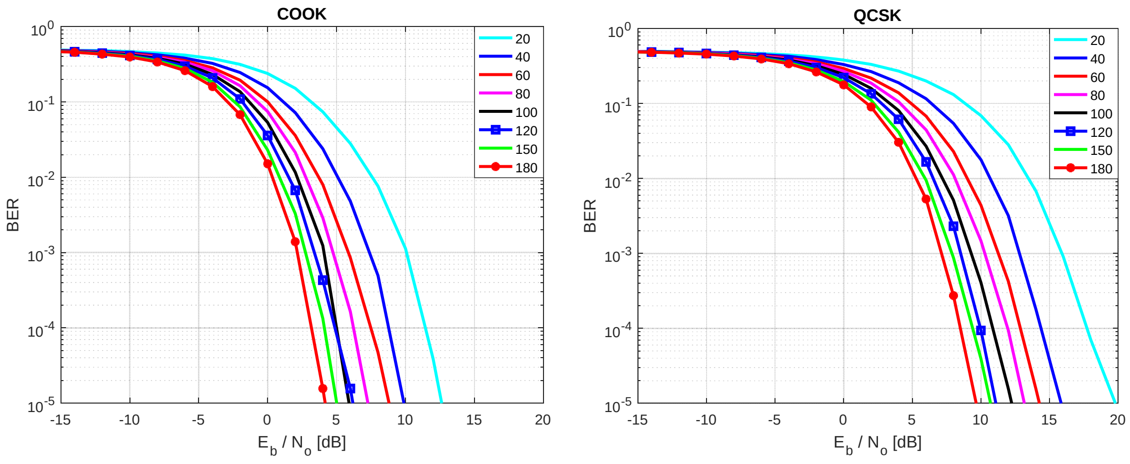


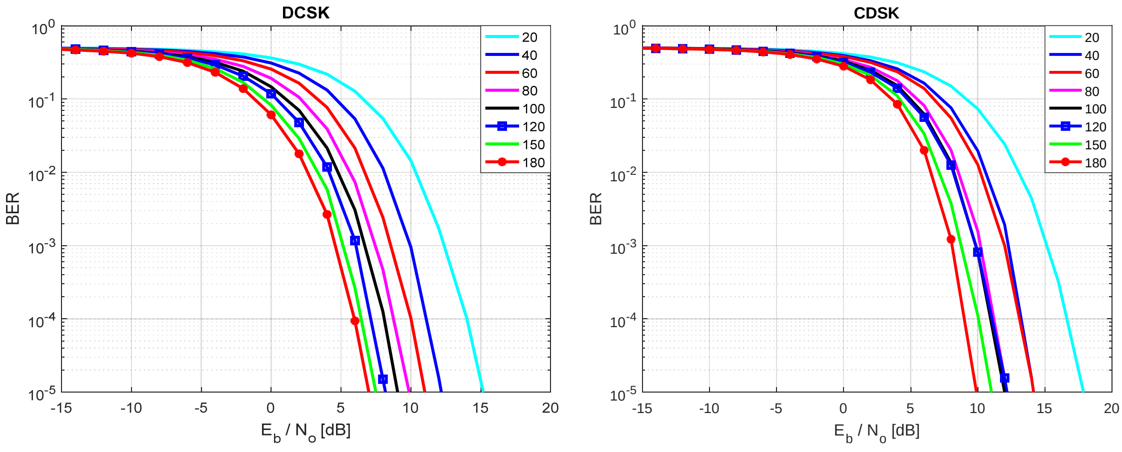
(a) (b)

FIG. 7. BER PERFORMANCE OF (a) FM-DCSK, (b) FM-CDSK.



(a) (b)

FIG. 8. BER PERFORMANCE OF (a) COOK, (b) QCSK



(a) (b)

FIG. 9. BER PERFORMANCE OF (a) DCSK, (b) CDSK

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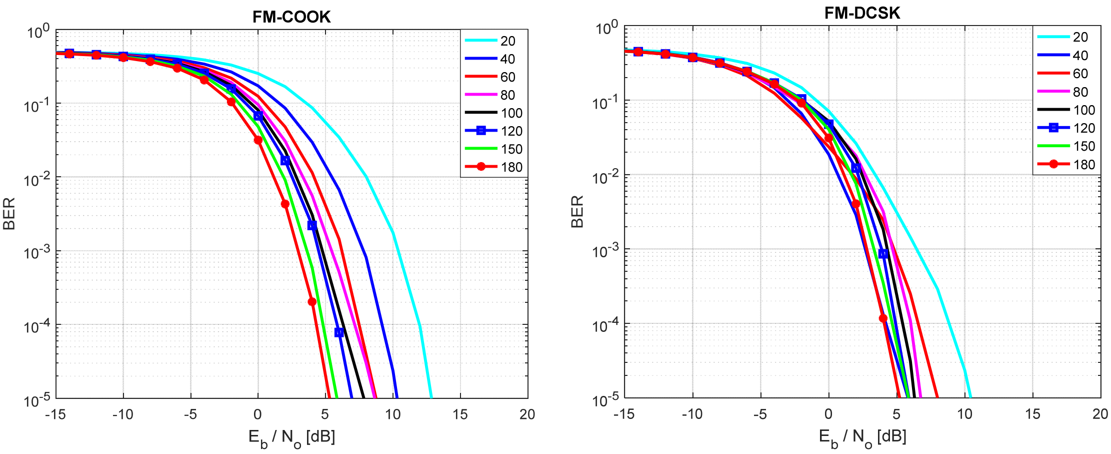

(a) (b)

FIG. 10. BER PERFORMANCE OF (a) FM-COOK, (b) FM-DCSK

Finally, the performance of ICM scheme is shown in Figure (11). It achieves a BER value of($10^{-4}$) at SNR value of (4.26 dB) for spreading factor value of (40) which is the same for the FM-DCSK. As shown in Figure (11), the performance achievement of ICM is comparable with those of ACSK and CSK. However, due to the nature of its structure, it takes more processing time than other CSK schemes.

Figure (12) shows a performance comparison among all chaotic modulation schemes for spreading factors equal to 40 and 100, respectively. These two values of the spreading factor will be adopted when the chaotic OFDM system is implemented in the future work. According to Figure (12), the suitable chaotic modulation scheme that achieves good BER can be determined.

## V. CONCLUSION

1. ACSK and CSK provide superior performance with respect to the other modulation schemes. However, these two techniques can serve from synchronization error, so their performance is related strongly to achieve good synchronization.
2. Increasing the spreading factor enhances the performance of the chaotic system but it also increases the time spent to process the data and the memory needed to store these data, which makes the implementation of the system more difficult. Therefore, this factor should be taken into consideration when choosing the appropriate chaotic modulation scheme.

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