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Effect of Power Amplifier Nonlinearity on M-ary FSK Modulation Using Two Different Media.

Fathia Abdusalam Hussain [1] , Mohamed M. M. Elfituri[2], Amer Ragab Zerek[3]

[1]Libyan Academy, Electrical and Computer Department
Triploi, Libya
E-mail: Om.shima24@gmail.com.
[2]Authority of Natural Science Research and Technology
Tripoli, Libya
E-mail: melfituri@yahoo.com
[3]Zawia University. Faculty of Engineering , Electrical and Electronic Eng. Department
Zawia Libya
E-mail anas_az94@yahoo.co.uk
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Abstract- **Wireless communication systems suffer a great deal from the inherent nonlinear nature of power amplifiers. Where the power amplifier is the most power-consuming block in wireless communication systems. It used to amplify the modulated signal before transmission. But in conversely the amplifier distort the transmitted signal.**
This paper presents the simulation of the effect of power amplifier nonlinearity on M-ary FSK. Where using Matlab/Simulink environment. Also we are used the constellation diagram to illustrate the nonlinearity affecting on constellation of the M-ary FSK modulation and BER curves are used as performance measure.

Keyword- M-ary Frequency Shift Keying (M-FSK), Nonlinear amplifier, bit error rate (BER), Additive White Gaussian Noise (AWGN).

1. Introduction.

Power amplifiers are an important component in modern communications systems, which are providing the transmit signal levels needed to overcome the loss between the transmitter and receiver. However, they also introduce problems. Amplifiers usually operate as a linear device under small-signal conditions and become more nonlinear and distorting with increasing drive level[1]. The nonlinear effects in RF Amplifier like Gain Compression cause Power Efficiency problems especially in multilevel modulation scheme such as M-ary Phase Shift Keying (MPSK) and M-ary Quadrature Amplitude Modulation (MQAM)[3]. The main problem with the nonlinearity behavior is amplitude (AM-to-AM) and phase (AM-to-PM) distortions in the system. This nonlinearity behavior causes adverse effects on the system performances such as bit error rate (BER) and constellation diagram[2].
In this paper we will simulate the M-FSK, modulation which is affected by nonlinear amplifier, and the results of simulation will be in section '5'.

2. M-ary Carrier Digital Modulation Techniques.

In M-ary modulation scheme two or more bits are grouped together to form symbols and one of possible signals $s_1(t)$, $s_2(t)$,…, $s_m(t)$ is transmitted during each symbol period T_s. Normally, the number of possible signals is $M = 2^n$, where n is an integer, and the symbol duration $T_s = nT_b$, where T_b is the bit duration. depending on whether the amplitude, phase or frequency is varied the modulation is referred to as M-ary Quadrature Amplitude Modulation M-ary QAM, M-ary PSK and M-ary FSK, respectively. These techniques achieve better bandwidth efficiency at the expense of power efficiency, conversely M-ary signaling results in poorer error performance because of smaller distances between signals in the constellation diagram[4].

2.1 M-ary FSK modulation.

In M-ary FSK, the input data sequence is divided into n-bit groups, then each group could be encoded as one of M carrier frequency, where one of these M frequencies will be sent during each bit time[5]. The mathematical representation of M-ary FSK signal is given by:

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$$s_i(t) = \sqrt{\frac{2E}{T}} \cos\left[\frac{\pi}{T}\,(n_c + i)t\right], \qquad 0 \le t \le T \qquad (1)$$

Where :

$i = 1,2,\ldots,M$, and $n_c = 2Tf_c$, for some fixed integer n_c .

3. Nonlinear Amplifier.

A high power amplifier (HPA) is an important component in communications systems, providing the high transmit signal level needed to overcome the loss between the transmitter and receiver. Under small signal conditions, the amplifier operates as a linear device. Their characteristic becomes more nonlinear and distorted when the drive level increases and goes beyond a contain threshold.

There are two main drawbacks of power amplifiers :

- The amplifier can consume a major fraction of the power used by the system.
- The amplifier can also distort the transmitted signal, introducing additional noise within the signal frequency band and generating unwanted frequencies in adjacent channels.

The complex envelope of the signal at the input of the HPA is

$$x(t) = p(t)\, e^{j\varphi(t)} \qquad (2)$$

where $p(t)$ is the amplitude and $\varphi(t)$ is the phase of input signal, and the complex envelope of the output signal can be expressed as

$$y(t) = A[p(t)]\, e^{j\{\varphi(t)+\Phi[p(t)]\}} \qquad (3)$$

$A[p(t)]$ represents the AM/AM conversion and $\Phi[p(t)]$ the AM/PM conversion characteristics of the power amplifier.

The nonlinearity in the amplifier has two major effects on the QAM signals:

- It introduces nonlinear distortion to transmitted signals.
- It expands the spectrum of the signals[6].

4. Bit Error Rate (BER).

BER is a performance measurement that specifies the number of bit corrupted or destroyed as they are transmitted from its source to its destination. Several factors that affect BER include bandwidth, SNR, transmission speed and transmission medium. The definition of bit error rate can be translated into a simple formula[7]:

$$\text{Bit Error Rate (BER)or } (p_b) = \frac{number\ of\ bits\ in\ error}{Total\ number\ of\ transfered\ bits}$$

Generally, high noise (low SNR) can lead to high BER. High BER is bad, and usually leads to observable problems with the signal. It is important to note that probability of error" POE" is proportional to Eb/No and is a form of signal to noise ratio.

The probability of symbol error p_e for M-FSK, M-PSK, and M-QAM respectively are:

For M-FSK:

$$p_e = \frac{1}{2}(M-1)\ erfc\left(\sqrt{\frac{E}{2N_o}}\right) \qquad (4)$$

5. Simulation Model:

M-ary FSK modulator and demodulator are implemented in Simulink (matlab) as shown in figure (2). The begins with the random Integer Generator block which generates uniformly distributed random integers in the range [0, *M*-1], where M is the M-ary number. Then the uniformly generated random integer is then fed to baseband modulator of the M-FSK modulation, where it is performed with a large carrier. The output is a baseband representation of the modulated signal where it is fed to the Raised Cosine Transmitter Filter block upsamples and filters the input signal using a square root raised Cosine FIR Filter. After that the signal is then passed through the ideal channel or to the AWGN channel which adds white Gaussian noise to a real or complex input signal. This block inherits its sample time from the input signal. On the receiver end the demodulator receives the copy of the original signal, which is now affected due to ISI and noise in the channel and bit error rate is calculated. The demodulated signal is also a baseband representation. Next we have error rate calculator in which the transmitted and received signal are compared and the difference is treated as 'error'. The error rate, total number of transmitted bits and total number of error bits are displayed by display block.

The simulation of the model will be made for different levels such as M=4,8,16, and 32. Also the model simulated at two different values of symbol rates (F=10MHz,40MHz), gains, and with/without presence of nonlinear amplifier. The simulation results are shown in the following section.

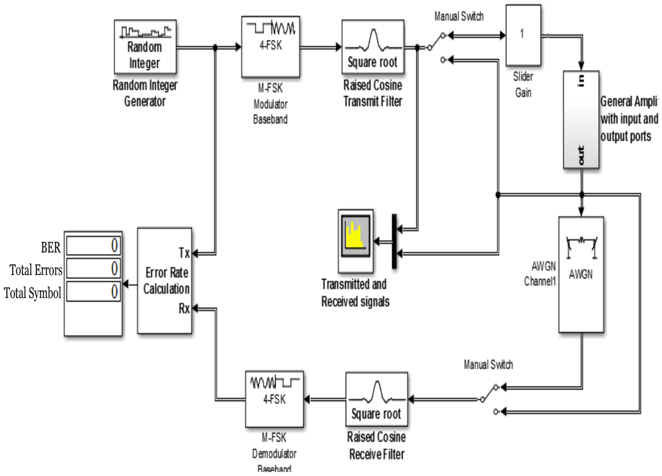


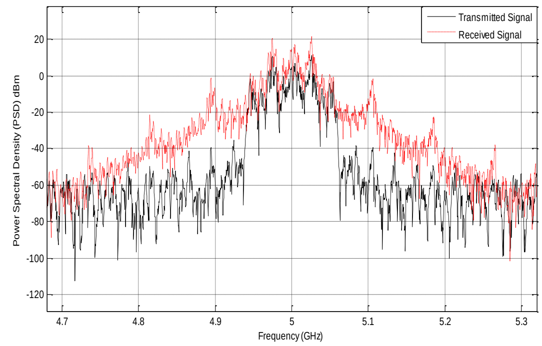
Figure 1: Simulink Model of M-ary FSK, Modulator/Demodulator.

6. Simulation Results:

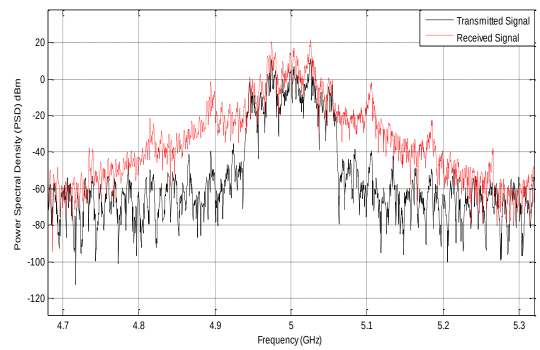
The simulation results of the model of figure 2 are classified as two way, first one for an ideal channel, and the second for AWGN channel.

●Ideal Channel.

- **M=4**

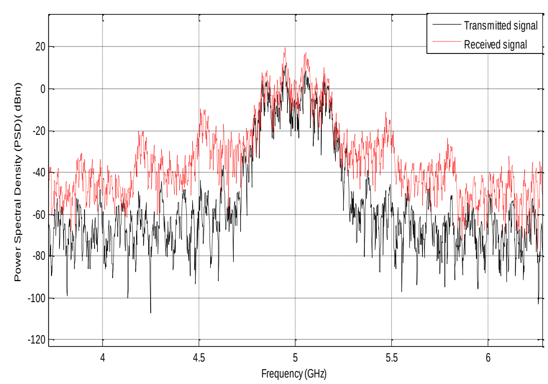


(a) Δ**f =109MHz, G=1.**

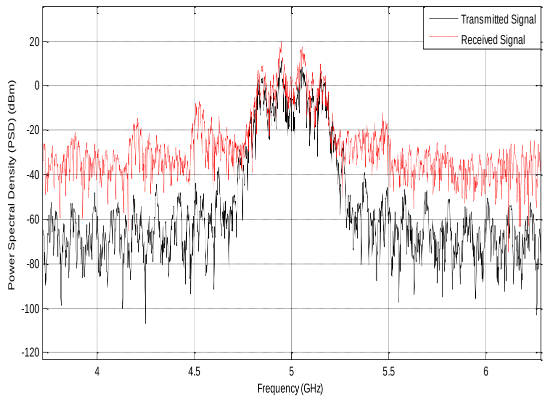


(b)Δ**f =109MHz, G=5.**

Figure 2: 4-FSK Amplifier Input/Output PSD's at Symbol Rate F=10MHz for Ideal Channel.



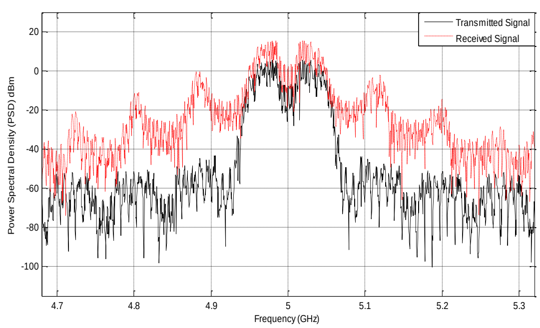
(a) Δ**f =109MHz, G=1.**



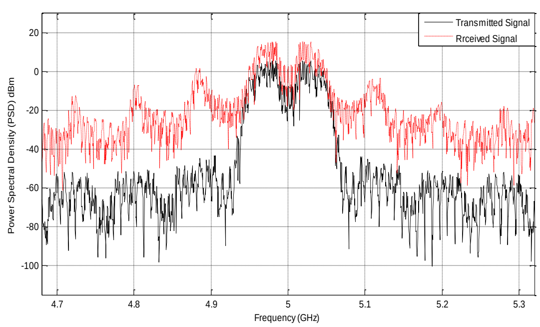
(b)Δf =**109MHz, G=5.**

Figure 3: 4-FSK Amplifier Input/Output PSD's at Symbol Rate F=40MHz for Ideal Channel.

- **M=8**

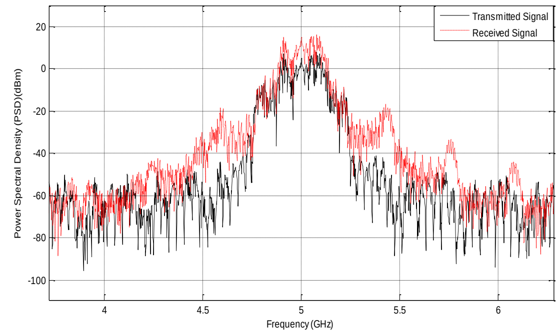


(a) **Δf =35MHz, G=1.**

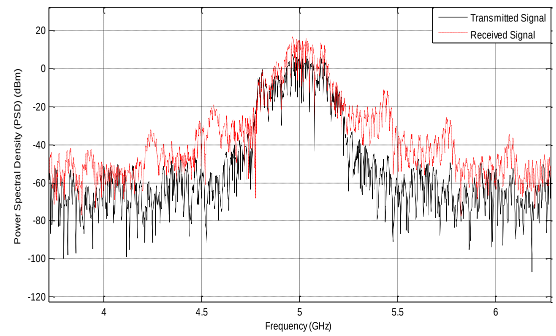


(b)**Δf =35MHz, G=5.**

Figure 4: 8-FSK Amplifier Input/Output PSD's for Ideal Channel at Symbol Rate 10MHz:



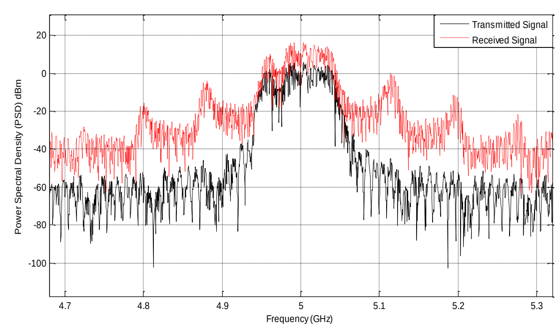
(a) **Δf =35MHz, G=1.**



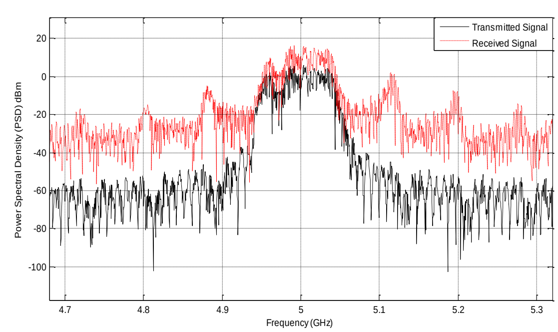
(b)**Δf =35MHz, G=5.**

Figure 5: 8-FSK Amplifier Input/Output PSD's for Ideal Channel at Symbol Rate 40MHz:

- **M=16.**

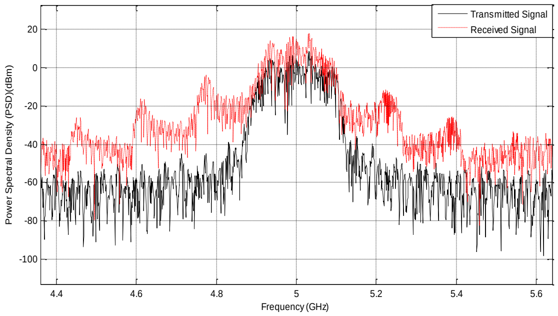


(a) **Δf =25MHz, G=1.**

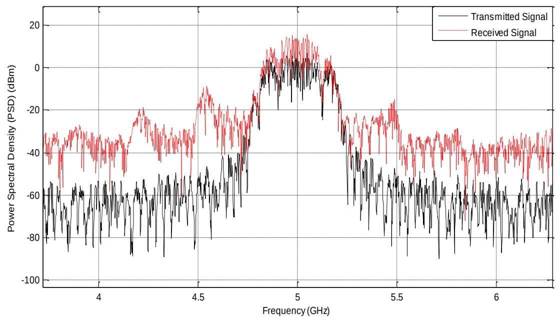


(b)**Δf =25MHz, G=5.**

Figure 6: 16-FSK Amplifier Input/Output PSD's for Ideal Channel at Symbol Rate 10MHz:



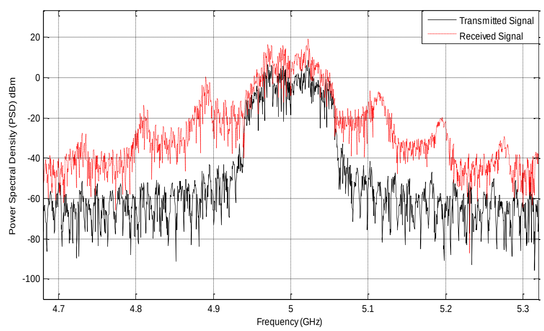
(a) **∆f =25MHz, G=1.**



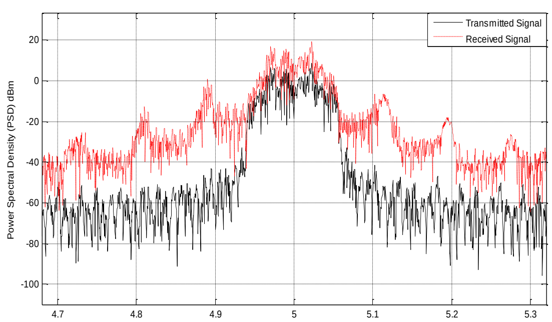
(b)**∆f =25MHz, G=5.**

Figure 7: 16-FSK Amplifier Input/Output PSD's for Ideal Channel at Symbol Rate 40MHz:

- **M=32.**

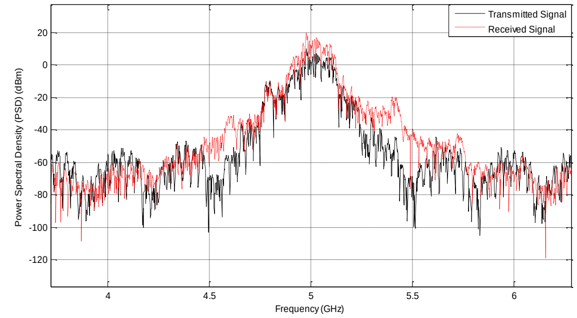


(a) **∆f =6.5MHz, G=1.**

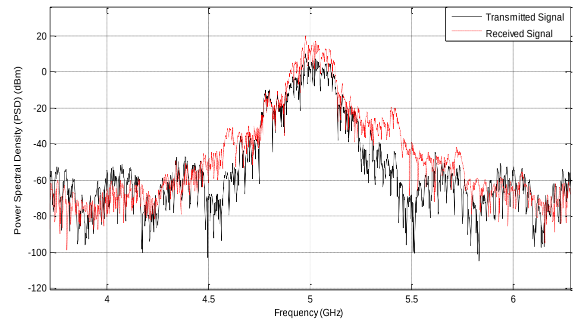


(b)**∆f =6.5MHz, G=5.**

Figure 8: 32-FSK Amplifier Input/Output PSD's for Ideal Channel at Symbol Rate 10MHz:



(a) **∆f =6.5MHz, G=1.**



(b)**∆f =6.5MHz, G=5.**

Figure 9: 32-FSK Amplifier Input/Output PSD's for Ideal Channel at Symbol Rate 40MHz:

Figures 3,4,5,6,7,8,9 and 10 show the amplifier input and output PSD signals for M-FSK modulation, where M=4,8,16,and 32 respectively. These figures illustrate the effect of amplifier nonlinearity, which appears as an out of band distortion in the form of spurious components in the frequency domain in the adjacency of the original signal bandwidth, which is often referred by **spectral regrowth** where it is increased by varying of nonlinearity amounts.

●*AWGN Channel.*

- **M=4**

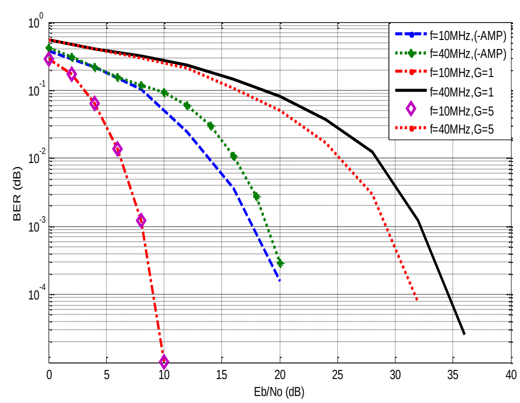


Figure 10:4-FSK BER Curves for ∆f=109MHz.

- **M=8**

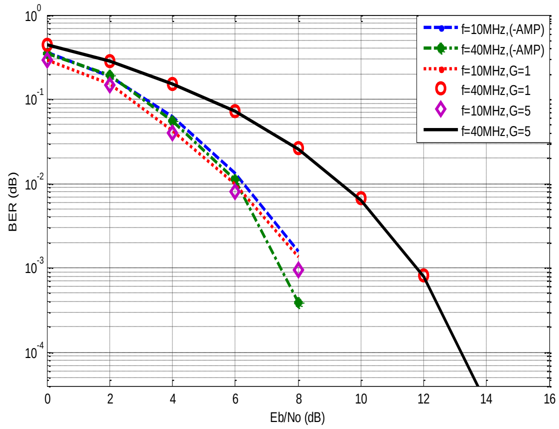


Figure 11:8-FSK BER Curves for Δf=35MHz.

- **M=16.**

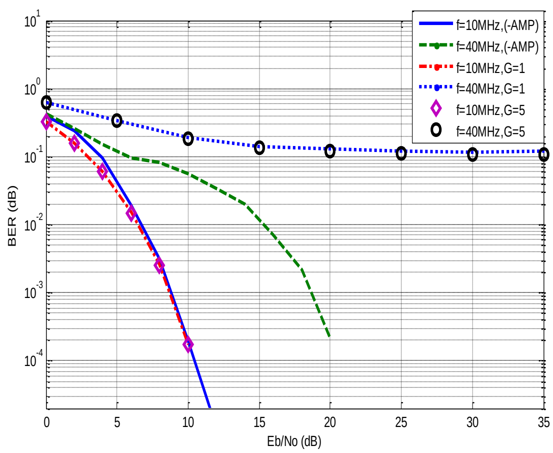


Figure 12:16-FSK BER Curves for Δf=25MHz.

- **M=32.**

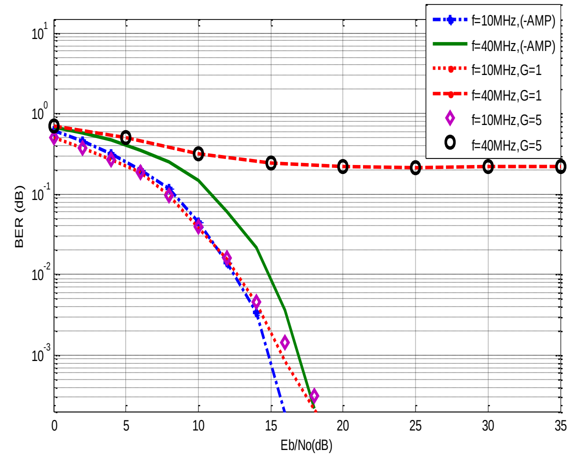


Figure 13:32-FSK BER Curves for Δf=6.5MHz.

● M-ary FSK Modulation Comparison.

The next figures indicate the BER curve measurements of the previous four types of M-ary FSK modulation, such as 4-FSK, 8-FSK, 16-FSK, and 32-FSK respectively, in the presence of nonlinear amplifier and AWGN channel for different values of symbol rate, and for different amount of nonlinearity.

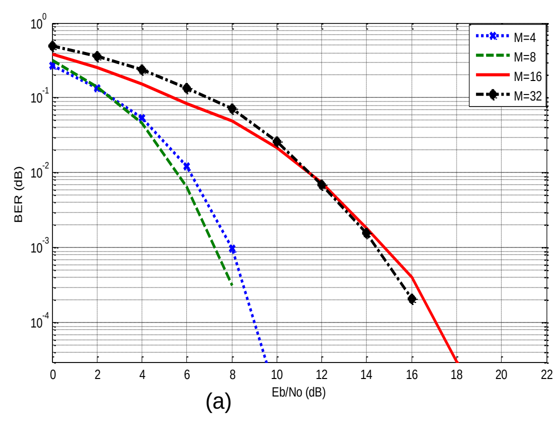


Figure 14:M-ary FSK BER Curve Measurements Comparison for Δf =17.5MHz, Symbol Rate 10MHz, G=1.

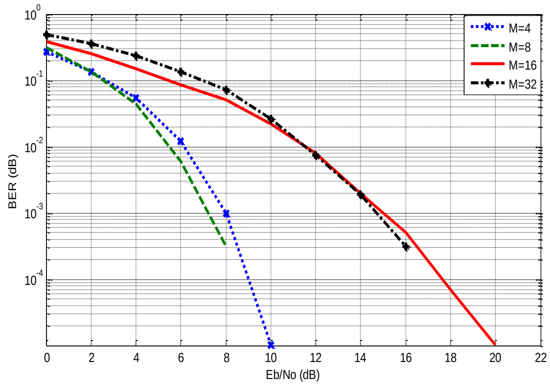


Figure 15:M-ary FSK BER Curve Measurements Comparison for Δf =17.5MHz, Symbol Rate 10MHz, G=5.

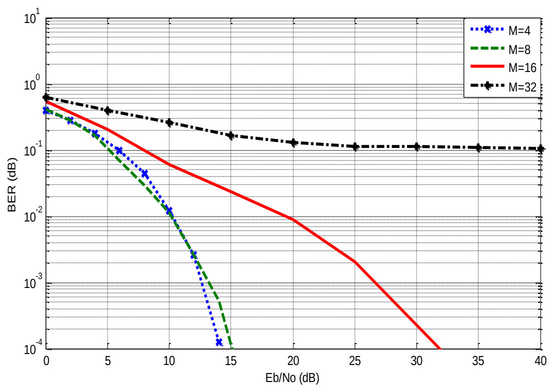


Figure 16:M-ary FSK BER Curve Measurements Comparison for Δf =17.5MHz, Symbol Rate 40MHz, G=1.

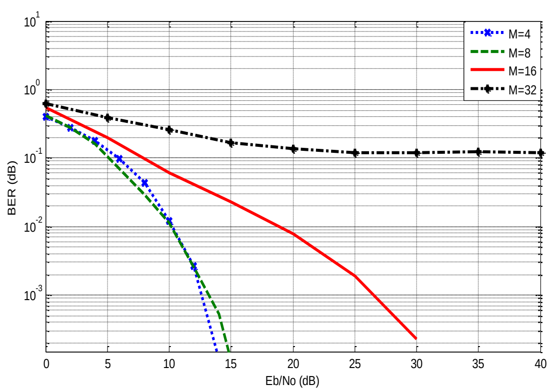


Figure 17:M-ary FSK BER Curve Measurements Comparison for Δf =17.5MHz, Symbol Rate 40MHz, G=5.

The previous figures show the comparison between BER versus (E_b/N_o) curves for M-ary FSK modulation and different values of symbol rates and gains. from these curves it is observed that beside the effect of noise, the changeable gain has not a big effect on BER versus (E_b/N_o) curves of M-ary FSK for M=4,8,16, and 32. Also it is observed that the BER values become high when level M and symbol rate increased.

7. conclusion:

The objective of this paper is to compare the performance of M-ary FSK modulation, when the modulated signal pass through a nonlinear amplifier and noisy channel. where the simulink model was applied for M=4,8,16, and 32, and it can conclude to the following points.

- When an amplifier is operating near or in the nonlinear region, it produces amplitude and phase distortion which are characterized in term of AM-AM and AM-PM conversions.
- Amplifier distortion can be divided into two main groups, generation of harmonic components, and generation of inter-modulation distortion which cause the spectral regrowth.

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2Department of Electronic and Communication Engineering, IIIT-Allahabad. bharathrgaddam@gmail.com
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