

**American International University- Bangladesh**  
**Department of Electrical and Electronic Engineering**  
 COE 3201: Data Communication Laboratory

**Title:** Study of Nyquist bit rate and Shannon capacity using MATLAB

**Abstract:**

This experiment is designed to-

- 1.To understand the use of MATLAB for solving communication engineering problems.
- 2.To develop understanding of Nyquist bit rate and Shannon capacity using MATLAB.

**Introduction:**

- I. **Nyquist Bit Rate:** The Nyquist bit rate formula defines the theoretical maximum bit rate for a noiseless channel.

$$BitRate = 2 \times bandwidth \times \log_2 L$$

In this formula, bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data, and BitRate is the bit rate in bits per second.

- II. **Shannon capacity:** Shannon capacity formula was introduced to determine the theoretical highest data rate for a noisy channel:

$$Capacity = bandwidth \times \log_2(1 + SNR)$$

In this formula, bandwidth is the bandwidth of the channel, SNR is the signal-to-noise ratio, and capacity is the capacity of the channel in bits per second.

**Signal-to-noise ratio (SNR):** To find the theoretical bit rate limit, we need to know the ratio of the signal power to the noise power. The signal-to-noise ratio is defined as

$$SNR = \frac{Average\ Signal\ Power}{Average\ Noise\ Power}$$

We need to consider the average signal power and the average noise power because these may change with time.

A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise.

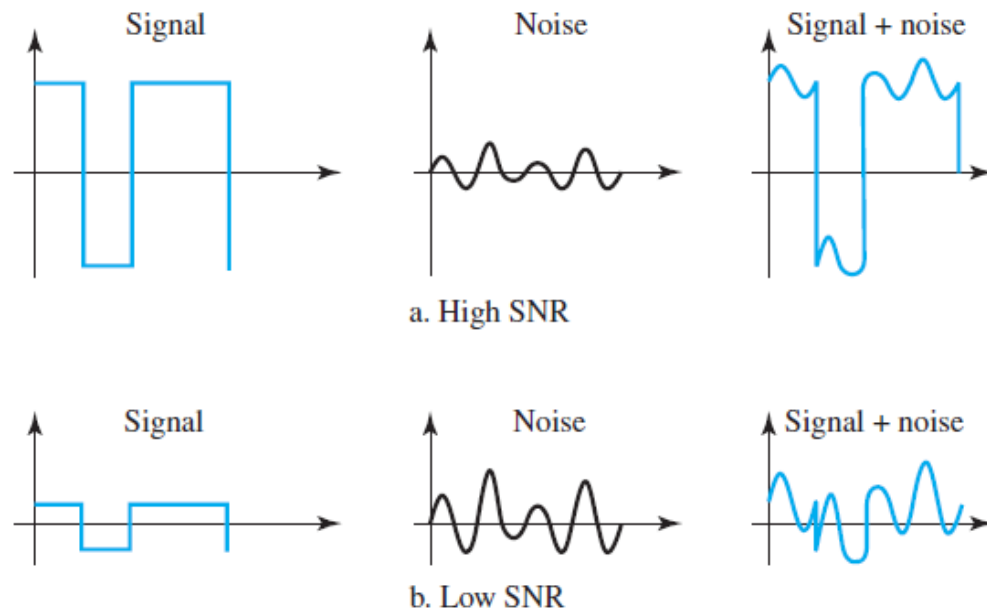


Fig: Two cases of SNR: a high SNR and a low SNR

Because SNR is the ratio of two powers, it is often described in decibel units,  $SNR_{dB}$ , defined as

$$SNR_{dB} = 10 \log_{10}(SNR)$$

Example of Nyquist bit rate calculation for a noiseless channel:

```
close all;
clc;
fs = 8000; % Sampling frequency
t = 0:1/fs:1-1/fs; % Time duration
cx = 1.1*sin(2*pi*100*t) + 1.3*cos(2*pi*300*t) +
1.5*sin(2*pi*2000*t);
bandwidth = obw(cx,fs); % Bandwidth of the signal
L=2; % Level of the signal
BitRate = 2*bandwidth*log2(L)
```

Output:

**BitRate =**

**3.8019e+03**

## Example: Calculation of SNR

```

close all;
clc;
%Define number of samples to take
fs = 8000; % Sampling frequency
f = 400; %Hz
%Define signal
t = 0:1/fs:1-1/fs;
A = 3.0;
powfund = A^2/2
s = 0.1;
varnoise = s^2;
signal = A*sin(2*pi*f*t);
%noise
noise = s*randn(size(signal));
%noisy signal
noisySignal = signal + noise;

SNR = snr(noisySignal) %Calculation of SNR using snr
function

defSNR = 10*log10(powfund/varnoise) %Calculation of SNR
following the definition

```

**SNR =**

**26.2571**

**defSNR =**

**26.5321**

Similar task can be done considering a noisy composite signal. Suppose our composite signal is,

$\text{signal} = 1.5 \cdot \sin(2\pi \cdot 2 \cdot t) + 0.9 \cdot \cos(2\pi \cdot 10 \cdot t) + 1.1 \cdot \sin(2\pi \cdot 20 \cdot t) + 0.13 \cdot \text{randn}(\text{size}(t));$

**\*\*\*\*\*Calculate the SNR value of the signal.**

**Total harmonic distortion (THD):** The total harmonic distortion (THD) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

When a signal passes through a non-ideal, non-linear device, additional content is added at the harmonics of the original frequencies. THD is a measurement of the extent of that distortion.

**Signal to noise and distortion ratio (SINAD):** Signal-to-noise and distortion ratio (SINAD) is a measure of the quality of a signal from a communications device, often defined as

$$SINAD = \frac{P_{signal} + P_{noise} + P_{distortion}}{P_{noise} + P_{distortion}}$$

Create a sinusoidal signal sampled at 48 kHz. The signal has a fundamental of frequency 1 kHz and unit amplitude. It additionally contains a 2 kHz harmonic with half the amplitude and additive noise with variance 0.1<sup>2</sup>.

```
fs = 48e3;
t = 0:1/fs:1-1/fs;
A = 1.0;
powfund = A^2/2;
a = 0.4;
powharm = a^2/2;
s = 0.1;
varnoise = s^2;
x = A*cos(2*pi*1000*t) + a*sin(2*pi*2000*t) +
s*randn(size(t));

THD = thd(x); % Total harmonic distortion
defTHD = 10*log10(powharm/powfund);
TH = [THD defTHD]

SINAD = sinad(x); % Signal to noise and distortion
ratio
defSINAD = 10*log10(powfund/(powharm+varnoise));
SI = [SINAD defSINAD]
```

**Output:**

**TH = 1×2**

**-7.9546 -7.9588**

**SI = 1×2**

**7.4571 7.4473**

Example of Shannon capacity calculation for a noisy channel:

```
SNR = snr(x);
bandwidth = obw(x,fs); % Bandwidth of the signal
C = bandwidth*log2(1+SNR) % Capacity of the channel
```

**C =**

**6.6576e+04**

### **Software:**

MATLAB2016a

### **Performance Task for Lab Report: (your ID = AB-CDEFG-H)**

**\*\*Generate a composite signal using two simple signals as,**

$x = A_1 \sin(2\pi(\text{C} \cdot 100)t) + A_2 \cos(2\pi(\text{G} \cdot 100)t) + s \cdot \text{randn}(\text{size}(t));$

- (a) Select the value of the amplitudes as follows: let  $A_1 = \text{AB}$ ,  $A_2 = \text{AF}$  and  $s = \text{AH}$
- (b) Calculate the SNR value of the composite signal.
- (c) Find the bandwidth of the signal and calculate the maximum capacity of the channel.
- (d) What will be the signal level to achieve the data rate?