Fundamentals of Communications
Communication System

- Transmitter: originates the signal
- Receiver: receives transmitted signal after it travels over the medium
- Medium: guides the signal from the transmitter to the receiver
Electrical Signal (Amplitude, Period, Frequency)

- Amplitude: the intensity of the signal’s voltage
- Period $T$ (s): time the wave takes to complete one cycle
- Frequency $f = 1/T$ (Hz): number of complete cycle per second
Electrical Signal (Phase Difference)

• Phase difference is meaningful when comparing 2 signals
• It describes the degree in which the 2 signals are aligned relative to each other, in other words it measure whether the 2 signals are in synch or else
Electrical Signal (Wavelength)

- The wavelength ($\lambda$) measures the physical length of the electrical signal
- $\lambda = \frac{c}{f} \text{ } (\text{m})$, $c = 3 \times 10^8 \text{ m/s} \text{ } \ldots \ldots \text{(1)}$
Signal Bandwidth

• The bandwidth of a signal represents the range of its frequency components.
• A complex signal is made of a range of frequencies called spectrum.
• The Bandwidth of a signal is calculated by subtracting the highest frequency component from the lowest frequency component.
Electromagnetic Wave

• Transmitting the signal over the air requires converting the electric signal into electromagnetic signal

• Antenna is the device used to convert electric signals to electromagnetic signals

• The length of the antenna depends on the electric signal wavelength

• The length of the antenna \( (l) \) has to be at least one tenth the length of the signal wavelength;

\[
\frac{l}{\lambda} = \frac{3 \times 10^8}{10 \times f} \quad \ldots \quad (2)
\]
The Radio Spectrum

• The frequency range of the electromagnetic spectrum between 3 Hz and 300 GHz is called the radio spectrum
• The radio spectrum is further divided into regions called frequency bands
• Radio Frequency (RF) systems use bands within the radio spectrum for communication
# The radio spectrum

Increasing frequency/Decreasing period/Decreasing wavelength

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Expanded name</th>
<th>Application</th>
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<td>ELF</td>
<td>Extremely low frequency</td>
<td>Submarine communication</td>
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<tr>
<td>SLF</td>
<td>Super low frequency</td>
<td>Submarine communication</td>
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<tr>
<td>ULF</td>
<td>Ultra low frequency</td>
<td>Submarine communication, navigation</td>
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<tr>
<td>VLF</td>
<td>Very low frequency</td>
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<tr>
<td>LF</td>
<td>Low frequency</td>
<td>Navigation</td>
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<tr>
<td>MF</td>
<td>Medium frequency</td>
<td>AM, amateur radio</td>
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<td>HF</td>
<td>High frequency</td>
<td>Citizens band radio, radio control, astronomy</td>
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<tr>
<td>VHF</td>
<td>Very high frequency</td>
<td>FM, TV</td>
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<td>UHF</td>
<td>Ultra high frequency</td>
<td>TV, cellular telephony, cordless phones, global positioning system (GPS), aircraft navigation, satellite communication, walkie-talkies</td>
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<tr>
<td>SHF</td>
<td>Super high frequency</td>
<td>Satellite communications, wireless computer networks, microwave ovens</td>
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<tr>
<td>EHF</td>
<td>Extremely high frequency</td>
<td>Space exploration, astronomy, satellite communications</td>
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Modulation/Demodulation

- Modulation is a technique used to convert a low frequency signal (information signal) to a higher frequency signal (modulated signal) using a higher frequency signal (carrier).
- In modulation, the carrier is modulated (reshaped) according to the information signal.
- Demodulation is the opposite technique where information signal is extracted from the carrier.
- Analogue Modulation is used to transmit analogue signals and digital modulation is used to convert digital signals.
a. Analogue Modulation

• The main idea of analogue modulation is to carry the information signal onto the carrier’s amplitude, frequency or phase.

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<th>Analog modulation techniques</th>
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<td>Carrying the information signal onto the carrier’s frequency</td>
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<td>Frequency modulation (FM)</td>
<td>Carrying the information signal onto the carrier’s phase</td>
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<td>Phase modulation (PM)</td>
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1. Amplitude Modulation (AM)

- The carrier’s amplitude is varied in proportion to the amplitude of the information signal.
Amplitude Modulation

• In AM, the information is carried on the carrier’s amplitude
• The demodulation is achieved by detecting the variation of the modulated signal’s amplitude called “envelop”
• AM is prone to noise interference as noise may change the amplitude of the modulated signal
2. Frequency Modulation (FM)

- The carrier’s frequency is varied in proportion to the amplitude of the information signal
Frequency Modulation

• In FM, the information is carried on the carrier’s frequency
• The demodulation is achieved by detecting the variation of the modulated signal’s frequency
• FM better performs in the presence of noise because noise don’t change the frequency of the modulated signal
b. Digital Modulation

- Digital information is made of 2 levels of amplitude representing two logical levels (0 and 1)
- In digital modulation the 0 and 1 are carried on the carrier’s amplitude, frequency and phase

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<td>Phase shift keying (PSK)</td>
<td>Carrying the 0s and 1s onto the carrier’s phase</td>
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1. Amplitude Shift Keying (ASK)

• The amplitude of the carrier varies according to the binary amplitude of the information signal

• In ASK, the modulated signal has 2 amplitude levels

• Logic 0 is modulated with amplitude of 0 and logic 1 is modulated with maximum amplitude value
ASK

Digital signal

1 1 0 0 0 0 1 1 1 1 0 0 1 1 1 0 0 1 1

Carrier

Digitally modulated waveform
2. Frequency Shift Keying (FSK)

- The frequency of the carrier varies according to the binary amplitude of the information signal.
- In FSK, the modulated signal has 2 frequencies.
- Logic 0 is modulated using one frequency and logic 1 is modulated using another frequency.
FSK

Digital signal

Carrier (f₁)

Carrier (f₂)

Digitally modulated waveform
3. Phase Shift Keying (PSK)

- The phase of the carrier varies according to the binary amplitude of the information signal.
- In PSK, the modulated signal has 2 different phases.
- Logic 0 is modulated using the carrier’s phase and logic 1 is modulated using the same carrier with a phase shift.
PSK

Digital signal

1 1 0 0 0 0 1 1 1 1 0 0 1 1 1 0 0 1 1

Carrier

Digitally modulated waveform

180° phase shift
ASK/FSK/PSK

- The bandwidth of the FSK is twice as much the bandwidth of the PSK and ASK
- FSK and PSK have better quality than ASK
- PSK is used for mobile digital mobile telephony
- FSK is used in fax machines
- ASK is used in satellite communications
Attenuation

• When the signal travels through a medium such as air or cable, it loses energy
• The loss of energy is called attenuation
• As the distance between the transmitter and receiver increases, signal attenuation increases
• The signal reduction in air follow the inverse square law
Attenuation in the air

• Attenuation in air is governed by the inverse square law

• Inverse Square law states that received signal power \((P_r)\) is inversely proportional to the transmit signal power \((P_t)\), the relation between the received and transmit signal powers is given by this equation:

\[
P_r = \frac{P_t}{r^2} \quad \text{(3)}
\]

where \(r\) is the distance between the transmitter and the receiver
Electric Signal Power

• The power of an electrical signal is the square value of its voltage;
  \[ P = V^2 \text{ (W)} \ldots \ldots (4) \]

• In communication we like to express the power in decibels;

• This relation used to express signal power in decibels:
  \[ P[\text{dB}] = 10 \log_{10} P \text{ (dB)} \ldots \ldots (5) \]
Inverse Square law in dB

\[ P_r = \frac{P_t}{r^2} \text{ (W)} \]

\[ P_r [\text{dB}] = 10 \log_{10} P_t - 10 \log_{10} (r^2) \]

\[ P_r [\text{dB}] = P_t [\text{dB}] - 20 \log_{10} r \quad \text{...... (6)} \]
Example 1

• Calculate the received power in dB when the distance between a 100 W transmitter and a receiver is 10000 mm?

Solution

\[ Pr[dB] = Pt[dB] - 20 \log r \]
\[ Pr[dB] = 10 \log 100 - 20 \log 10 \]
\[ Pr[dB] = 20 - 20 = 0 \text{ dB} \]
Attenuation in wired medium

• In wired medium, signal attenuation depends on the type of the medium as some type of wired mediums are more prone to attenuation than other types of wired medium.

• For example, some fiber-optics cable transmit signal attenuates at the rate of (0.2 dB/km) compare to coaxial cable which attenuates at (175 dB/km) in the best case.
Example 2 (using repeaters)

• (a) Calculate the received power at the end of a 30 km cable that has attenuation rate of (10 dB/km) if the transmit power is 100 dB? (b) Using 2 Repeaters spaced at 10 km each, what is the received power if the repeater can amplify the received signal by 10 dB?

\[
\begin{align*}
\text{Tx} & \quad \text{Pt} = 100 \text{ dB} \\
10 \text{ dB/ km} & \quad 30 \text{ km} \\
\text{Rx} & \quad \text{Pr} = ?
\end{align*}
\]
Solution

(a): $P_r = 100 - 30 \times 10 = -200 \text{ dB}$

(b)

At R1
$P_{r,1} = 100 - 10 \times 10 = 0 \text{ dB}$
$P_{t,1} = 0 + 10 = 10 \text{ dB}$

At R2
$P_{r,2} = 10 - 10 \times 10 = -90 \text{ dB}$
$P_{t,2} = -90 + 10 = -80 \text{ dB}$

$\rightarrow P_r = -80 - 10 \times 10 = -180 \text{ dB}$
Noise

• Noise is undesirable electric energy that falls within the bandwidth of the transmitted signal.
• As signal bandwidth increases, noise interference increases.
• Noise interference will result in poor quality of the received signal.
• Noise interference with the transmitted signal is unavoidable.
Communication system

- Transmitter
- Medium
- Receiver
- Noise
Noise Categories

A. External Noise: Noise that is generated in the communication medium:
   1. Atmospheric Noise
   2. Extraterrestrial Noise
   3. Man-made noise

B. Internal Noise: Noise that is generated inside the Receiver hardware:
   1. Thermal Noise; temperature dependant noise
Signal To Noise Ratio (SNR)

• SNR is a figure of merit that expresses the ratio of the received signal power \( P_r \) to the noise power \( P_N \)

\[
\text{SNR} = \frac{P_r}{P_N}
\]

\[
\text{SNR [dB]} = P_r [dB] - P_N [dB] \quad \text{...... (7)}
\]

• Using equation (6), (7) can be rewritten as:

\[
\text{SNR [dB]} = P_t [dB] - 20 \log_{10} r - P_N [dB] \quad \text{.... (8)}
\]
Example 3

• Calculate the SNR at the receiver when the distance between a 100 W transmitter and the receiver is 1 km and the noise power in the channel is 15 dB? How could we increase SNR of the received signal?

Solution

\[
\text{SNR [dB]} = 10 \log_{10} 100 - 20 \log_{10} 1000 - 15
\]

\[
= 20 - 60 - 15 = -55 \text{ dB}
\]
Error Correction in Digital Communication

- Incorrect detection of a binary digit will result in error.
- Signal attenuation and noise interference are the factors that cause errors.
- The rate of error depends on the type of modulation and the SNR of the received signal.
- In digital communication, errors are detected and corrected using special coding techniques.
- These coding techniques are based on the addition of extra bits, called redundant bits.
- The redundant bits are not part of the original information but added specifically for error checking.
Error Control Coding

• Error control coding (ECC) is the name of techniques used to encode the message prior to transmission.

• Block coding are a type of ECC, Block coding consist 2 type of coding:
  1. Single Parity Checking
  2. Rectangular Coding
1. Single Parity Checking

- Single Parity Checking is implemented simply by adding a single redundant bit called the parity bit.
- This parity bit is calculated by XORing all bits in the block.
- If the block consists of an even number of 1’s, the output of XORing the block bits is 0, and if the block consists of an odd number of 1’s, the output of XORing the block bits is 1.
Example 4

- Encode the following blocks using single check parity:
  a. 1100110
  b. 1000011

**Solution**

a.
1 XOR 1 XOR 0 XOR 0 XOR 1 XOR 1 XOR 0 = 0
→ 11001100

b.
1 XOR 0 XOR 0 XOR 0 XOR 0 XOR 0 XOR 1 XOR 1 = 1
→ 10000111
Example 5

• The following blocks has been received, Determine whether they have been received correctly or not knowing that those codes have been encoded using single parity checking?

a. 10011110 → received incorrectly
b. 11100000 → received incorrectly
c. 10100000 → received correctly
Limitations on Single parity Checking

1. The receiver can detect that an error has occurred but it cannot determine exactly which bit is in error. However parity checking is still useful in a way that, once error is detected the Receiver will inform the transmitter to re-transmit the block again.

2. It only work for odd number of errors occurring during transmission.
Rectangular Coding

• Rectangular Coding is more complex than single parity checking.
• These coding technique can detect and correct errors.
• In this technique, 2 blocks of data (encoded using single parity checking) are XORed together and the resulted block “redundant block” is added at the end of the message
Example 6

• Encode the following blocks of data using rectangular coding:
  1100011  1010101

Solution

\[
\begin{array}{c}
1100011 \quad 0 \\
1010101 \quad 0 \\
\end{array} \quad \begin{array}{c}
\text{XOR} \\
\text{XOR} \\
\end{array} \\
\begin{array}{c}
0110110 \quad 0 \\
0110110 \quad 0 \\
\end{array}
\]

→ the code to transmitted is 11000110 10101010 01101100
Error Detection and Correction

• To detect an error, each block is checked using single parity checking

• If error is detected in one of the two first blocks, then the error can be corrected

• To correct the error, XOR the correct block with the redundant block and compare the result with the incorrect block. Error is detected when the output of XORing dose not match its corresponding in the incorrect bit
Example 7

- Detect and Correct errors in the following stream of bits knowing that the received stream has been encoded using rectangular coding

Received data stream:

11000110 10100010 01101100

Solution

11000110 received correctly
10100010 received incorrectly

To correct the second block XOR the first block with the redundant block

11000110
01101100 XOR

10101010 therefore the error was in the fifth bit in the second block