# QAM SIMULATION

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# Effects of differing QAMs

In this section we will cover:

- What is QAM
- Why higher values of M are used
- Our findings
- (change this slide as we populate next section)

# What is QAM and why is it used?

- In carrier phase modulation we view the signal as two orthogonal carrier signal (cos2nfct and sin2nfct) amplitude modulated by their information bits, but constrained to have energy Es
- In Quadrature Amplitude Modulation (QAM) we remove this restriction and obtain signals with the format $u_m(t) = A_{mc} g_T(t) \cos 2\pi f_c t - A_{ms} g_T(t) \sin 2\pi f_c t, \quad m = 1, 2, \ldots, M,$
- Changing M, or moving to larger constellations, allows use to transmit more bits per symbol; each symbol in a constellation represents a potential pulse that carries log2(M) bits of information
- This allows higher data rates as pulses (symbols) no longer signal only "0" or "1"
- A large reason QAM is used is that since simple amplitude modulation requires the carrier signal to have twice the bandwidth of the modulating signal, QAM lessens the use of the available frequency spectrum by having two signals out of phase by ninety degrees occupy the same area of the frequency spectrum
- QAM has both phase and amplitude modulation components

# Effects of differing Ms

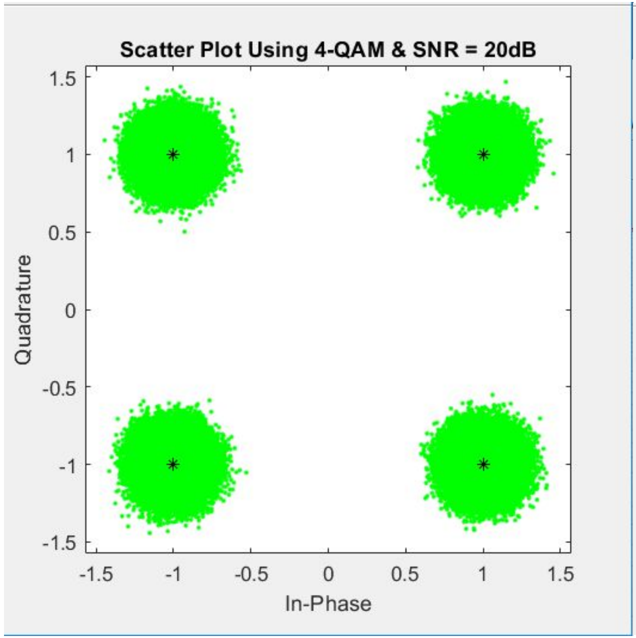
## Why did we use rectangular constellations for all three values?

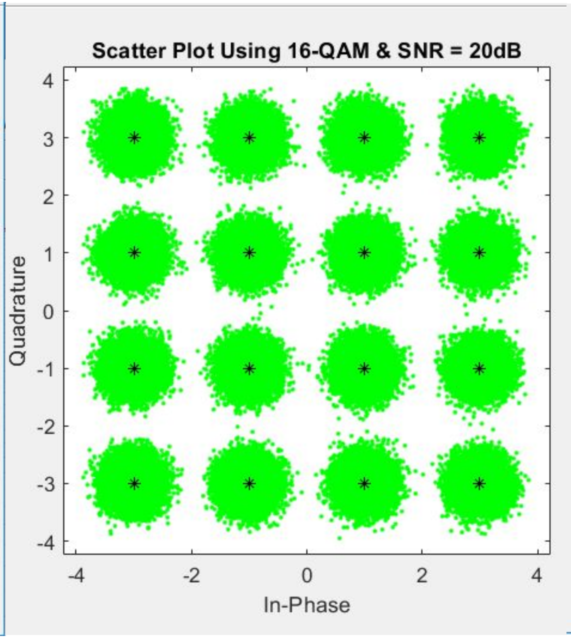
- Although more energy efficient constellations exist for $M \geq 4$, they are not more efficient by a large margin
- Rectangular constellations can be represented by two PAM signals modulated by phase quadrature carriers
- This eases analysis by allowing us to use a modification of the probability of error for PAM signals:

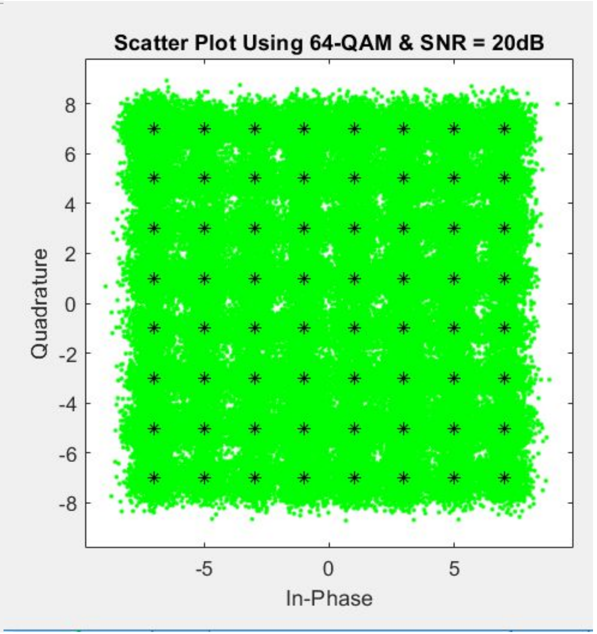
$$P_{\sqrt{M}} = 2\left(1 - \frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3}{M-1}\frac{\mathcal{E}_{\mathrm{av}}}{N_0}}\right),$$

- Where the theoretical probability for a M-QAM system is:

$$P_M = 1 - \left(1 - P_{\sqrt{M}}\right)^2.$$


Scatter Plot Using 4-QAM & SNR = 20dB
Quadrature
In-Phase
1.5
1
0.5
0
-0.5
-1
-1.5


Scatter Plot Using 16-QAM & SNR = 20dB
Quadrature
In-Phase
4
3
2
1
0
-1
-2
-3
-4


Scatter Plot Using 64-QAM & SNR = 20dB
Quadrature
In-Phase
8
6
4
2
0
-2
-4
-6
-8
-5
5

# Bit Rate Error Analysis Results

The Gray coding bit error rate = 0.00e+00, based on 0 errors for M = 4 & SNR = 20dB

The binary coding bit error rate = 0.00e+00, based on 0 errors for M = 4 & SNR = 20dB

The theoretical binary coding bit error rate = 0.00e+00, for M = 4 & SNR = 20dB

The Gray coding bit error rate = 3.86e-06, based on 3 errors for M = 16 & SNR = 20dB

The binary coding bit error rate = 7.72e-06, based on 6 errors for M = 16 & SNR = 20dB

The theoretical binary coding bit error rate = 2.90e-06, for M = 16 & SNR = 20dB

# Bit Rate Error Analysis Results

The Gray coding bit error rate = 9.13e-03, based on 7102 errors for M = 64 & SNR = 20dB

The binary coding bit error rate = 1.56e-02, based on 12159 errors for M = 64 & SNR = 20dB

The theoretical binary coding bit error rate = 8.38e-03, for M = 64 & SNR = 20dB

Transmitted Image

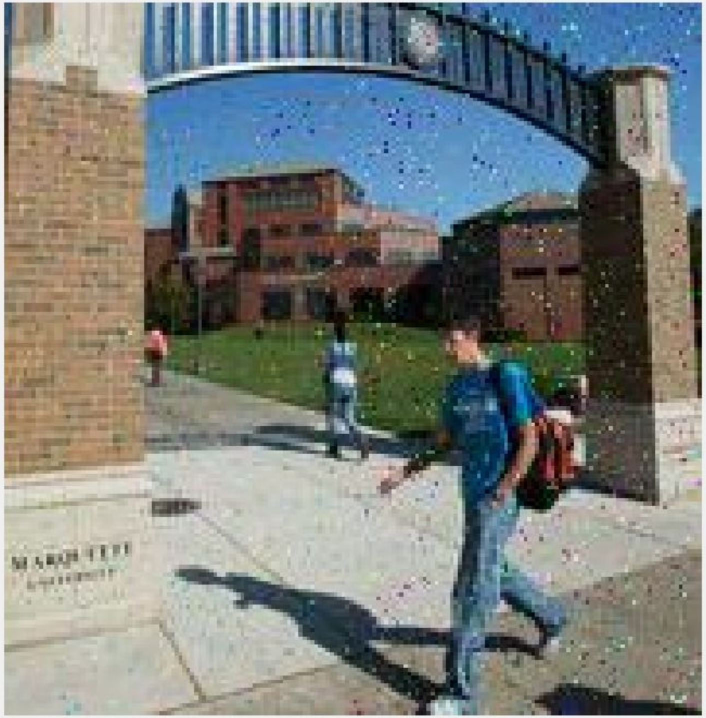
Received Image Using 4-QAM & SNR = 20dB

Transmitted Image


Received Image Using 16-QAM & SNR = 20dB

Transmitted Image

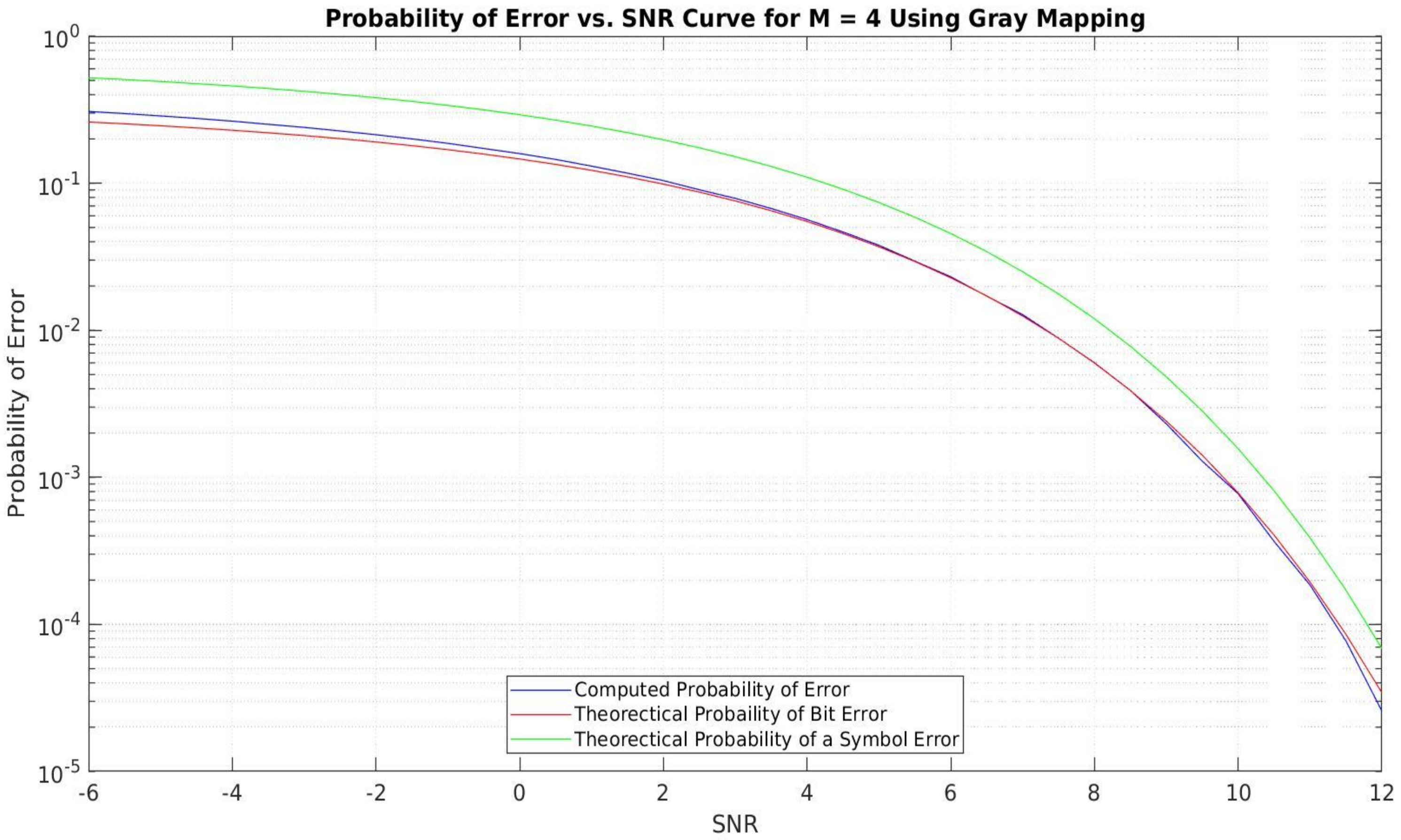

Received Image Using 64-QAM & SNR = 20dB



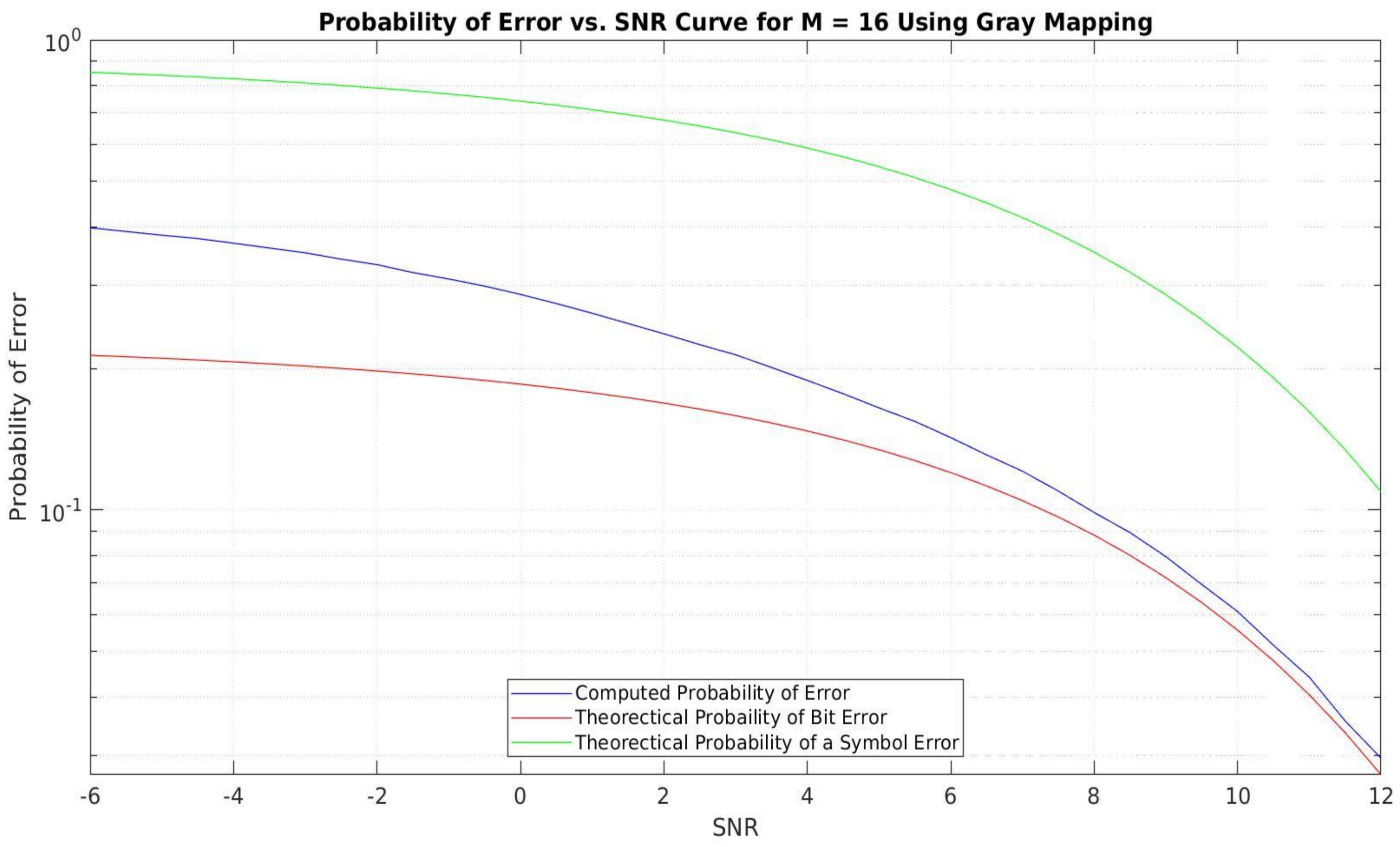
# More distortion as M increases, why?

- As we can see, the higher the M value the more points there are on our constellation
- However all other factors remaining constant these points get closer together
- This increases the likelihood of error as there is less distance between the symbols and a higher likelihood the transmitted bits will be mapped to an incorrect symbol
- Due to this QAM is useful primarily when there is a high Signal-to-Noise Ratio; whether this is achieved by reducing noise or increasing the power of the signal

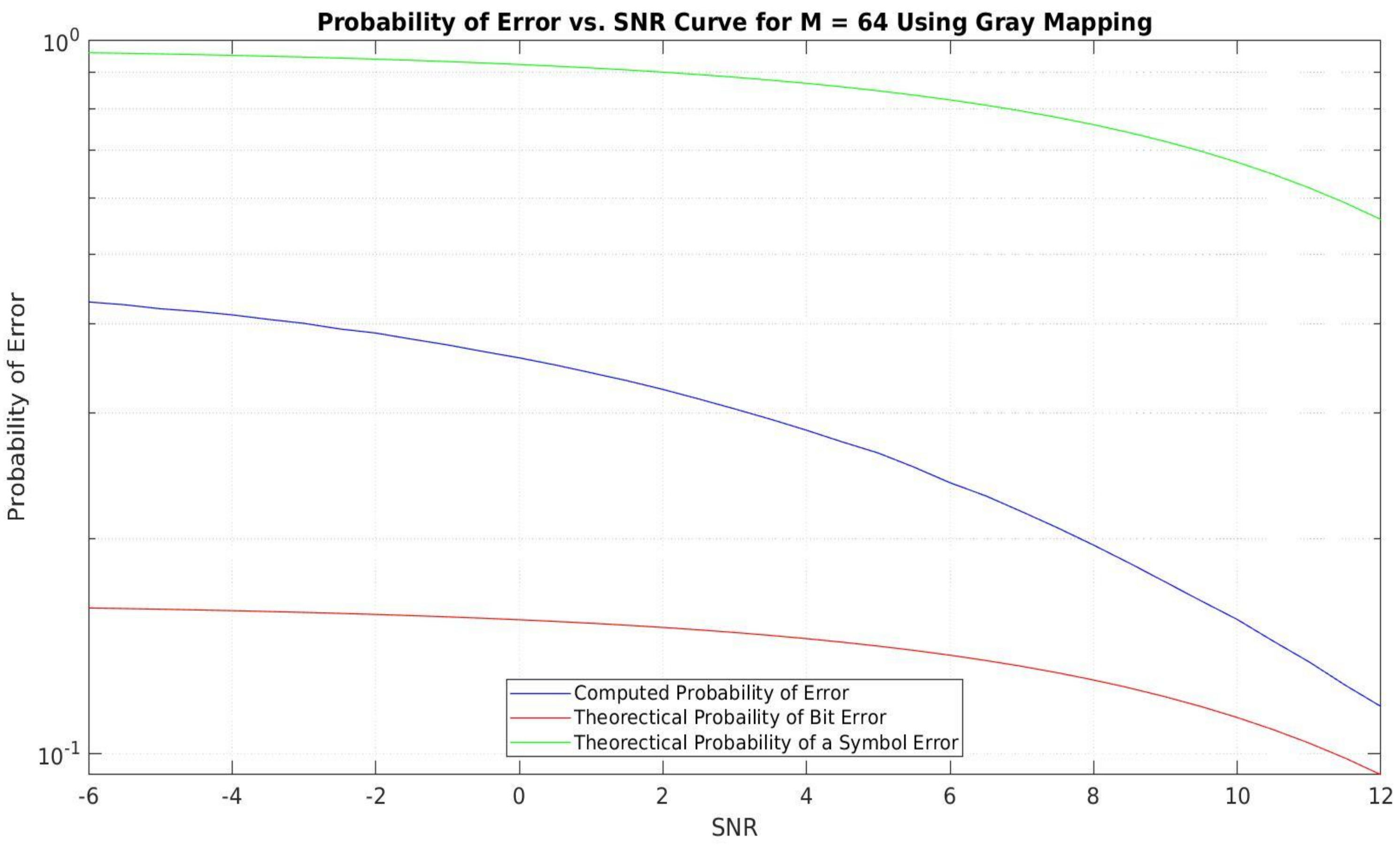
# Changing SNR



Probability of Error vs. SNR Curve for M = 4 Using Gray Mapping
Probability of Error
SNR
Computed Probability of Error
Theorectical Probaility of Bit Error
Theorectical Probability of a Symbol Error

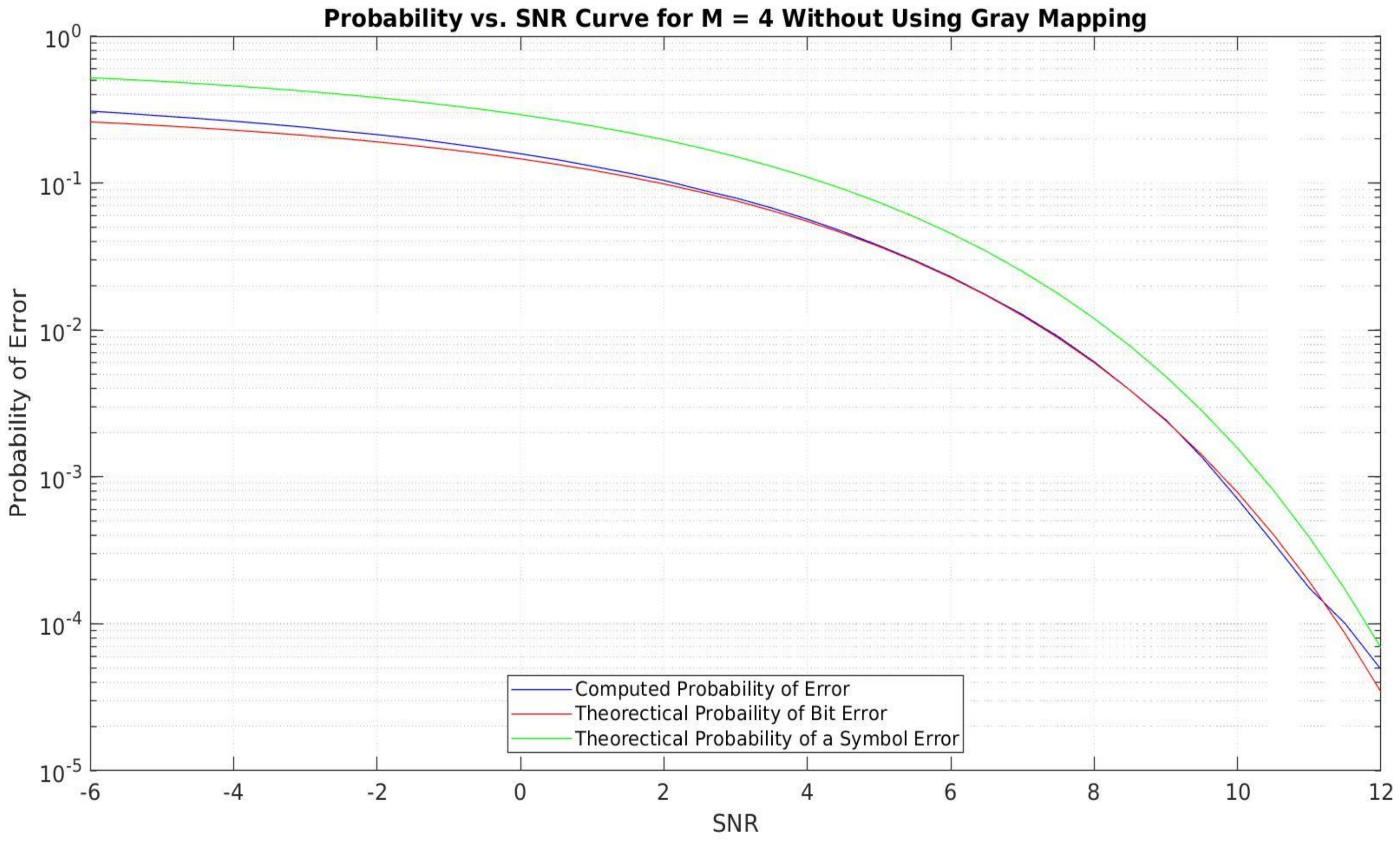


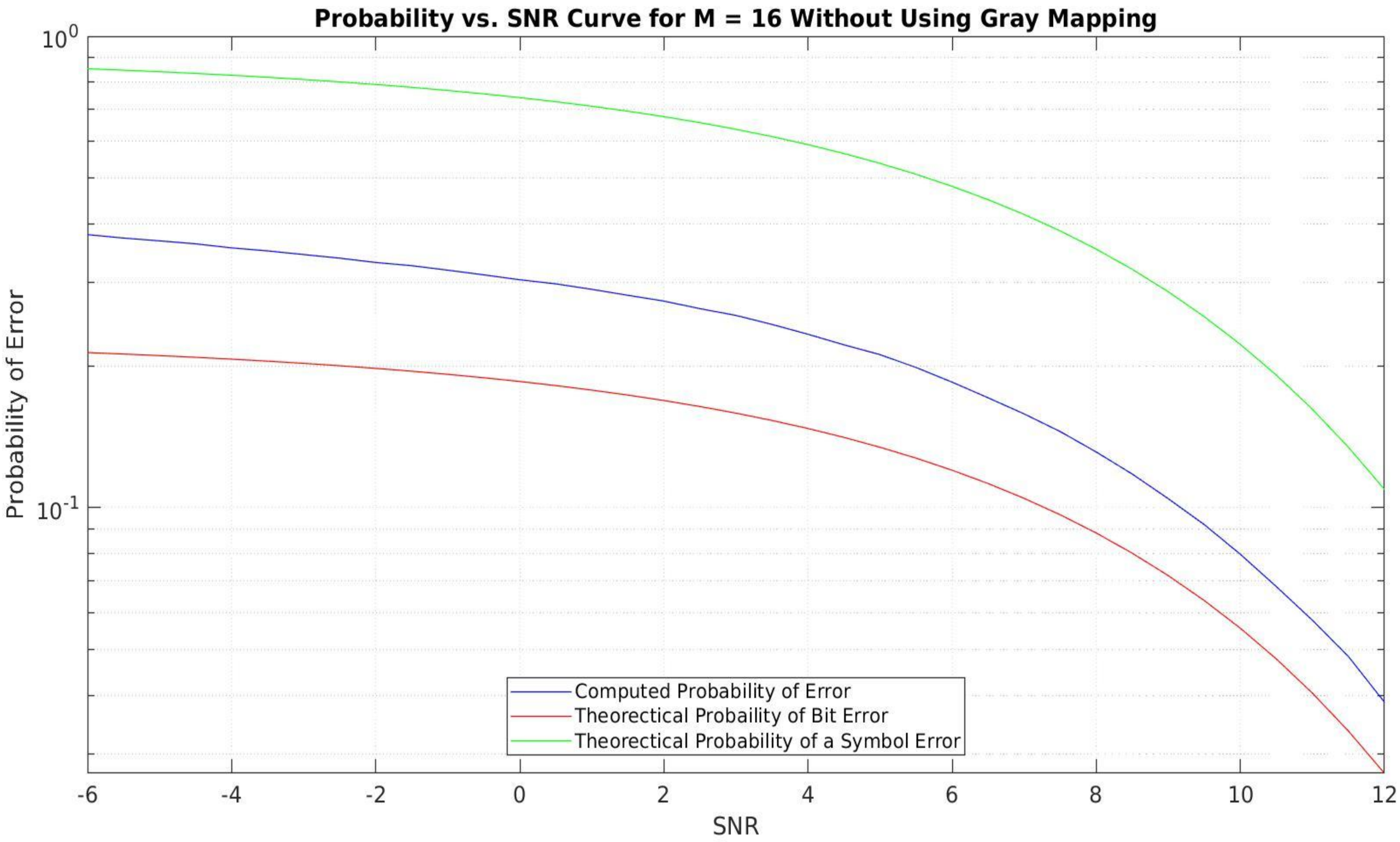
Probability of Error vs. SNR Curve for M = 16 Using Gray Mapping
Probability of Error
10^0
10^-1
-6
-4
-2
0
2
4
6
8
10
12
SNR
Computed Probability of Error
Theorectical Probaility of Bit Error
Theorectical Probability of a Symbol Error


Probability of Error vs. SNR Curve for M = 64 Using Gray Mapping
Probability of Error
SNR
10^0
10^-1
-6
-4
-2
0
2
4
6
8
10
12
Computed Probability of Error
Theorectical Probaility of Bit Error
Theorectical Probability of a Symbol Error

# On Gray Code

- Gray Code is an encoding scheme where subsequent binary numbers are represented by a single bit changing.
- EX: in four bits 1,2,3,4 is represented by 0001,0011,0010,0110 instead of 0001,0010,00011,0100
- This helps for our project because in the case of an error where an incorrect symbol is transmitted, there is likely only a 1 bit difference, which should have limited effect on the RGB value of a pixel
- However in real world applications this has limited utility; a one bit difference could lead to a completely different ASCII symbol if words are being transmitted, which could turn a message of “$2000” into “$3000”


Probability vs. SNR Curve for M = 4 Without Using Gray Mapping
Probability of Error
SNR
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
-6
-4
-2
0
2
4
6
8
10
12
Computed Probability of Error
Theorectical Probaility of Bit Error
Theorectical Probability of a Symbol Error


Probability vs. SNR Curve for M = 16 Without Using Gray Mapping
$10^0$
$10^{-1}$
Probability of Error
-6
-4
-2
0
2
4
6
8
10
12
SNR
Computed Probability of Error
Theorectical Probaility of Bit Error
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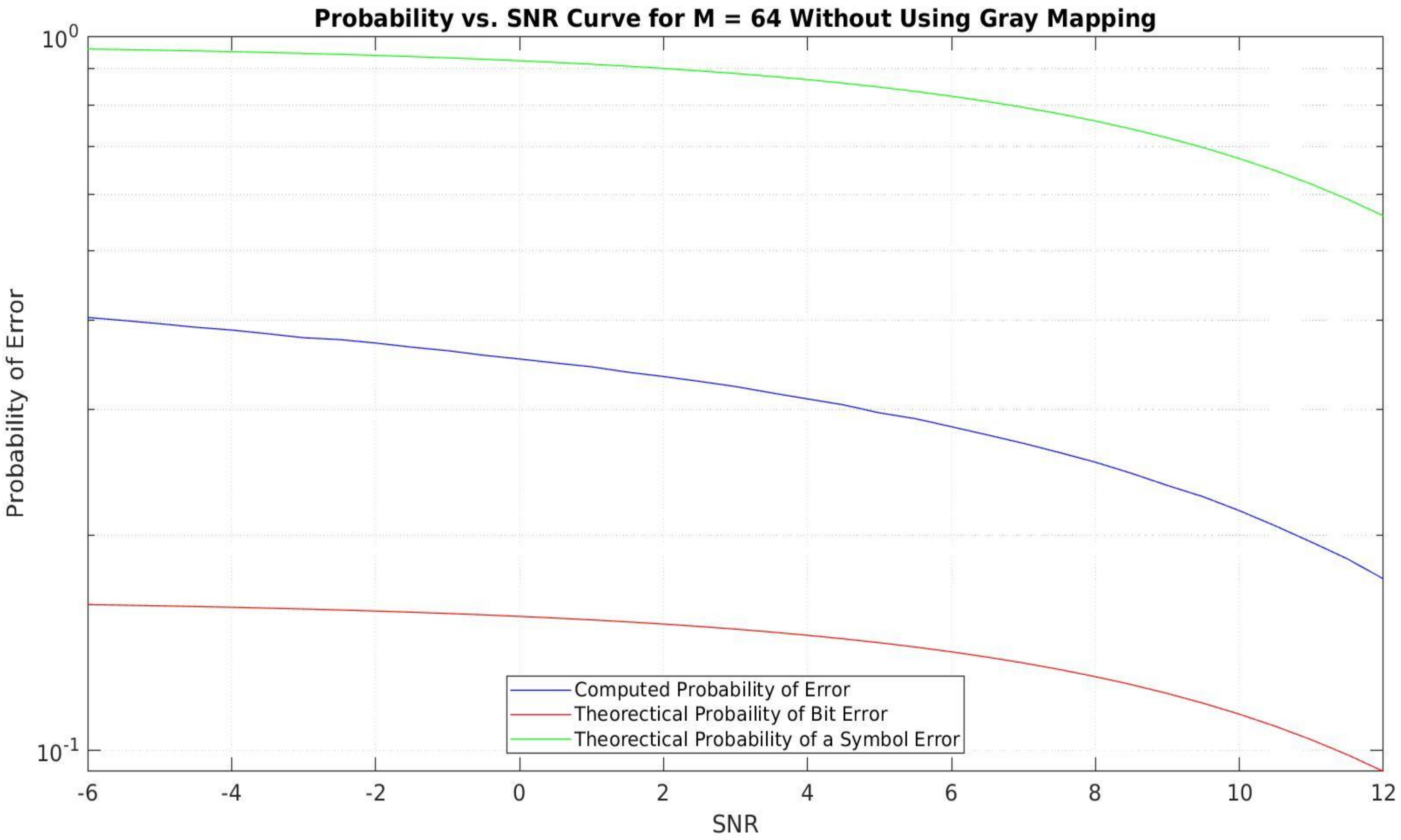
Probability vs. SNR Curve for M = 64 Without Using Gray Mapping
Probability of Error
SNR
$10^0$
$10^{-1}$
-6
-4
-2
0
2
4
6
8
10
12
Computed Probability of Error
Theorectical Probaility of Bit Error
Theorectical Probability of a Symbol Error

# PROBABILITY OF BIT ERROR FORMULA

$k = \log_2(M)$

$\varepsilon b/N_0$ (dB) = SNR - 10log(k)

$\varepsilon b/N_0 = 10\text{^}(SNR - 10\log(k)/10)$

$\varepsilon av = \varepsilon b * k$

$P\sqrt{M} = 2(1 - 1/\sqrt{M})Q(\sqrt{(3\varepsilon av/((M - 1)N_0))})$

$PM = (1 - (1 - P\sqrt{M})^2)/k$

# PROBABILITY OF A SAMPLE ERROR FORMULA

- The procedure is the same as the probability of bit error formula except

$$PM = (1 - (1 - P\sqrt{M})^2)$$