

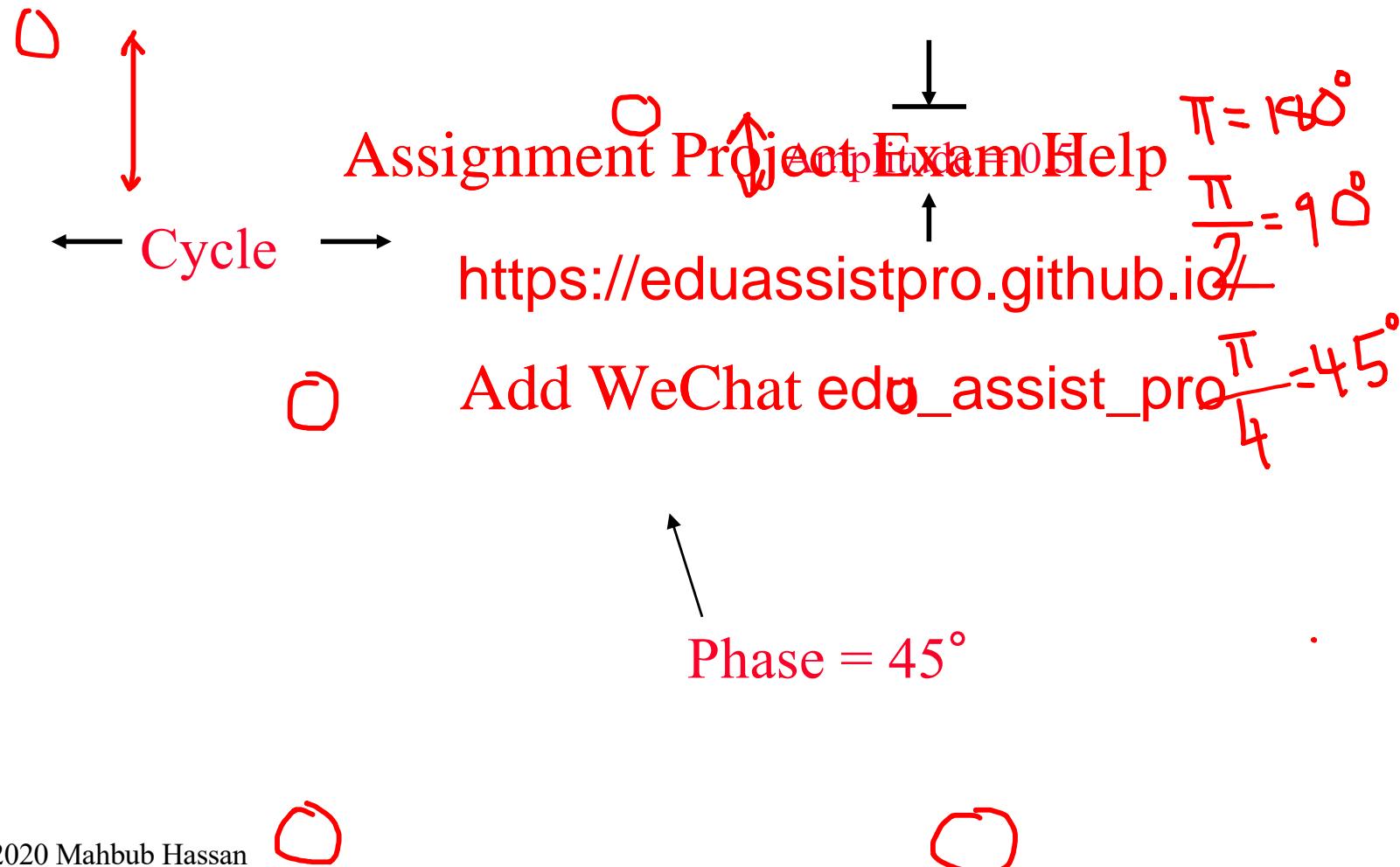
Assignment Project PHE FUNDAMENTALS I  
Co <https://eduassistpro.github.io/>  
Add WeChat edu\_assist\_pro

# Overview

1. Frequency, Wavelength, Amplitude, and Phase
2. Electromagnetic Spectrum
3. Time and Frequency Domains
4. Decibels **Assignment Project Exam Help**
5. Coding and mo <https://eduassistpro.github.io/>
6. Channel Capacity (Shannon's Theorems)
7. Hamming Distance and Error Correction
8. Multiple Access Methods (TDMA, FDMA, CDMA)
9. Spread Spectrum (Frequency Hopping and Direct Sequence)
10. Doppler Shift, Doppler Spread, Coherence Time
11. Duplexing

# Frequency, Period, and Phase

- $A \sin(2\pi ft + \phi)$ , A = Amplitude,  $f$ =Frequency,  
 $\phi$  = Phase, Period  $T = 1/f$ ,  
Frequency is measured in Cycles/sec or **Hertz**



# Phase and Amplitude: 2D Representation

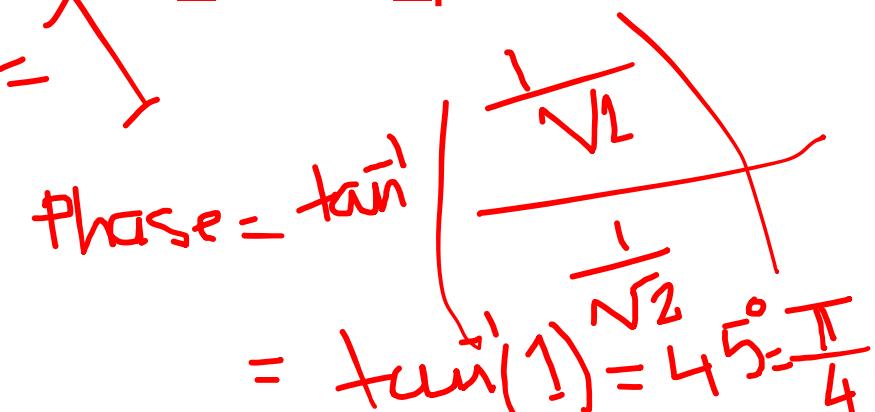
- Sine wave with a phase of  $45^\circ$

$$A=1 \sin\left(2\pi ft + \frac{\pi}{4}\right) = \sin(2\pi ft) \cos\left(\frac{\pi}{4}\right) + \cos(2\pi ft) \sin\left(\frac{\pi}{4}\right)$$
$$= \frac{1}{\sqrt{2}} \sin(2\pi ft) + \frac{1}{\sqrt{2}} \cos(2\pi ft)$$

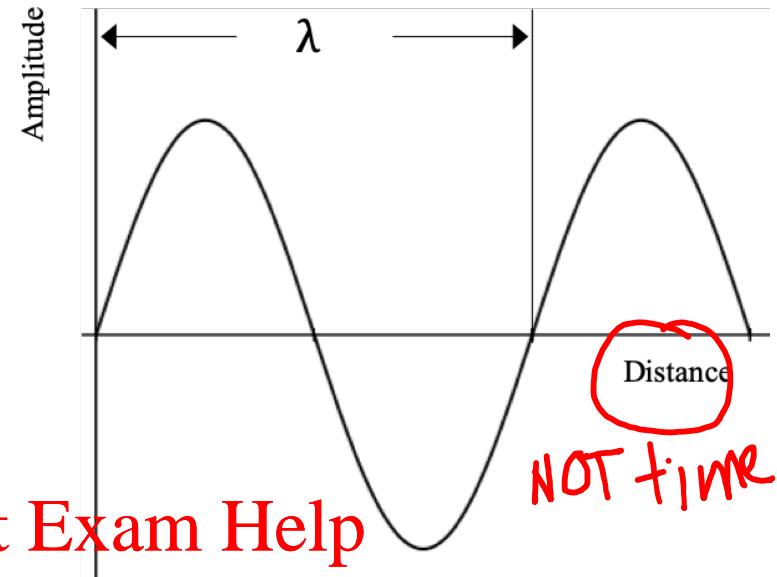
In-phase component I + Quadrature component Q

<https://eduassistpro.ghthub.io/>

Add WeChat  $A=N$   $N1$   $N2$   $\sim$   
 $edu\_assist\_pro$

$$\text{Phase} = \tan^{-1} \left[ \frac{N2}{N1} \right]$$
$$= \tan^{-1}(1) = 45^\circ = \frac{\pi}{4}$$


# Wavelength



- Distance occupied by one cycle
- Distance between consecutive cycles
- Wavelength =  $\lambda$
- Assuming signal velocity  $v$ 
  - $\lambda = vT$
  - $\lambda f = v$
  - $c = 3 \times 10^8 \text{ m/s}$  (speed of light in free space) =  $300 \text{ m}/\mu\text{s}$

## Example: converting frequency to wavelength

- Frequency = 2.5 GHz

Assignment Project Exam Help

<https://eduassistpro.github.io/>

Add WeChat edu\_assist\_pro

## Example: converting wavelength to frequency

- Wavelength =  $\lambda = 5 \text{ mm}$

$$\text{Frequency } f = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{(5 \times 10^{-3} \text{ m})}$$

m)

<https://eduassistpro.github.io>  
60  
Add WeChat edu\_assist\_pro

## Well-known frequencies & wavelengths

- The higher the frequency, the smaller the wavelength
  - 900 MHz has a wavelength of  $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{900 \times 10^6} = 333.33 \text{ mm}$
  - 2.4 GHz has a wavelength of  $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2.4 \times 10^9} = 125 \text{ mm}$
  - 60 Ghz has a wavelength of  $\lambda = \frac{c}{f} = \frac{3 \times 10^8}{60 \times 10^9} = 5 \text{ mm}$
- The technology is called *millimeter wave or mmWave*.  
Add WeChat <https://eduassistpro.github.io/> edu\_assist\_pro

# Time and Frequency Domains

Assignment Project Exam Help

<https://eduassistpro.github.io/>

Add WeChat edu\_assist\_pro

$f=1$   $f=3$

# Electromagnetic Spectrum

- Wireless transmissions use the airwaves
  - Airwaves are radio frequencies
- Useful frequencies constitute the Spectrum
- Spectrum is 'virtual'
  - We cannot touch it <https://eduassistpro.github.io/>
- A gift from nature (the force of nature)
  - Has been there ever since the world was created
- A (**limited**) natural resource

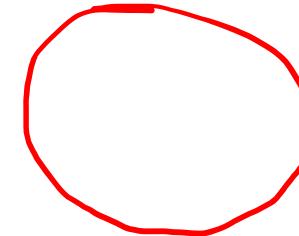
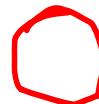
# Electromagnetic Spectrum

Assignment Project Exam Help

Wireless

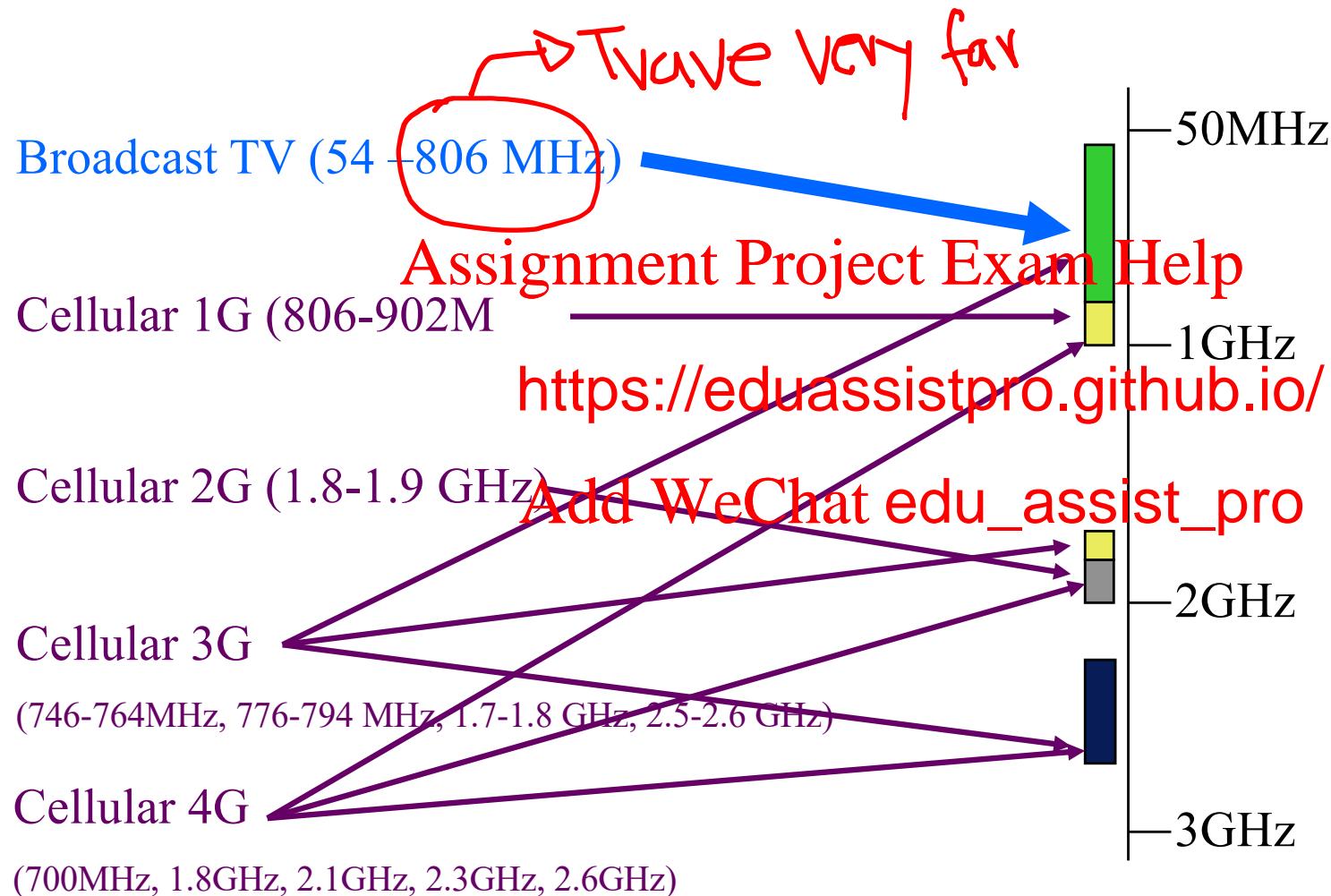
<https://eduassistpro.github.io/>

Add WeChat edu\_assist\_pro



- ❑ Wireless communication mostly uses 100 kHz to 6 GHz
- ❑ > 6 GHz are currently being explored and 60 GHz is used in some latest WiFi products

# Spectrum use by TV and cellular services



Assignment Project Exam Help

<https://eduassistpro.github.io/>

Add WeChat edu\_assist\_pro

# Spectrum regulation and licensing

- Many users use the same airspace
  - Recipe for collision
  - No one would get anything useful done
- Spectrum use is <https://eduassistpro.github.io/>
  - By govt. auth A)
- Spectrum is often licensed
  - By big companies, eg Telstra
  - Gives exclusive rights to certain freq. bands
  - Interference avoidance by regulation

# Spectrum allocation

- Bulk of it reserved for government use
  - Scientific exploration
  - Public safety
  - Military
- Some for com <https://eduassistpro.github.io/>
  - TV broadcast
  - Mobile phone
- Some for free-to-use
  - High-speed wireless local area network (WiFi)
  - Cordless phone handsets at home
  - Can you name a few more?

Assignment Project Exam Help

Add WeChat edu\_assist\_pro

# Key principles of spectrum allocation

- Maximize spectrum utilization
- Spectrum made available to new technologies and services Assignment Project Exam Help
  - Adapt to ne <https://eduassistpro.github.io/>
- Fair licensing Add WeChat edu\_assist\_pro
- Promote competition
- Ensure spectrum availability for public safety, health, defense, scientific experiments...

## Free/unregulated/license-exempt spectrum

- - Not subject to license
  - Has rules for products (eg *power limitation*)
  - More frequencies are being released as license-exempt
  - Some current li
    - 900 MHz
    - 2.4 GHz ISM band (WiFi, Micro)
    - 5.2/5.3/5.8 GHz (WiFi, Cordless phone etc.)
    - Can you identify more?

<https://eduassistpro.github.io/>

Add WeChat [edu\\_assist\\_pro](#)

# Decibel

- Tx\_power for practical mobile systems vary by many orders of magnitude
  - 100kW or kilowatt (FM radio station)
  - 500mW or milliwatt (cellular phone tx power)
  - 2.5mW (Bluetooth with ~10m range)
  - 100pW or picowatt
  - Femto watt? (nano <https://eduassistpro.github.io/>)
  - $1 \text{ W} = 10^3 \text{ mW} = 10^6 \mu\text{W} = 10^9 \text{ nW} = 10^{12}$
- Decibel is a more convenient (logarithmic) way to compare these powers, which are many orders of magnitude apart
- Also path loss (attenuation) can be many orders of magnitude
  - Path loss therefore is usually expressed in decibels

# Decibel (dB) Formula

- In Honour of Graham Bell
- The number of decibels is ten times the logarithm to base 10 of the ratio of two power quantities (dB =  $10 \log_{10}(\frac{P_1}{P_2})$ )  
➢ The quantity “Be ot used
- Decibel can be used <https://eduassistpro.github.io/>
  1. Path Loss: To express path loss or  $P_1 = \text{transmit power}; P_2 = \text{receive power}$ ]
  2. SNR: To express signal ( $P_1$ ) to noise ( $P_2$ ) ratio at the receiver
  3. Signal Power: To express signal power ( $P_1$ ), which can be either transmit or receive power, to a reference power ( $P_2$ )

# Decibel Examples for Path Loss

- Example 1:  $P_t = 10 \text{ mW}$ ,  $P_r = 5 \text{ mW}$  (power reduced by half)  
Attenuation (path loss) =  $10 \log_{10} (10/5) = 10 \log_{10} 2 = 3 \text{ dB}$
- Example 2:  $P_t = 100 \text{ mW}$ ,  $P_r = 1 \text{ mW}$  (power reduced by a factor of 100)  
Attenuation =  $10 \log_{10} (100/1) = 10 \log_{10} 100 = 20 \text{ dB}$

<https://eduassistpro.github.io/>

Power Ratio	
10,000,000,000 (ten billion times)	$10 \times 10$
1,000,000 (1 million times)	60 ( $10 \times 6$ )
10 (ten times)	10 ( $10 \times 1$ )
0.001 ( $10^{-3}$ )	-30 ( $10 \times -3$ )
0.0001 ( $10^{-4}$ )	-40 ( $10 \times -4$ )

## Decibel Examples for Signal-to-Noise Ratio

- Example 1:  $P_{\text{signal}} = 1 \text{ mW}$  (received signal strength),  $P_{\text{noise}} = 100 \mu\text{W}$

$$\text{SNR} = 10 \log_{10} (1000/100) = 10 \log_{10} 10 = 10 \text{ dB}$$

- Example 2: Received signal strength is measured at 10 mW. What is the noise power if SNR

<https://eduassistpro.github.io/>

$$\text{SNR} = 10 \text{ dB} = 10 \log_{10} \left( \frac{10 \text{ mW}}{P_{\text{noise}}} \right)$$

$$P_{\text{noise}} = 1 \text{ mW}$$

# Expressing Power in dBm

- ❑ dBm is in reference to 1 milliwatt
- ❑ First, express power in milliwatt
- ❑ Then apply the following formula to obtain dBm

<https://eduassistpro.github.io/>

Add WeChat edu\_assist\_pro

Power in dBm =  $10 \log (\text{power in milliwatt})$

# Conversion to dBW

- ❑ dBW is in reference to 1 watt
- ❑ First express power in watt
- ❑ Then apply the formula to convert dBW

<https://eduassistpro.github.io/>

Add WeChat edu\_assist\_pro

Power in dBW =  $10 \log_{10} (\text{power in watt})$

# Relationship between dBm & dBW

- Note that  $1 \text{ W} = 1000 \text{ mW}$
- This gives [Assignment](#) [Project](#) [Exam](#) [Help](#)
  - Note  $\log(a) = \frac{10}{10} \log\left(\frac{P_{out}}{P_{ref}}\right)$

Add WeChat edu\_assist\_pro

$$\text{dBm} = \text{dBW} + 30$$

If you've calculated a power in dBW, you can simply derive the equivalent dBm by adding 30 to dBW, and vice versa.

## Examples for converting Watt to dBm/dBW

- Example 1: Express 1 mW power in units of dBm

Assignment Project Exam Help

~~https://eduassistpro.github.io/~~

$$10 \log(1) = 0 \text{ dBm}$$

So, ZERO dBm does not mean there is no power !

## Example (2)

- Example 2: Express 50 W in
  - (a) dBW
  - (b) dBm

<https://eduassistpro.github.io/>

$$(a) P(\text{dBW}) = 10 \log_{10} \left( \frac{P}{P_0} \right) \text{ dBW}$$

$$(b) P(\text{dBm}) = 10 \log_{10} (P / 1 \text{ mW}) \text{ dBm}$$

$$= 10 \log_{10} (50) + 10 \log_{10} (1000) \text{ dBm}$$

$$= 17 + 30 = 47 \text{ dBm}$$

# Coding Terminology

- **Symbol:** the smallest element of a signal with a given amplitude, frequency, and phase that can be detected
- **Modulation Rate.**  $= \frac{1}{\text{symbol\_duration}} = \text{Baud rate}$  (or symbol rate)  
<https://eduassistpro.github.io/>
- **Data Rate:** Bits per second (bps)  
Add WeChat: [edu\\_assist\\_pro](https://edu_assist_pro)
- A symbol may carry multi
  - A binary signal with only two different symbols would carry 1 bit per symbol (baud rate = data rate)
  - For an M-ary signal, data rate =  $\text{baud rate} \times \log_2(M)$

# Modulation

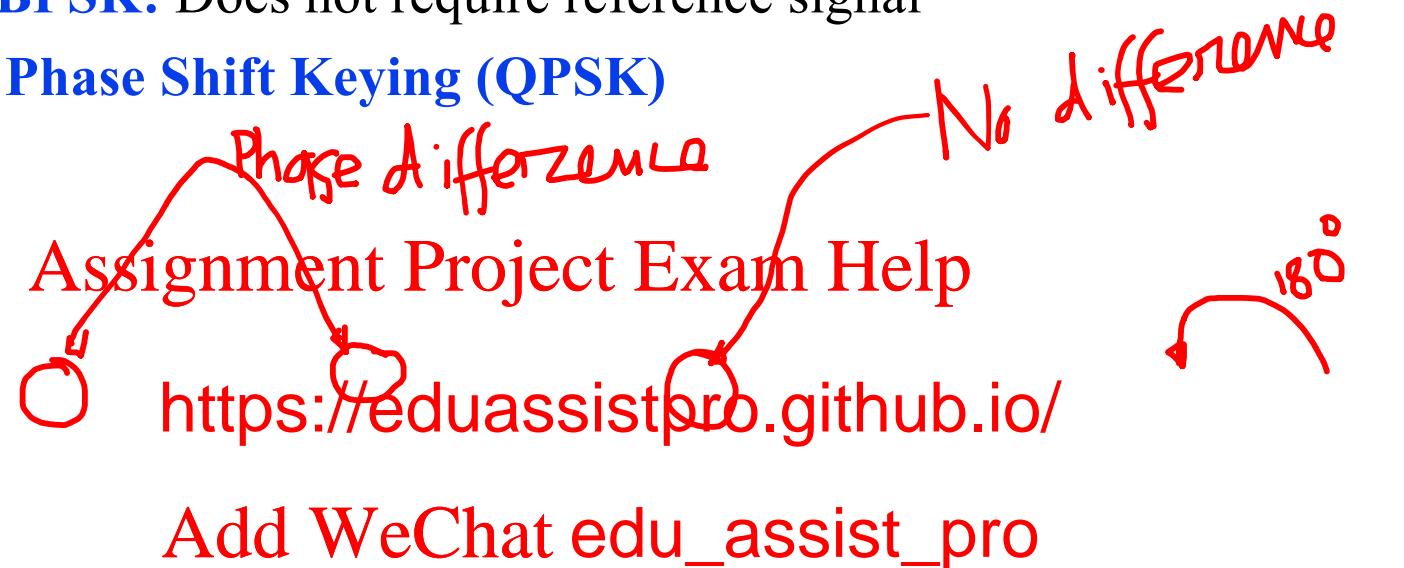
- Digital version of modulation is called **keying**
  - **Amplitude Shift Keying (ASK)**
  - **Frequency Shift Keying (FSK)**
  - **Phase Shift Keying (PSK):** Binary PSK (BPSK)

Assignment Project Exam Help



## Modulation (Cont)

- **Differential BPSK**: Does not require reference signal
- **Quadrature Phase Shift Keying (QPSK)**



# QAM

- - Quadrature **Amplitude** and **Phase** Modulation
  - 4-QAM, 16-QAM, 64-QAM, 256-QAM, ...
  - Used in DSL and wireless networks
  - Constellation diagram (shows combinations of amplitudes and phases)

**Assignment Project Exam Help**

<https://eduassistpro.github.io/>

Add WeChat edu\_assist\_pro

- 4-QAM  $\Rightarrow$  2 bits/symbol, 16-QAM  $\Rightarrow$  4 bits/symbol, ...

# QAM in Action

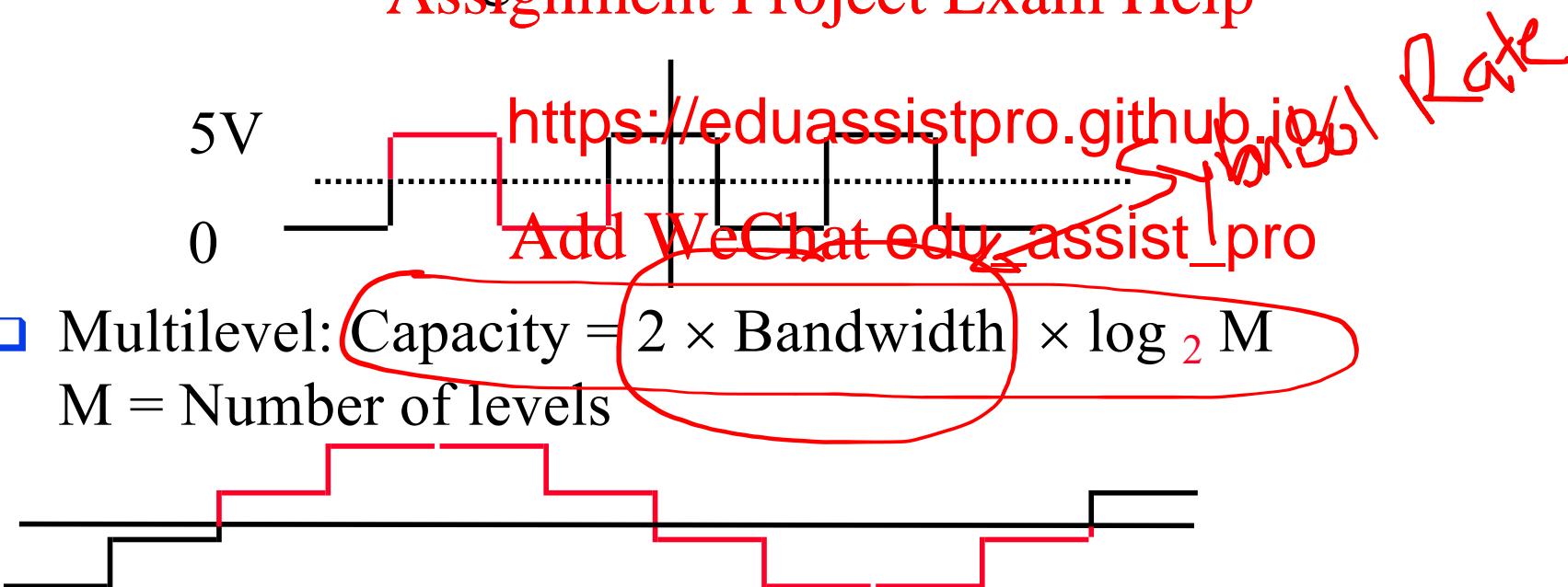
Wireless Technology	QAM Supported
4G	Assignment Project Exam Help 256 QAM
5G	<a href="https://eduassistpro.github.io/">https://eduassistpro.github.io/</a>
WiFi 802.11n	16 QAM Add WeChat edu_assist_pro
WiFi5 802.11ac	256 QAM
WiFi6 802.11ax	1024 QAM

10 bits per symbol

# Channel Capacity

- Capacity = Maximum data rate (bps) for a channel
- Nyquist Theorem (noiseless channel): Bandwidth =  $B$  Hz  
Baud rate  $\leq 2 B$
- Bi-level Encoding: Max. Data rate  $= 2 \times \text{Bandwidth}$

~~Assignment Project Exam Help~~



**Example:  $M=4$ , Capacity =  $4 \times \text{Bandwidth}$**

# Example

Assume that you have discovered a novel material that has negligible electrical noise. What is the maximum data rate that this material could achieve over a phone wire having a bandwidth of 3100 Hz if data was encoded with 64-QAM?

Assignment Project Exam Help

## Solution

We have  $B = 3100$     $M = \text{https://eduassistpro.github.io/}$

Data rate =  $2 \times 3100 \times \log_2 64 = 37,200 \text{ bps}$

## Shannon's Theorem (noisy channel)

- Bandwidth =  $B$  Hz  
Signal-to-noise ratio =  $S/N$
- Maximum number of bits/sec =  $B \log_2 (1+S/N)$  [error free communication Project Exam Help]
- Example: Phone 3100 Hz  
<https://eduassistpro.github.io/>

Add WeChat edu\_assist\_pro  
 $10 \log_{10} S$

$$\log_{10} S/N = 3$$

$$S/N = 10^3 = 1000$$

$$\text{Capacity} = 3100 \log_2 (1+1000) = 30,894 \text{ bps}$$

# Hamming Distance

- Hamming Distance between two sequences  
= Number of bits in which they disagree

- Example:

Difference

011011  
Assignment Project Exam Help

<https://eduassistpro.github.io/>

101010  $\Rightarrow$  Add WeChat edu\_assist\_3\_pro

# Error Correction Example

- 2-bit words transmitted as 5-bit/word

<u>Data</u>	<u>Codeword</u>
00	00000
01	00111
11	11001

Received = 00100  $\Rightarrow$  No <https://eduassistpro.github.io/>

Distance (00100, 00000) = 1      Distance (00100, 11001) = 4  
Distance (00100, 00111) = 2      Distance (00100, 11110) = 3

$\Rightarrow$  Most likely 00000 was sent. Corrected data = 00

b. Received = 01010 Distance(...,00000) = 2 = Distance(...,11110)  
Error detected but cannot be corrected

c. Three-bit errors will not be detected. Sent 00000, Received 00111.

# Multiple Access Methods



(c) <https://eduassistpro.github.io/>  
ess  
g turns)

Add WeChat edu\_assist\_pro

## Code Division Multiple Access

(all communicating groups are talking at the same time)

# **Multiple Access**

## **FDMA (frequency division multiple access)**

**Assignment Project Exam Help**

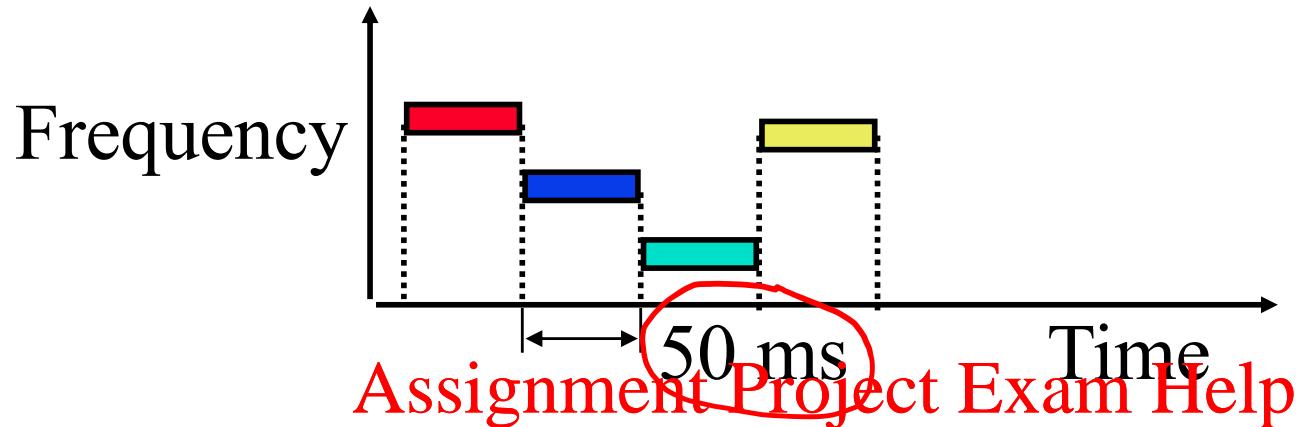
**<https://eduassistpro.github.io/>**

**Add WeChat edu\_assist\_pro**

# CDMA

- Each communicating group is using a different “code”
- You can understand a conversation only if you know the code used in that conversation
- Much like a *multiple* <https://eduassistpro.github.io/> (different languages are all <https://eduassistpro.github.io/> code = language)
- Two popular coding methods for CDMA
  - Frequency hopping spread spectrum (FHSS)
  - Direct sequence spread spectrum (DSSS)

# Frequency Hopping Spread Spectrum



- Transmit over a narrow spectrum (hop) frequency over a wide spectrum
  - Spreads the transmission power (ctrain)
  - ⇒ <https://eduassistpro.github.io/>
- Pseudo-random frequency hopping (both transmitter and receiver use the same pseud-random number sequence = code)
  - Developed initially for military
  - Patented by actress Hedy Lamarr (idea came while playing a piano; tone changes continuously)

# FHSS Advantages and Disadvantages

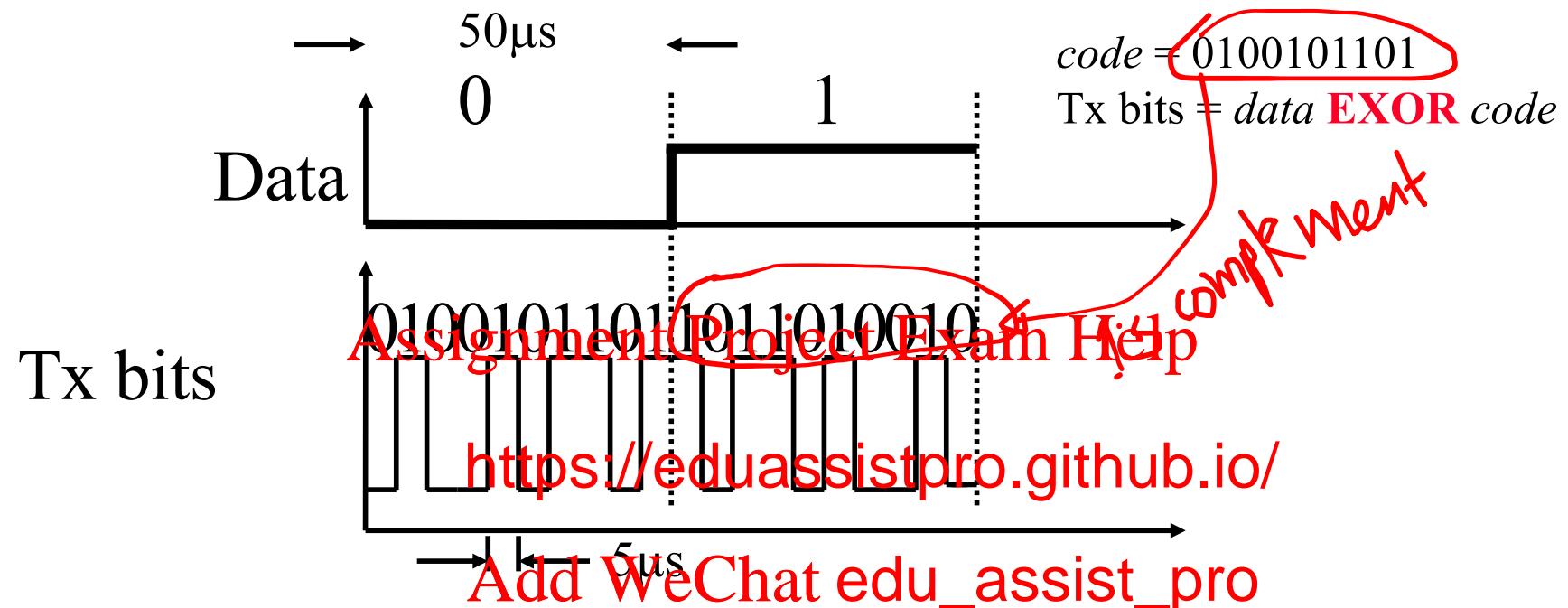
## □ Advantages

- Difficult to intercept (appears as random ‘blips’)
- Narrowband interference can't jam

## □ Disadvantage Assignment Project Exam Help

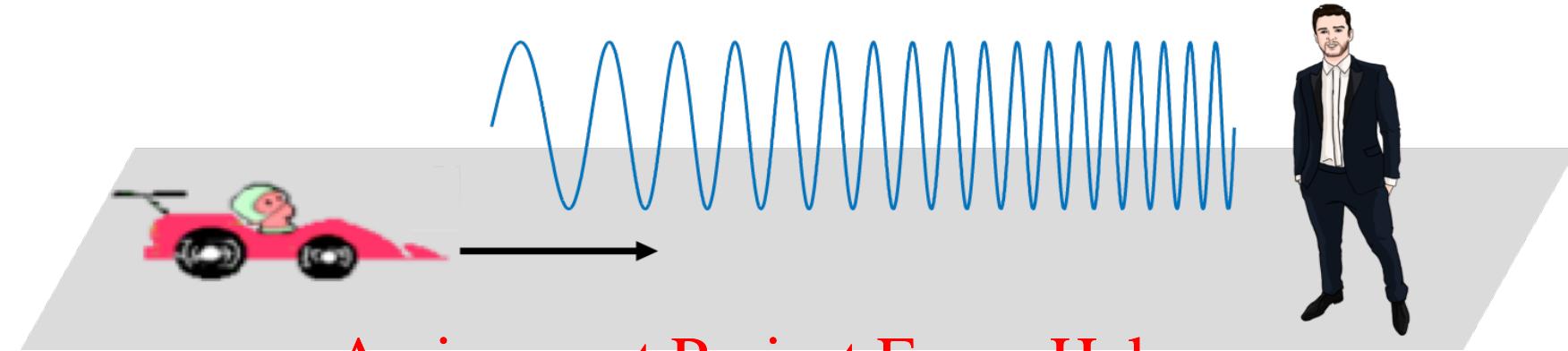
- Requires increase frequencies → 10 mly hop between 1000
- Both time and frequency synchroni Add WeChat edu\_assist\_pro

# Direct-Sequence Spread Spectrum



- Many bits are transmitted for each data bit
- Spreading factor = Code bits/data bit, 10-100 commercial (Min 10 by FCC), **10,000** for military
- Signal bandwidth  $>10 \times$  data bandwidth
- Code sequence synchronization
- Correlation between codes  $\Rightarrow$  Interference (Orthogonal to avoid interference)

# Doppler Shift



- If the transmitter or receiver or both are mobile the frequency of received signal increases
- Moving towards increases
- Moving away from each other  $\Rightarrow$  decreases

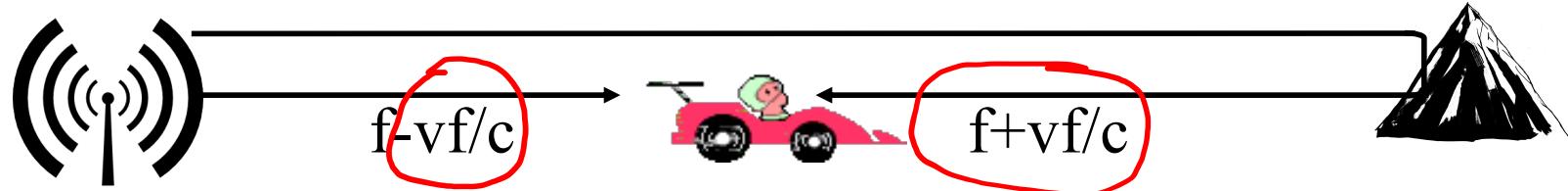
$$\text{Frequency difference} = \text{velocity}/\text{Wavelength} = v/\lambda = vf/c$$

**Example:**  $2.4 \text{ GHz} \Rightarrow \lambda = 3 \times 10^8 / 2.4 \times 10^9 = 0.125 \text{ m}$

$$v = 120 \text{ km/hr} = 120 \times 1000 / 3600 = 33.3 \text{ m/s}$$

$$\text{Freq diff (Doppler shift)} = 33.3 / 0.125 = 267 \text{ Hz}$$

# Doppler Spread and Coherence Time



## Assignment Project Exam Help

- Two rays will be added (cancel each other out)
- Doppler Spread** <https://eduassistpro.github.io/> shift
- They will add or cancel-out each other if the receiver moves
- Coherence time**: Time during which the channel response is constant =  $1/\text{Doppler spread} = c/2vf = \lambda/2v$

# Example

- What is the *coherence time* for a 2.4 GHz wifi link connecting a car travelling at 72 km/hr?

**Assignment Project Exam Help**  
 $V = (72 \times 1000) / 3600 = 20 \text{ m/s}$

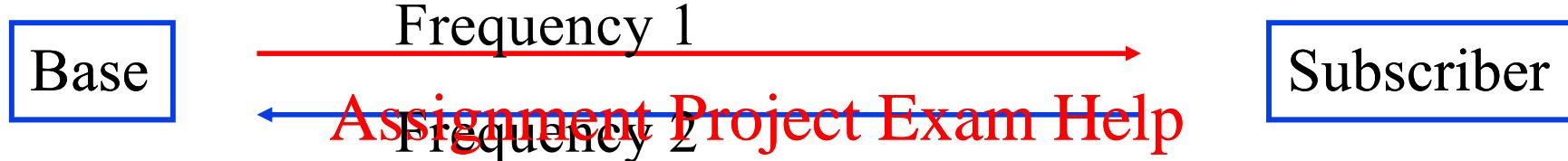
Doppler spread =  $2vf$  <https://eduassistpro.github.io/>  $\approx 320 \text{ Hz}$

Coherence time =  $1/320 = 0.003125 \text{ s}$

Add WeChat [edu\\_assist\\_pro](#)

# Duplexing

- ❑ Duplex = Bi-Directional Communication
- ❑ Frequency division duplexing (FDD) (Full-Duplex)

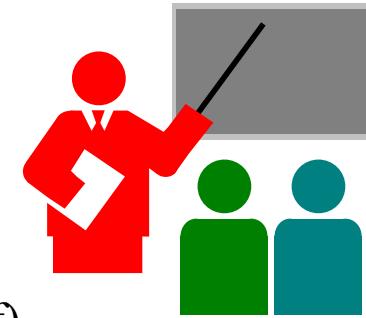


- ❑ Time division du <https://eduassistpro.github.io/>



- ❑ Many LTE deployments will use TDD.
  - Allows more flexible sharing of DL/UL data rate
  - Does not require paired spectrum
  - Easy channel estimation  $\Rightarrow$  Simpler transceiver design
  - Con: All neighboring BS should time synchronize

# Summary



1. Electric, Radio, Light, X-Rays, are all electromagnetic waves
2. Wavelength and frequency are inversely proportional ( wavelength =  $c/f$ )
3. Historically, wireless communications mostly used frequencies below 6 GHz, but beyond 6 GHz is actively explored in modern wireless networks.
4. Hertz and bit rate are related by Nyquist and Shannon's Theorems
5. Nyquist's theorem explains
6. Shannon's capacity takes Signal-to-Noise Ratio into account
7. By spreading the original signal over a wide bandwidth, spread spectrum can provide better immunity against interference and jamming, allowing multiple parties to communicate over the same frequency at the same time
8. FHSS and DSSS are two fundamental methods of realizing spread spectrum
9. Doppler effect explains the shift in frequency experienced by mobile objects
10. Doppler spread is twice the Doppler shift
11. Channel coherence time is inversely proportional to doppler spread
12. FDD and TDD are two fundamental methods of resource allocation between the transmitter and the receiver so they both can exchange information with each other

**Assignment Project Exam Help**

<https://eduassistpro.github.io/>

Add WeChat [edu\\_assist\\_pro](#)