Lecture 1: Introduction to Communication Systems

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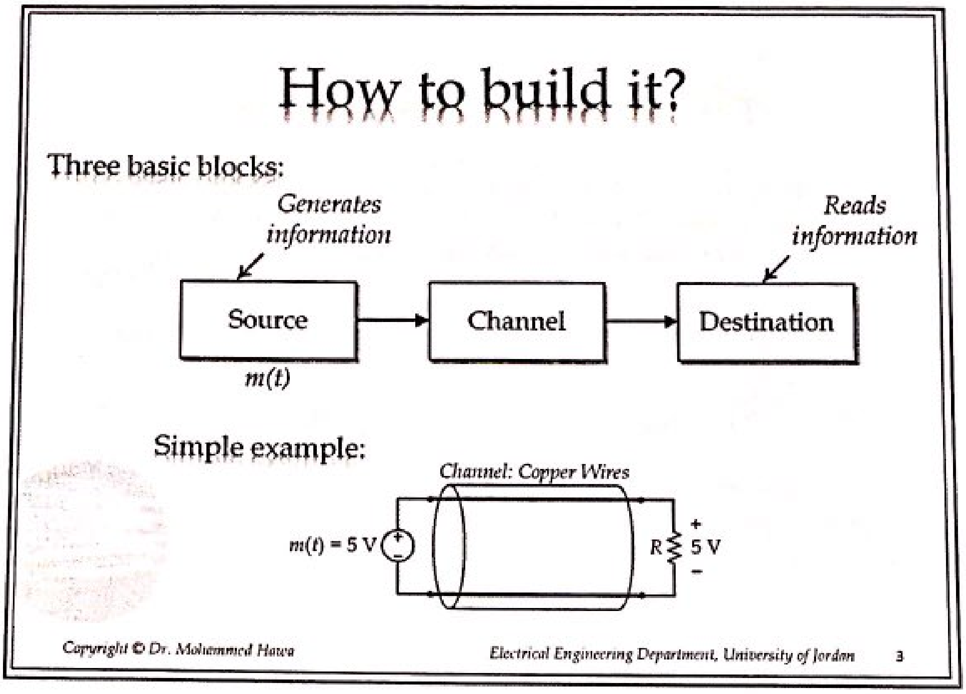
A Communication System

- Purpose of a communication system: Carry information from one point to another.
- A typical communication system consists of three main components:
  - – Source
  - – Channel
  - – Destination



How to build it?

Three basic blocks:

Generates information → Source → Channel → Destination ← *Reads information*

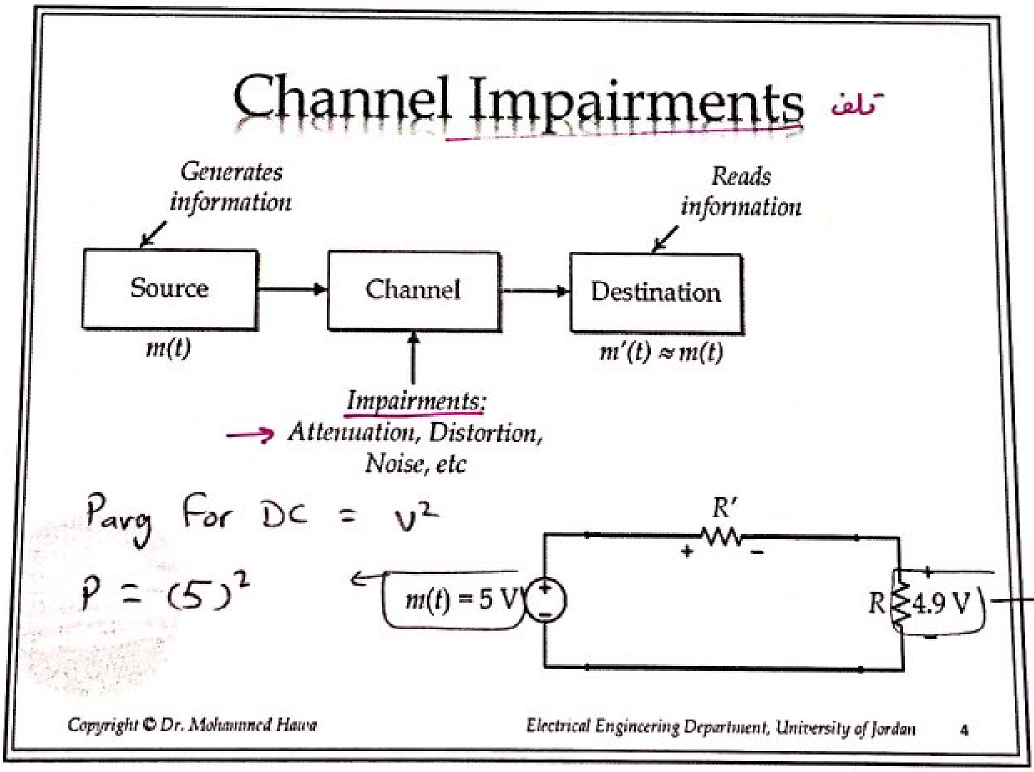
m(t)

Simple example:

Channel: Copper Wires

$m(t) = 5\text{ V}$

R + 5 V −



Channel Impairments تلف

Generates information → Source → Channel → Destination ← *Reads information*

m(t)

$m'(t) \approx m(t)$

Impairments:
Attenuation, Distortion, Noise, etc

P_{avg} For DC $= v^2$

$P = (5)^2$

R′ + −

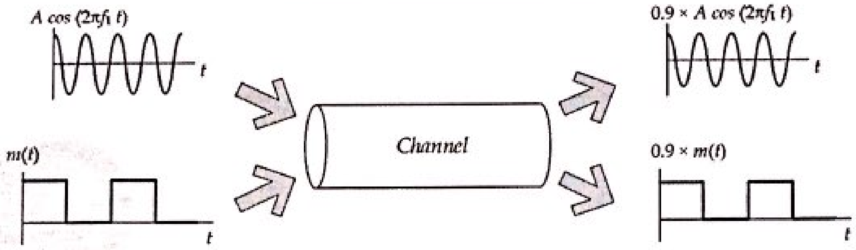
$m(t) = 5\text{ V}$

R 4.9 V → $P = (4.9)^2$

Channel Impairments

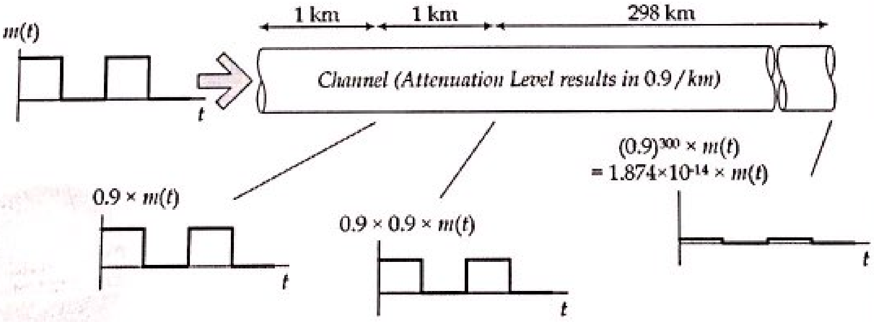
Power loss ←

1. Attenuation: As the signal travels through the channel it loses some of its energy (*power*) as heat in the internal resistance of the channel. We say the signal is attenuated.

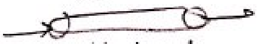


Attenuation

- Attenuation can be problematic for long distance communications (say cross-country).



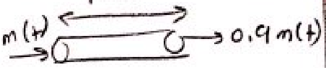
cH2



att level 0.8/Km

1Km

m(t) → 0.9m(t)



$\frac{out}{in} = \frac{0.9m(t)}{m(t)}$

$= 0.9$

(less attenuation compared to cH2)

L↑ R'↑

* 3 properties for Attenuation :-

① Att → signal types

② Att → channel types

③ increases as the chanel length increase

* Short - medium distance → use an amplifier at source or destination

* long distance → multiple amplifiers at intermediate cities

1/28/2018

* optical fibers has small attenuation levels.

* long distance communications → optical fiber.

* for copper wires, you need an amplifier every 5-10 Km

$v_{in} = (0.9)^{300}\ m(t)$

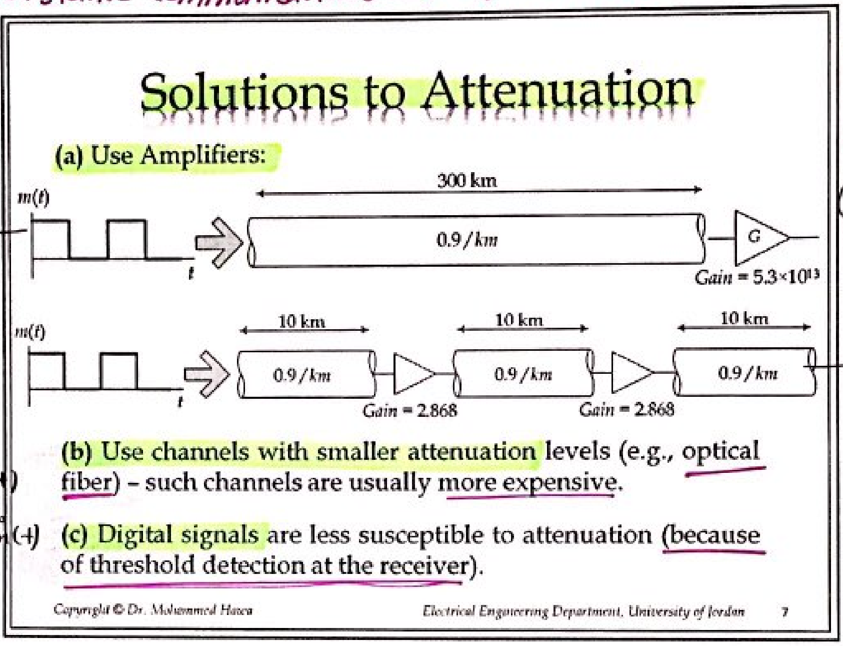
$\text{Gain} = \frac{1}{(0.9)^{300}}$

Inverse gain

$m(t) = v_0$

$v_0(t) = \text{Gain} \times v_{in}(t)$

$m(t) = \frac{1}{(0.9)^{300}} \times (0.9)^{300} m(t)$



Solutions to Attenuation

(a) Use Amplifiers:

(b) Use channels with smaller attenuation levels (e.g., optical fiber) – such channels are usually more expensive.

(c) Digital signals are less susceptible to attenuation (because of threshold detection at the receiver).

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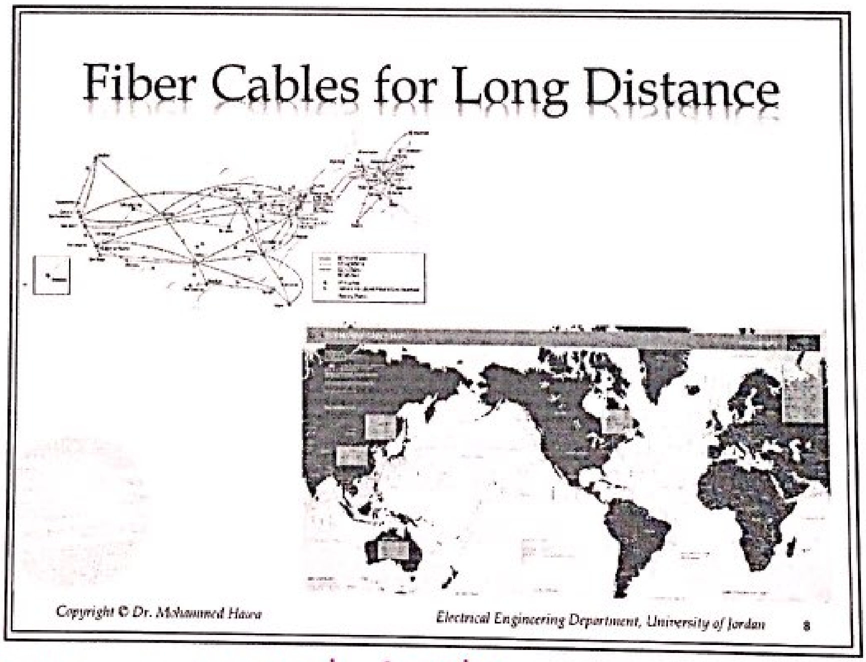
* For optical fibers, you need an amp every 50 - 100 Km

Amplifiers need power supply

$(0.9)^{10} m(t) \rightarrow \triangleright \rightarrow m(t)$

$\text{Gain} = \frac{1}{(0.9)^{10}}$

Attenuation is not easy to overcome



Fiber Cables for Long Distance

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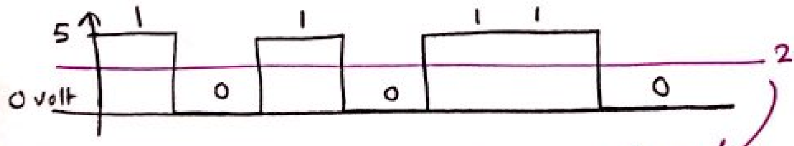
* Using Digital signals instead of analog



→ we don't care about the voltage, we care if it above the threshold or not!.

(أي شي أقل من 2.5 ← 0
أي شي أكثر من 2.5 ← 5

threshold detection

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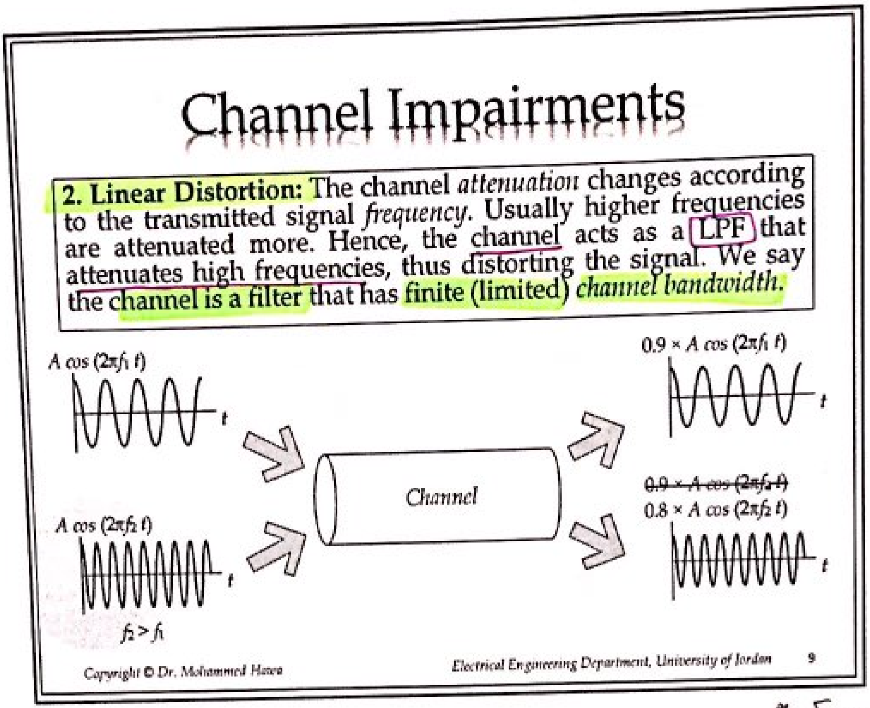

Channel Impairments

2. Linear Distortion: The channel *attenuation* changes according to the transmitted signal *frequency*. Usually higher frequencies are attenuated more. Hence, the channel acts as a $\boxed{\text{LPF}}$ that attenuates high frequencies, thus distorting the signal. We say the channel is a filter that has finite (limited) *channel bandwidth.*

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* Frequency transfer function:
higher frequency → higher attenuation.

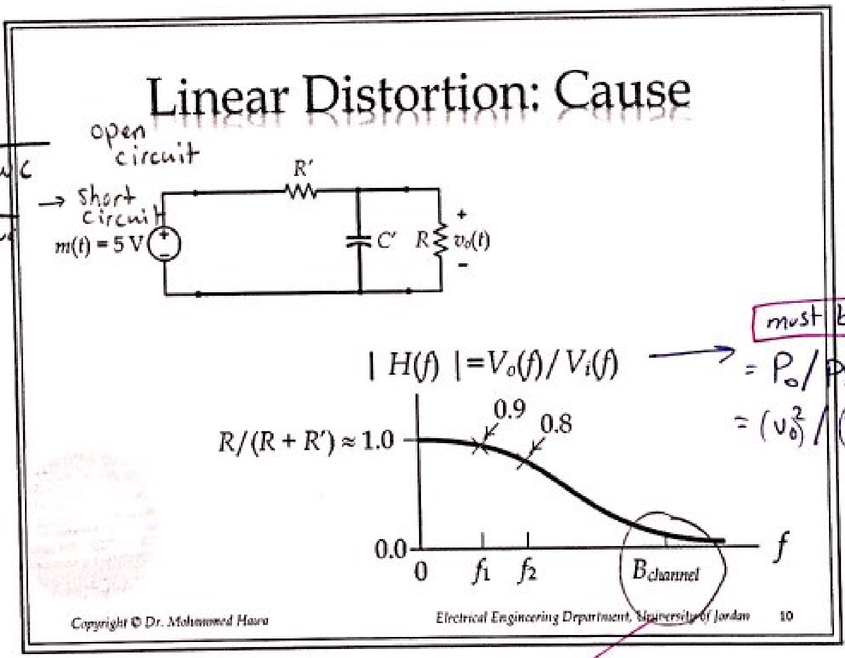
$Z_R = R'$

$Z_L = j\omega L$

$Z_C = \frac{1}{j\omega C}$

$\omega = 0 \rightarrow Z_C = \frac{1}{j\omega C}$ open circuit

$\omega = \infty \rightarrow Z_C = \frac{1}{j\omega}$ → short circuit



Linear Distortion: Cause

$| H(f) | = V_o(f) / V_i(f) \rightarrow$ $\boxed{\text{must be}}$ $= P_o / P_{in}$

$= (v_o^2) / (P_{in}^2)$

↓

but this is unitless so, we must use dB.

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$\boxed{\log 0 = -\infty}$

log goes down.

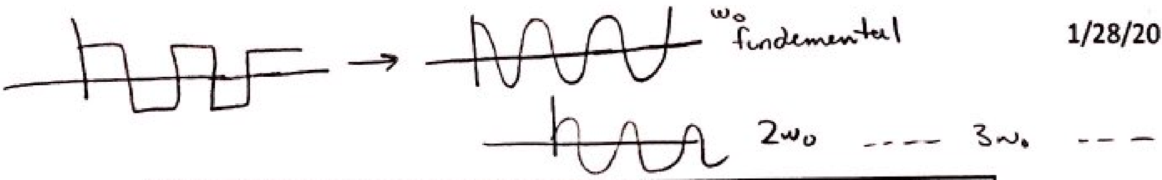
cut-off ≡ Bandwidth of the channel

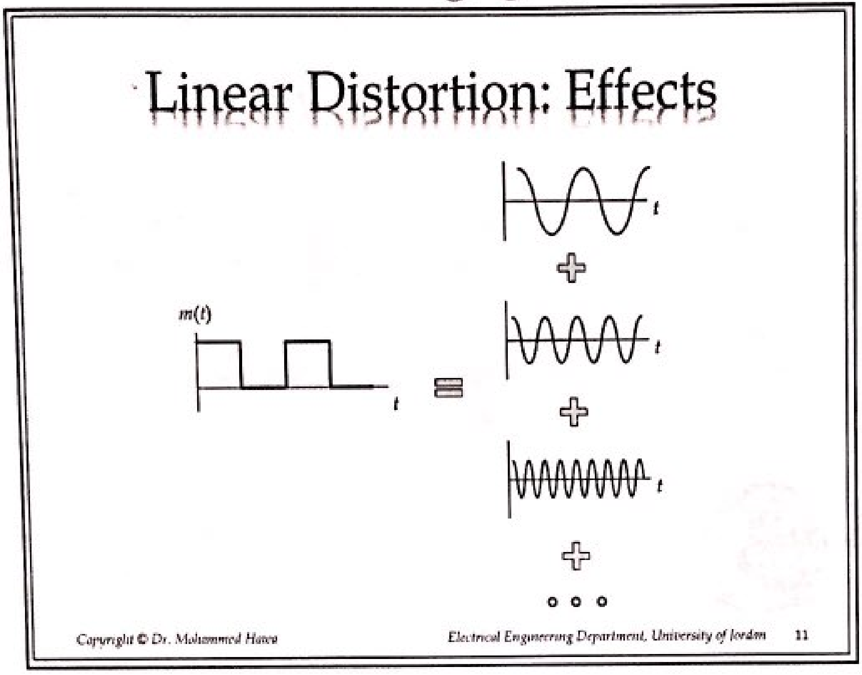
$= 10 \log_{10} (P_{out} / P_{in}) \rightarrow$ dB

$= 10 \log_{10} (V_{out}^2 / V_{in}^2)$

Periodic signals:-

x(t) periodic = $\sum_{\infty}$ cosines





Linear Distortion: Effects

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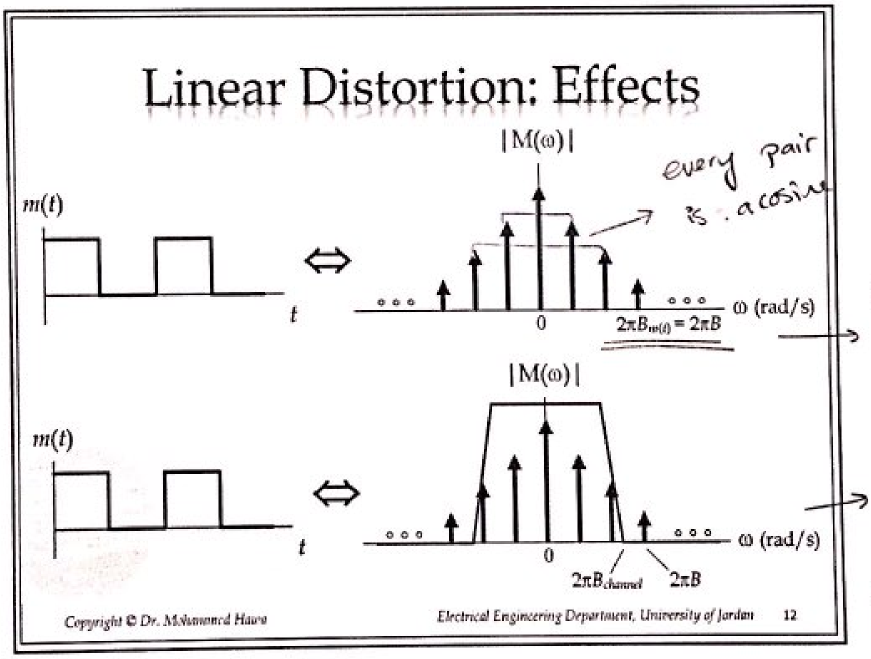

Linear Distortion: Effects

every pair is a cosine

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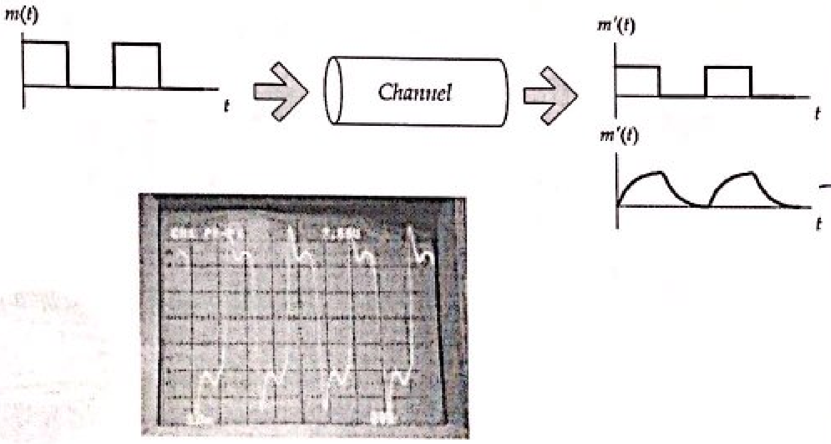
لازم تكون بال Hz
اذا كانت Rad/s
بضرب 2π * B

message should fit in the channel bandwidth

Linearly-Distorted Signals



the shape was changed.

To Summarize:

- Channel Bandwidth $B_{channel}$:
  - A property of the channel.
  - You read it from the data sheet of the channel.
  - The *frequency* after which the channel presents very high attenuation.
- Signal Bandwidth $B_{m(t)} = B$:
  - A property of the signal.
  - You figure it out from the Fourier transform of the signal.
  - The *frequency* above which $m(t)$ has insignificant (negligible) harmonics.
- *Rule of thumb*: signal bandwidth should be less than or equal to channel bandwidth.

$B_{m(t)} \leqslant B_{channel}$

The message should fit in channel Bandwidth.

- Bandwidth of 1km copperwires, is about 1-2 MHz
- 1 Km of Coax cable → 1-2 GHz
- 1Km fiber → too big (many THz)
  ↳ more expensive.

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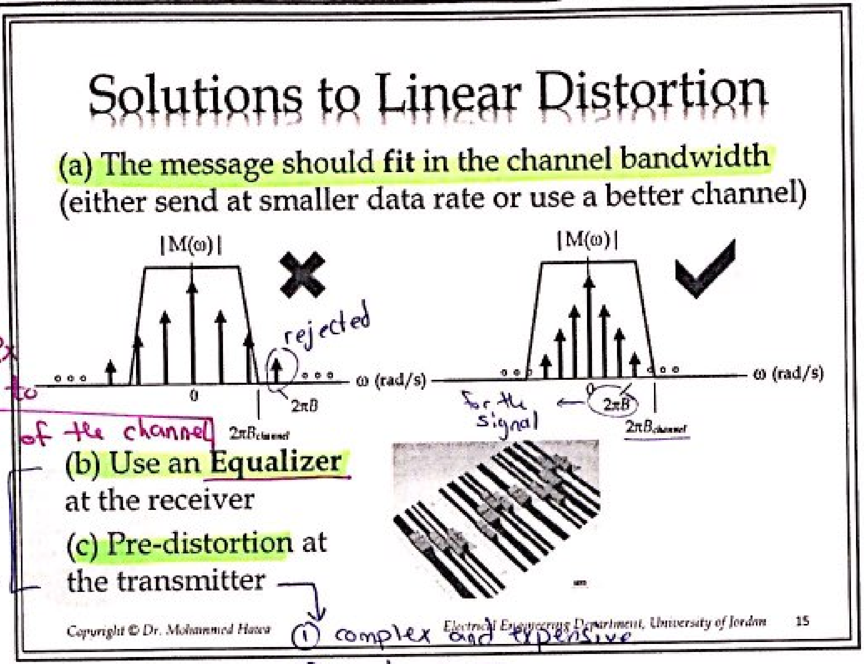
Compress in Time → expand in freq | and vice versa



Solutions to Linear Distortion

(a) The message should fit in the channel bandwidth (either send at smaller data rate or use a better channel)

rejected

for the signal

(b) Use an Equalizer at the receiver

(c) Pre-distortion at the transmitter

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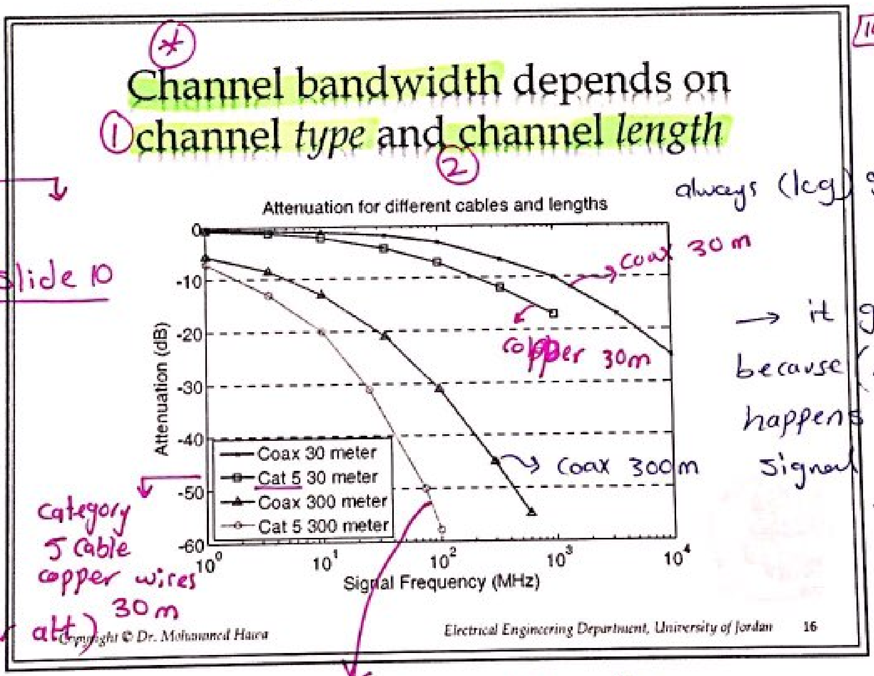
① device used in Rx
② equalizer tries to do the opposite job of the channel
expensive solutions
(very complex) ←
③ complex and expensive

① complex and expensive
② used at Tx
③ does the opposite job of channel

14 Record



(*) Channel bandwidth depends on ① channel type and channel length ②

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More realistic data sheet than that in slide 10

always (log) goes down

coax 30 m

copper 30m

coax 300m

→ it goes down because (more power loss) happens when the signal is higher frequency.

category 5 cable copper wires 30 m

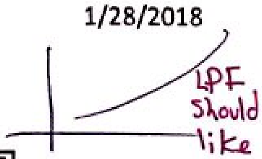
(has higher att.)

higher attenuation

why all the numbers is negative ?!

$10 \log_{10} \left(\frac{P_o}{P_i} \right)$ $P_o \to <1$ because of power loss → so we apply: $\left| 10 \log_{10} \left(\frac{P_o}{P_{in}} \right) \right|$

$= -ve$



LPF
Should act
like this

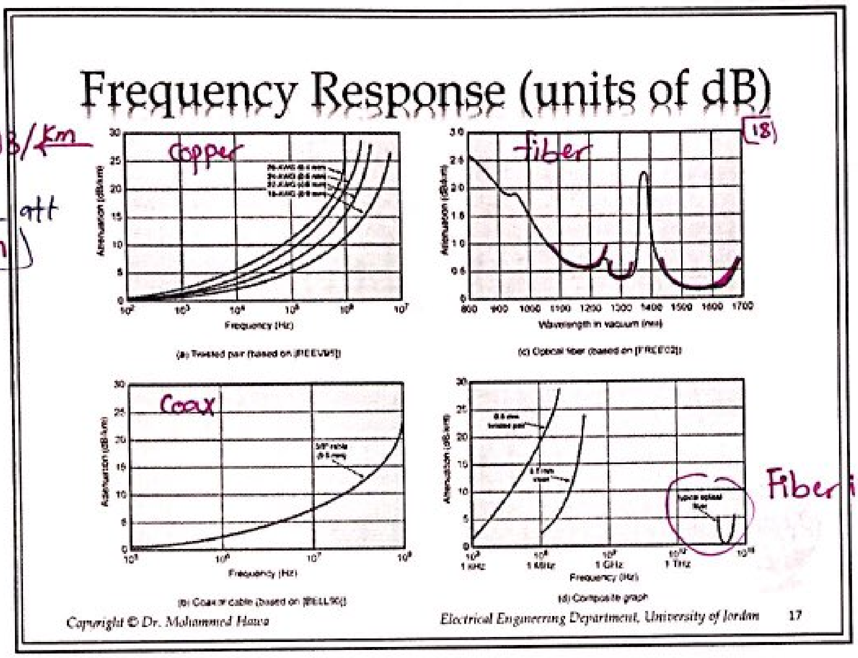
مع إنها بالسالب

10^5 Hz → att = 5dB/Km

= 100 K Hz

actually → $\boxed{-5dB/Km}$

att



Frequency Response (units of dB)

(18)

(a) Twisted pair (based on [REEV95])

(c) Optical fiber (based on [FREE02])

(b) Coaxial cable (based on [BELL90])

(d) Composite graph

Fiber is less attenuation.

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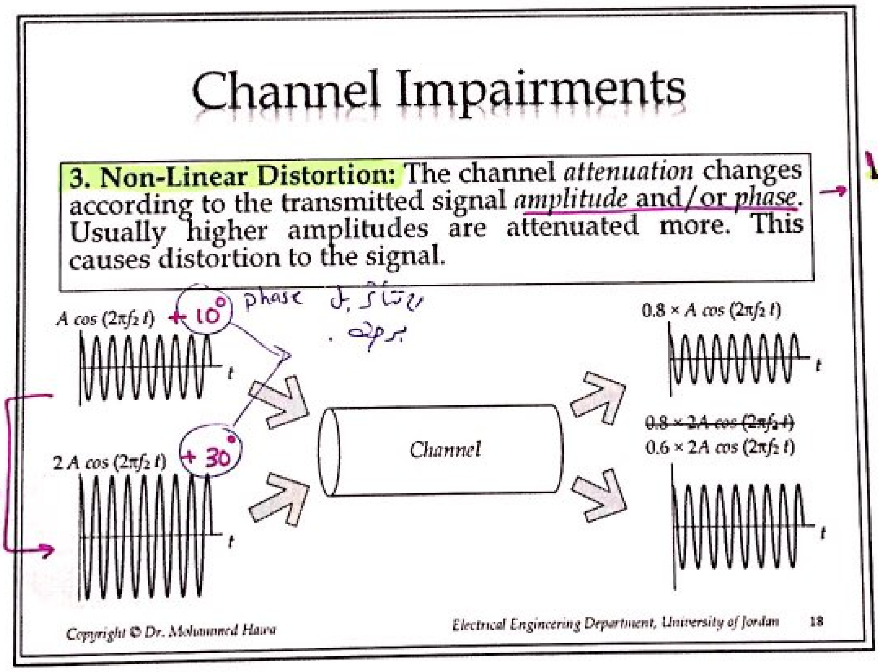

Channel Impairments

3. Non-Linear Distortion: The channel *attenuation* changes according to the transmitted signal *amplitude* and/or *phase*. Usually higher amplitudes are attenuated more. This causes distortion to the signal.

→ Linear distortion → Frequency

phase ال بتتغير برضه.

Same frequency but different Amplitude

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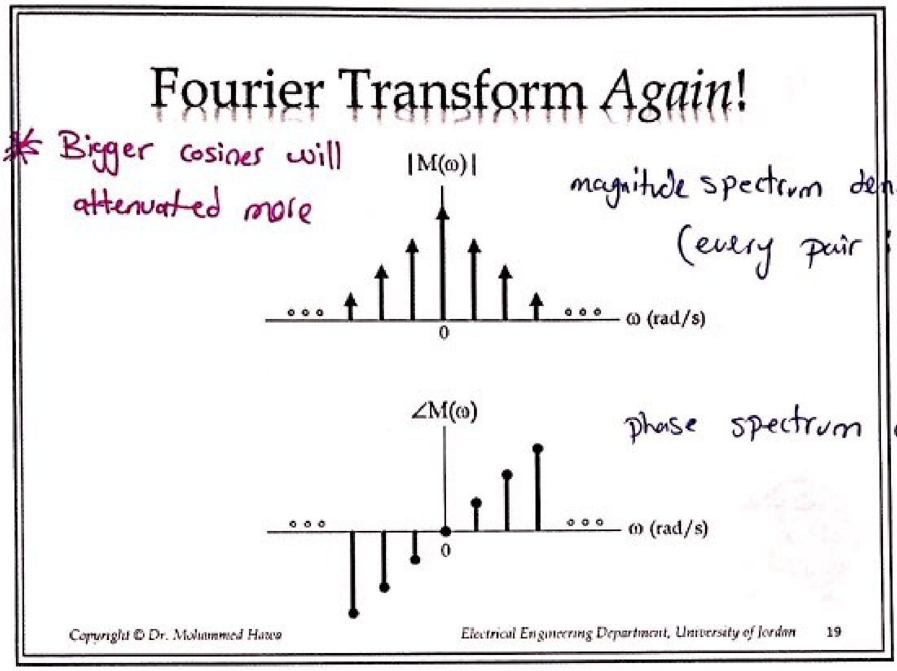
there is no rule of thump for the change of phase. it depends on the channel it self.

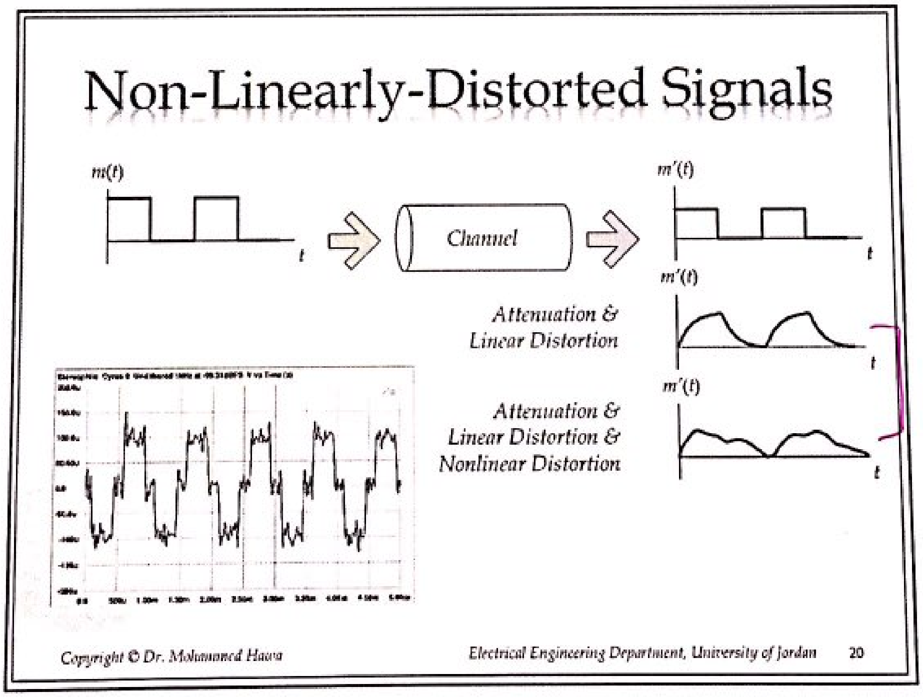


Fourier Transform *Again*!

* Bigger cosines will attenuated more

magnitude spectrum density
(every pair is a cosine)

phase spectrum density.



Non-Linearly-Distorted Signals

Attenuation &
Linear Distortion

Attenuation &
Linear Distortion &
Nonlinear Distortion

the shape has changed (problem)

Distorted signals are not desired!

- **Solutions to Non-Linear Distortion:** Use an Equalizer at the receiver or Pre-distortion at the transmitter.

① Rx

② Tx

expensive and complex.

* attenuation, linear and Non-linear distortion work on ~~[illegible]~~ your signal.

but Noise adds another part to the original signal.

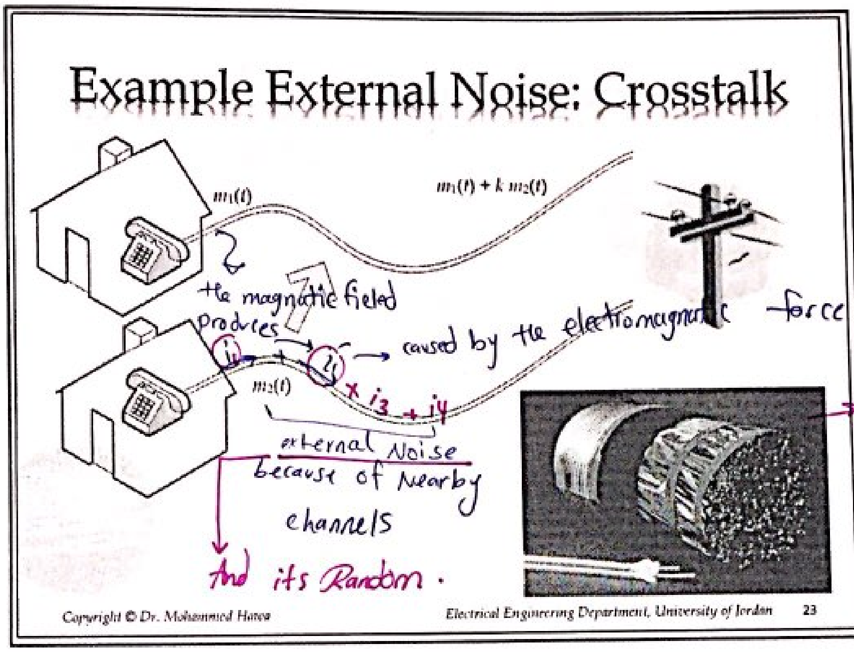
Channel Impairments

4. Noise: All the undesired signals (not part of the original signal) that are added by the channel. Noise is a random (*non-deterministic*) signal generated by external and internal sources.

you cannot write an equation

- **External Sources:** interference from signals transmitted on nearby channels (crosstalk), interference generated by contact switches, automobile ignition radiation, fluorescent lights, natural noise from lightning, solar radiation, etc.

Land line telephony :- channels behave like LPF



Example External Noise: Crosstalk

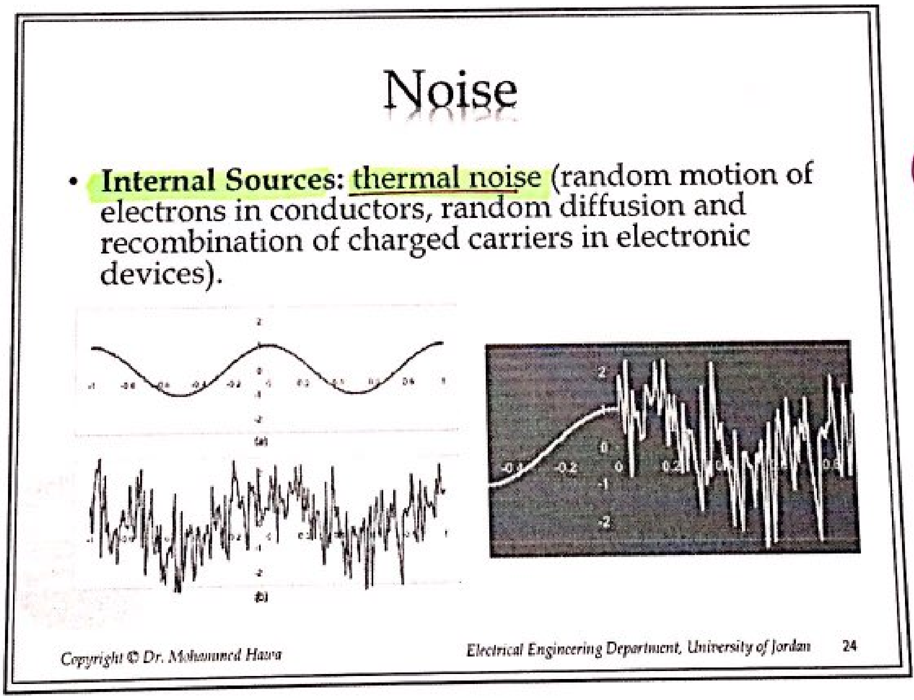
the magnetic field produces $i_1 + i_2$ → caused by the electromagnetic force (EMF)

$\times\ i_3 + i_4$

external Noise because of Nearby channels

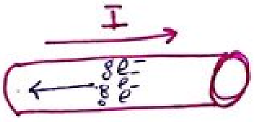
And its Random.

→ many cables there put together to save money but it causes Noise (Crosstalk) because of the magnetic field.



Noise

- **Internal Sources:** thermal noise (random motion of electrons in conductors, random diffusion and recombination of charged carriers in electronic devices).

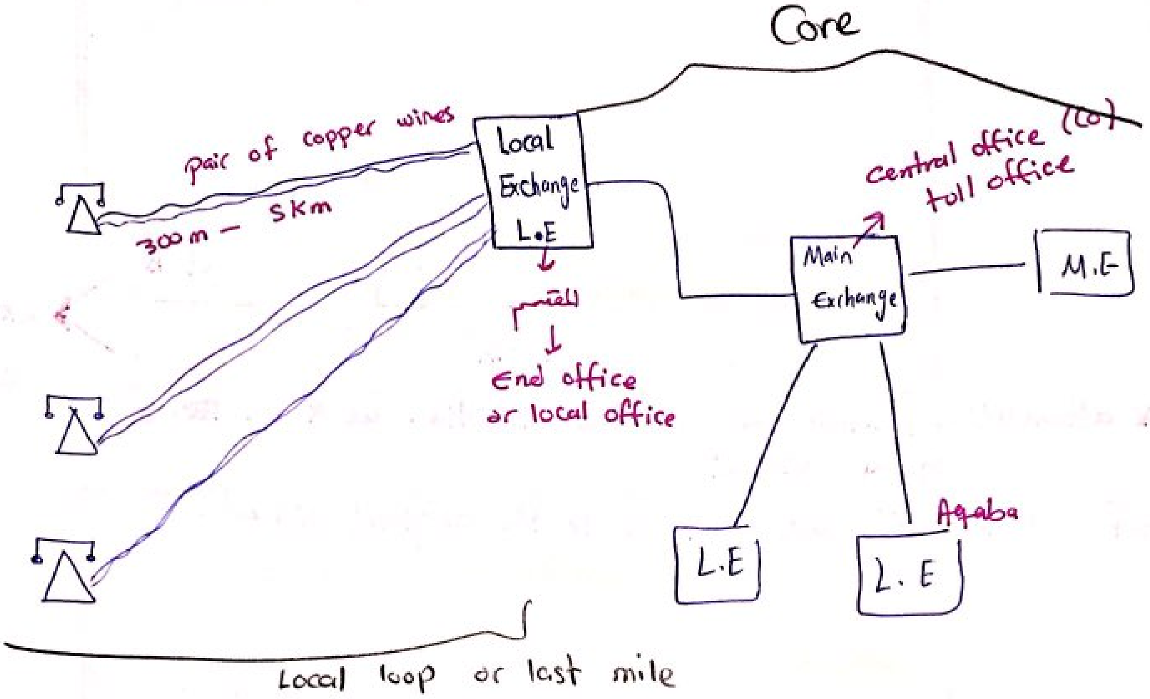


Bandwidth for copper → 1-2 MHz

coax → 1-2 GHz

Load line telephony :-

wireless channel ≡ in cellular

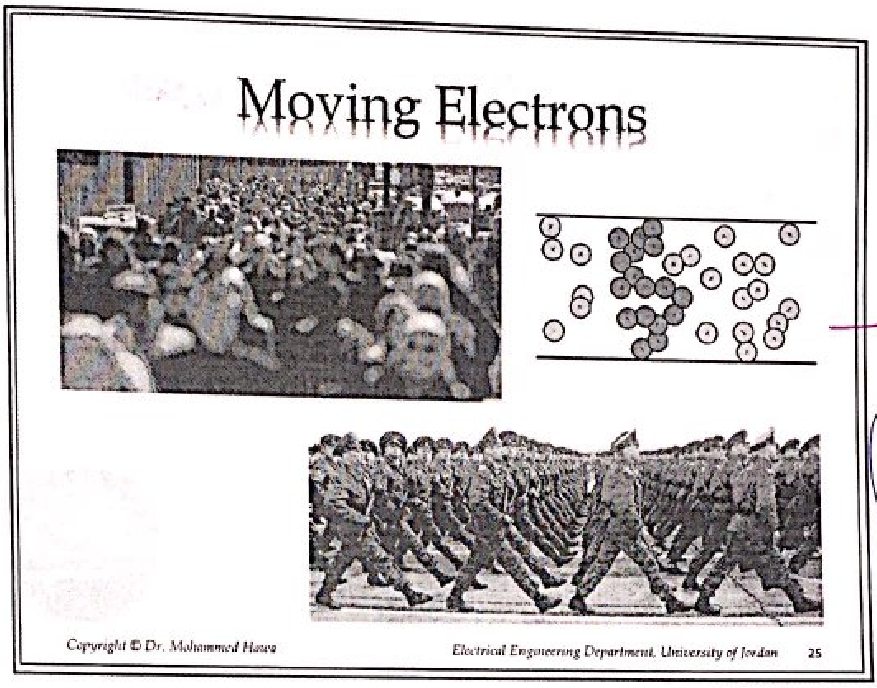


M.E → to connect L.E together

L.E → to connect users together

Fiber → big bandwidth and very low attenuation

load line telephony
- → PSTN : public switched telephone network
- → POTS : plain old telephony system.



Moving Electrons

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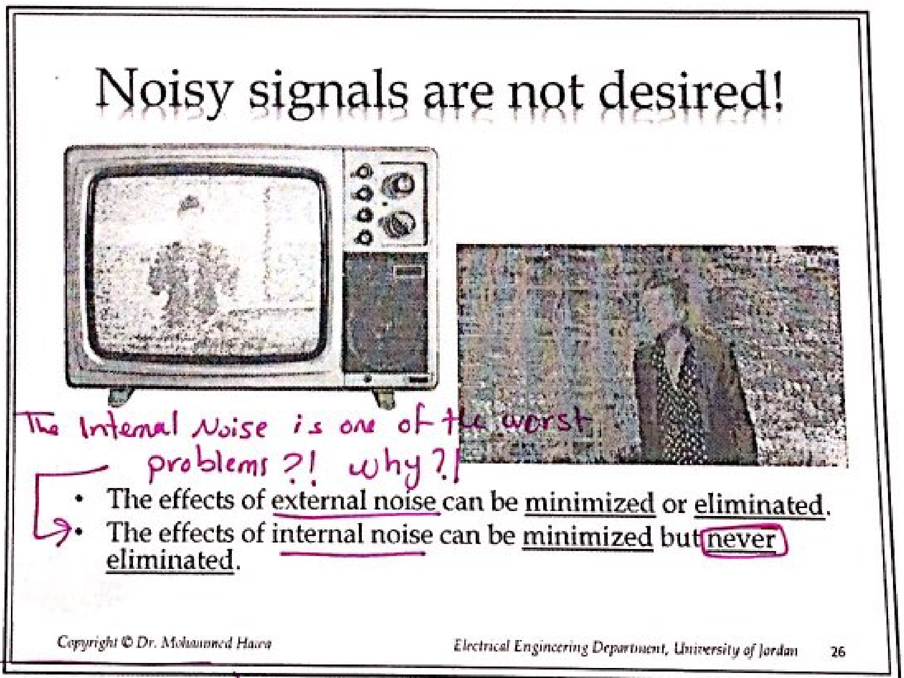
electrons move like this → Because of thermal energy (tempreture is not 0 kelvin) → gives energy to electrons.



Noisy signals are not desired!

The Internal Noise is one of the worst problems ?! why ?!

- The effects of external noise can be minimized or eliminated.
- The effects of internal noise can be minimized but never eliminated.

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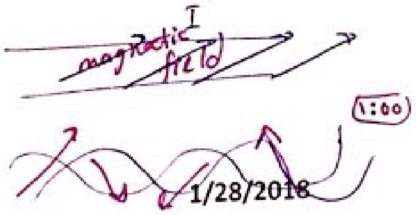
$\boxed{0^{\circ}K = -273^{\circ}C}$ → we need tempretune to be zero kelvin to eliminate internal Noise and this is impossible.

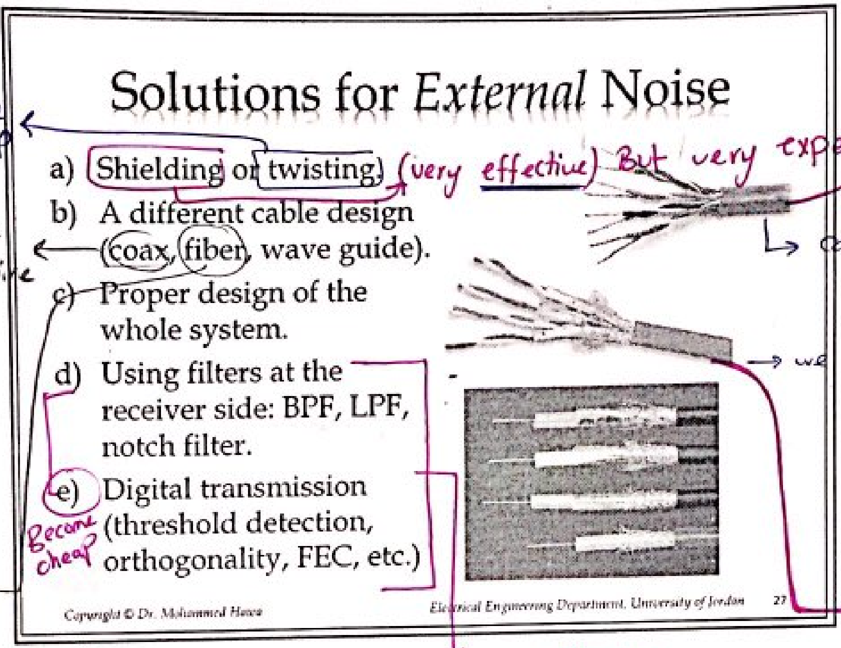
why (twisting) is effective ?¿



electric field is avector (has direction)

$\overrightarrow{}\,\overrightarrow{}^{\,5} = \longrightarrow 10$ ↳ can minimize some of the vectors

$\overleftarrow{}\underset{5}{}\overrightarrow{} = 0$ (because they have direction)



Solutions for *External* Noise

a) Shielding or twisting (very effective) But very expensive
b) A different cable design (coax, fiber, wave guide).
c) Proper design of the whole system.
d) Using filters at the receiver side: BPF, LPF, notch filter.
e) Digital transmission (threshold detection, orthogonality, FEC, etc.)

Become cheap

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effective and cheap

the inner wire inside the outer wire the outer one acts as conductor and sheild. so, that's prevents Interference from happen.

uses light (It has reflacted Index) Its like a mirror (reflects the light)

unsheilded twisted pair UTP

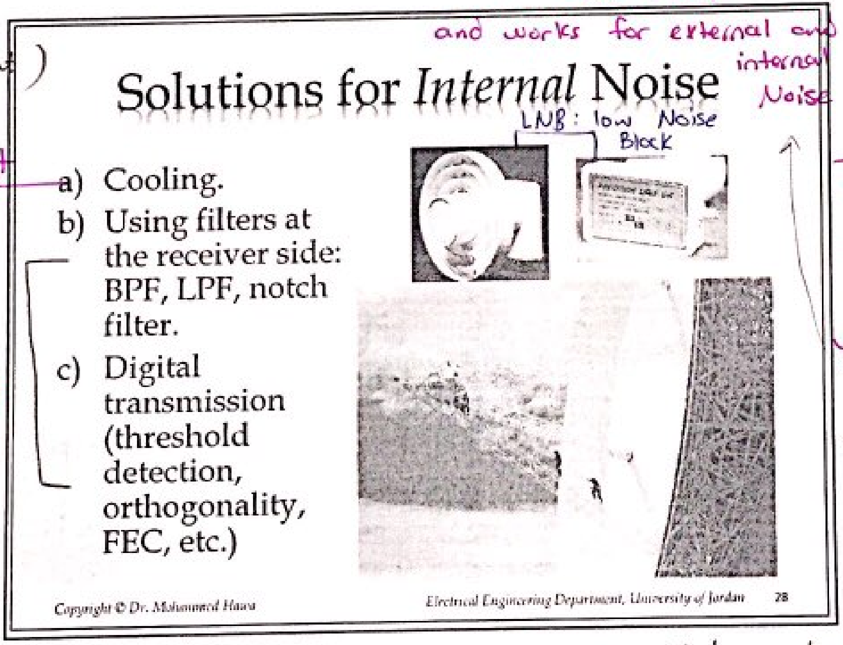
↳ cat 5 cable (used in ethernet)

→ we covered each pair with piece of metal to avoid Interference

Shielded twisted pair STP

very effective and cheap

and works for external and internal Noise



Solutions for *Internal* Noise

a) Cooling.
b) Using filters at the receiver side: BPF, LPF, notch filter.
c) Digital transmission (threshold detection, orthogonality, FEC, etc.)

LNB: low Noise Block

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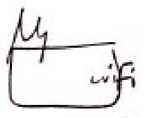
very effective but very expensive we use it in limited situations ex satellite

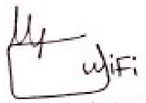
very effective and cheap

* what is the first stage you should use in your system ?¡

A filter effective and cheap



2.4 GHz
5 GHz

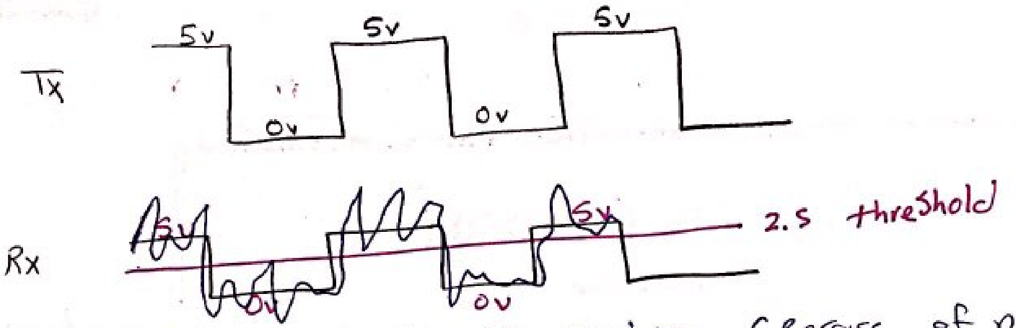


2.4 GHz
5 GHz

→ If you put these 2 wifi's nearby each other there will be Interference (they will create electro magnetic Interference against each other)

Bltooth 2.4 GHz
Microwave oven 2.4 GHz

ISM → HW



the Blue signal will receive. (Because of noise)

16 the reciever confused

why do we need satellite ?!

If you want to send a wireless signal from Point to another ~~thm~~ earth it will pass through heavy attenuation

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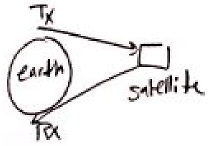
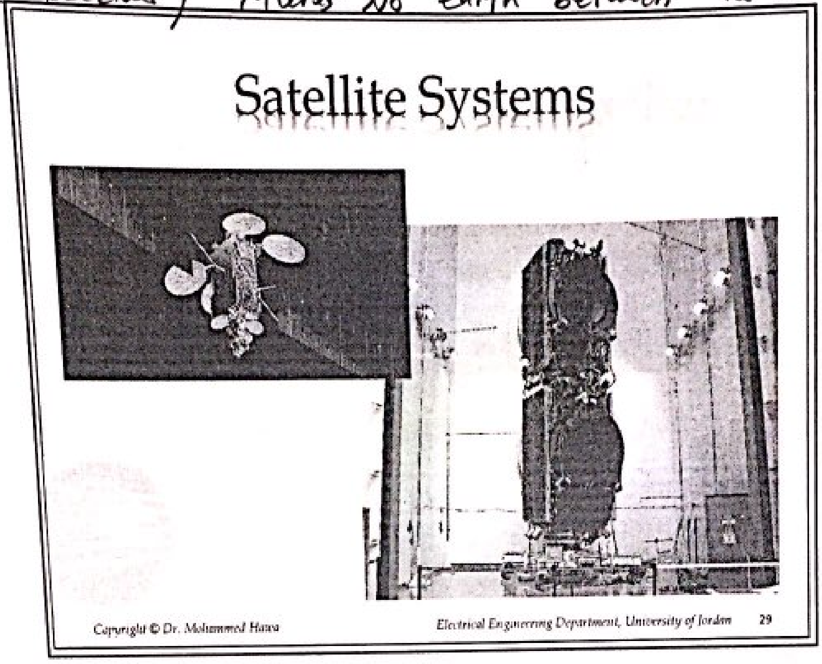
So, we use satellite to act like an amplifier (we send our signal to the satellite and it sends it back to the ~~transmitt~~ Receiver), there's No earth between Tx and Rx





Satellite Systems

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LEO : Low earth orbit

~ 1000 Km above surface of earth

Less attenuation and less Noise

MEO : Medium earth orbit

~ 10,000 Km

need 5-6 Satellite

GEO

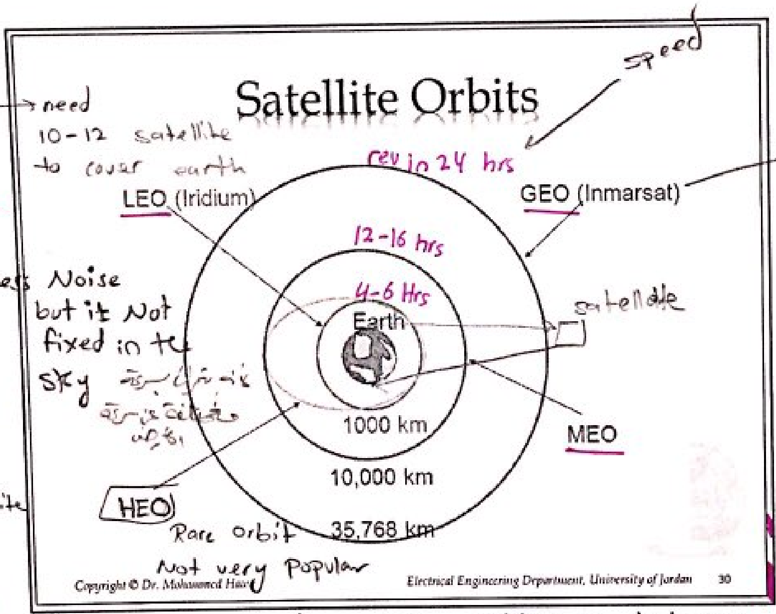
① geosynchranous or geostationary earth orbit

~ 36,000 Km

② fixed in sky → It rotates at the same speed of earth

③ need 3 satellite minimum to cover surface of earth

④ wider Footprint



Satellite Orbits

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GEO → we need 3 satellite from this type.

The difference between these 3 orbits:-

* Rotation speed.

(How fast the satellite rotate in it's orbit)

Disadvantage for GEO :-

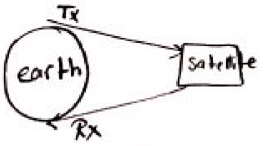
more attenuation and more Noise Because of the distance

why do we need satellite ?!

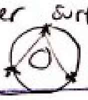
If you want to send a wireless signal from point to another on earth, it will pass through heavy attenuation.

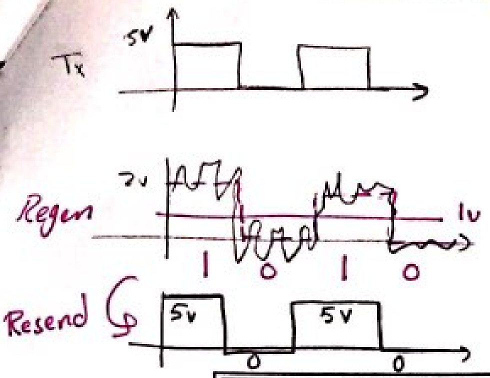
So, we use satellite to act like an amplifier (we send our signal to the satellite and it sends it back to the Receiver)

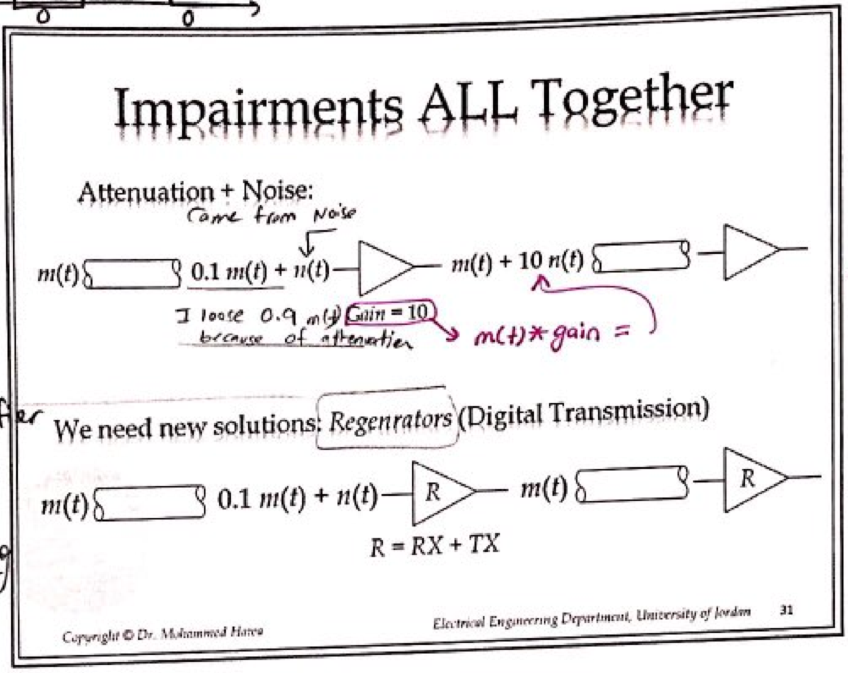
There's No earth between Tx and RX



* satellite orbits :-

	LEO Low earth orbit	~~A~~ MEO Medium earth orbit	GEO geosynchrounous or geostationary earth orbit
	~ 1000 Km above surface of earth	~ 10,000 Km	~ 36,000 Km
	needs 10-12 Satellite to cover earth	5-6 satellite (Between LEO and GEO)	needs 3 satellites minimum to cover surface of earth 
	Not fixed in the sky يدور بسرعة ثابتة غير سرعة الأرض	Not fixed in the sky	Fixed in sky (It rotates at the same speed of earth)
	less attenuation and less Noise	Between LEO and GEO	more attenuation and more noise (because of the distance) (disadvantage)
speed	4-6 hrs	12-16 hrs	Rev in 24 hrs





Impairments ALL Together

Attenuation + Noise:

Came from Noise

$m(t)$ — $0.1\, m(t) + n(t)$ — Gain = 10 — $m(t) + 10\, n(t)$

I loose 0.9 m(t) because of attenuation

m(t)*gain =

We need new solutions: *Regenrators* (Digital Transmission)

$m(t)$ — $0.1\, m(t) + n(t)$ — R — $m(t)$ — R

R = RX + TX

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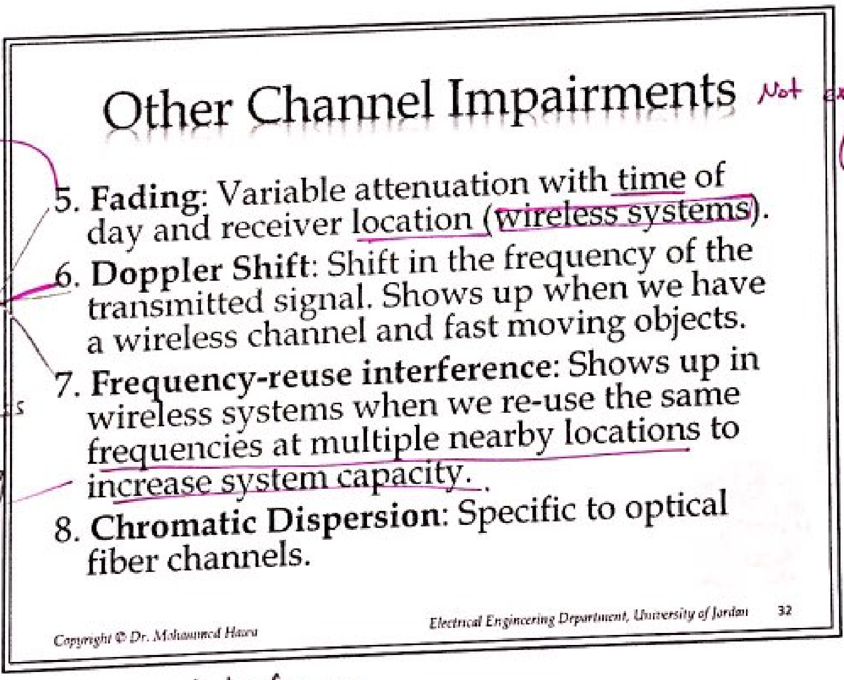
Nowadays, Satellites are Regenerator Not Amplifiers

transporder in Satellite is Regenerator.

(*) much more difficult to build than amplifier

① more expensive

② error propagating



Other Channel Impairments

Not exist in all channels (Just in specific ones)

5. **Fading**: Variable attenuation with time of day and receiver location (wireless systems).
6. **Doppler Shift**: Shift in the frequency of the transmitted signal. Shows up when we have a wireless channel and fast moving objects.
7. **Frequency-reuse interference**: Shows up in wireless systems when we re-use the same frequencies at multiple nearby locations to increase system capacity.
8. **Chromatic Dispersion**: Specific to optical fiber channels.

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examples

① celluler
② WiFi
③ w/Max
④ satellite

any wireless thing problems In cellular

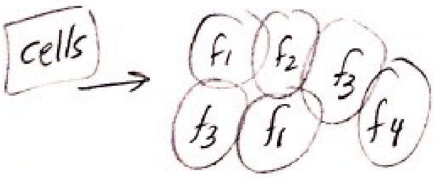
examples

①celluler
②satellite
③airplane comm

wireless and moving

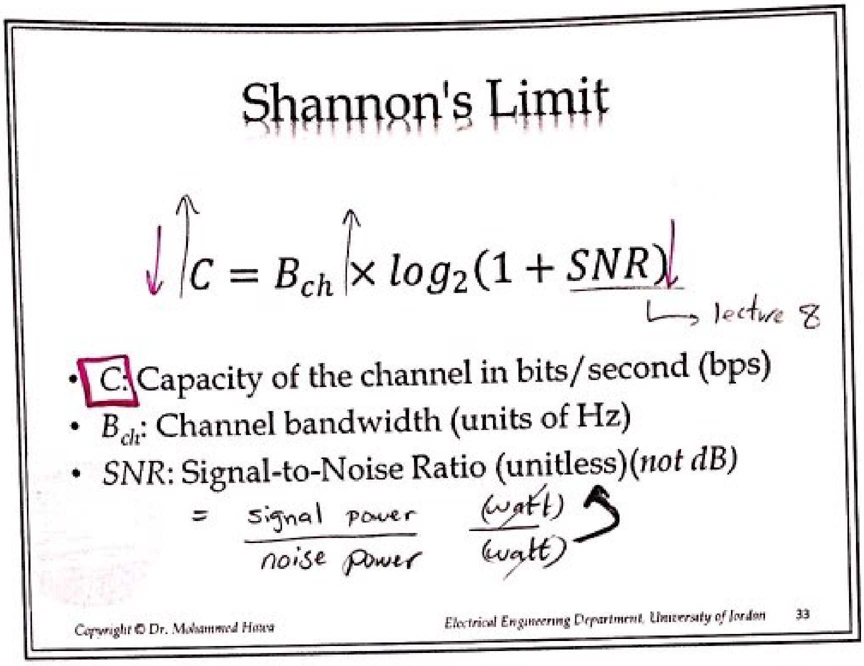
Frequency-reuse-interference

cellular f1 f2 f3 f4



* what is the effect of channel Impairments ?!

they are working against sending Information.



Shannon's Limit

$$\downarrow \uparrow C = B_{ch} \uparrow \times log_2(1 + \underline{SNR}) \downarrow$$

↳ lecture 8

- $\boxed{C:}$ Capacity of the channel in bits/second (bps)
- B_{ch}: Channel bandwidth (units of Hz)
- *SNR*: Signal-to-Noise Ratio (unitless)(*not dB*)

$$= \frac{\text{signal power}}{\text{noise power}} \quad \frac{(\text{watt})}{(\text{watt})}$$

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Bandwidth of the channel limits the capacity of the channel

noise ↑	SNR ↓	C ↓
signal power ↓	↓	↓

---

* Be careful to substitute signal power and Noise power unitless

Not in $\underline{\underline{dB}}$

ex → 1000 unitless ≡ 30 dB

㊀ $\boxed{log_2}$ Not Log_{10} *

$$30\ dB = 10 \log_{10}(1000)$$

How to use log_2

$$log_2(x) = log_2(10)\ log_{10}(x)$$

بنحل على الآلة

او باستخدام Calculator

$$\simeq 3.322 \log_{10}(x)$$

Lecture 2: Classification of Communication Systems

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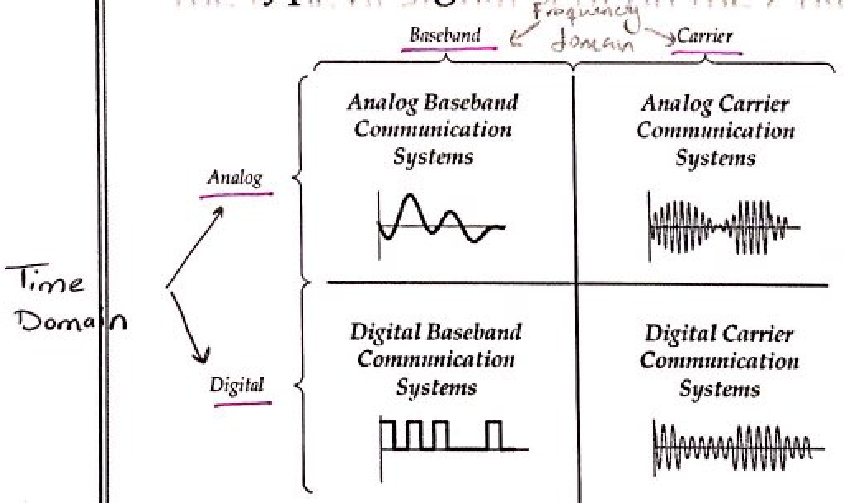
Comm Systems are classified based on the type of signal sent on the Channel



Each system has its advantages!

Analog Baseband

- *Simplest system to build*
- *Inexpensive*

Analog Carrier

- *Allows use of* ***Antennas***
- *Allows* ***Multiplexing*** *(FDM)*
- *Allows* ***exchanging*** *SNR for Bandwidth*

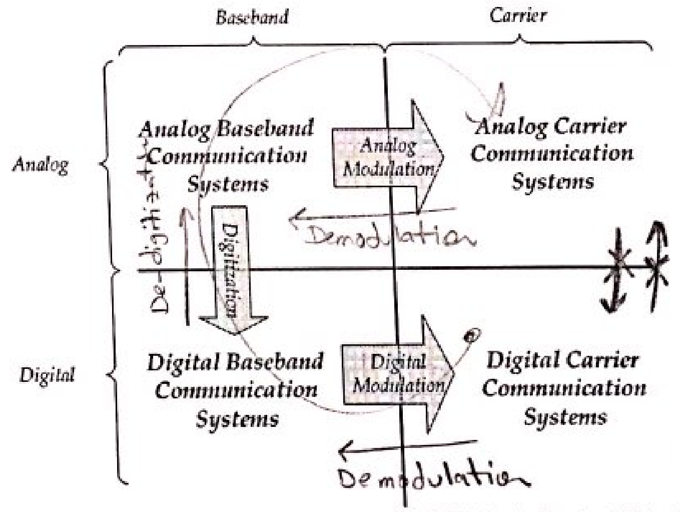
Digital Baseband

- *Immunity to* ***Noise***
- *Allows* ***Multiplexing*** *at baseband level (TDM)*
- *More bandwidth efficient*
- *Allows exchanging SNR for Bandwidth*
- *For more, see Handout*

Digital Carrier

- *Allows use of* ***Antennas***
- *Allows* ***Multiplexing*** *(FDM)*
- *Allows* ***exchanging*** *SNR for Bandwidth*
- *Also the advantages of digital baseband*

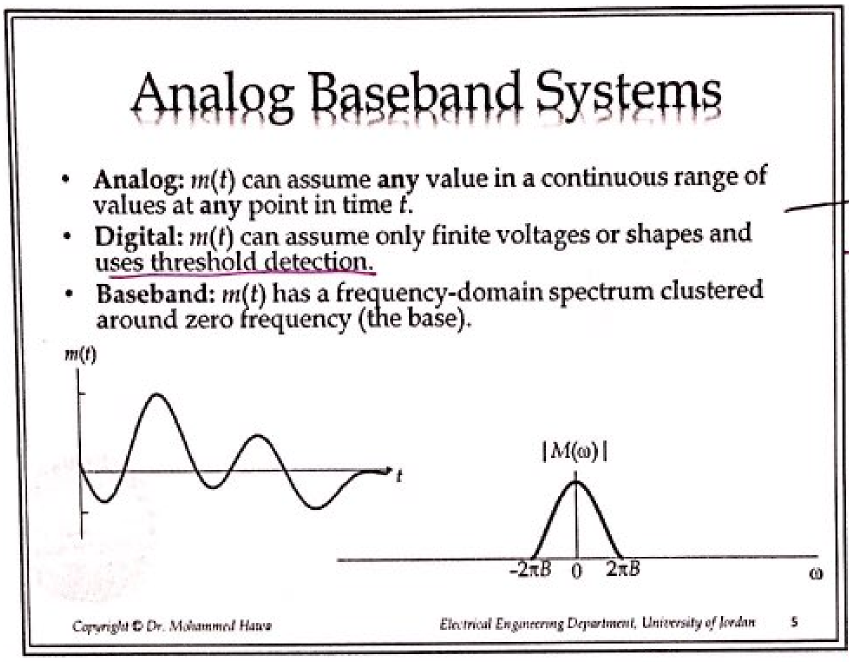
Modulation and Digitization



$m(t) \rightarrow$ t-domain $\longrightarrow$ analog vs Digital

$\mathcal{F}\{m(t)\} = M(\omega) \rightarrow$ f-domain $\longrightarrow$ Baseband vs carrier

t-domain $\longrightarrow$ Periodic vs aperiodic
or f-domain



Analog Baseband Systems

- **Analog:** $m(t)$ can assume **any** value in a continuous range of values at any point in time t.
- **Digital:** $m(t)$ can assume only finite voltages or shapes and uses threshold detection.
- **Baseband:** $m(t)$ has a frequency-domain spectrum clustered around zero frequency (the base).

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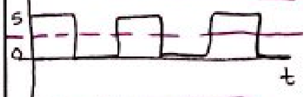
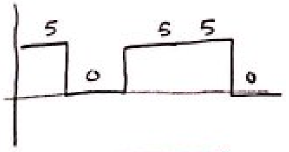
It doesn't come from nature, you create it

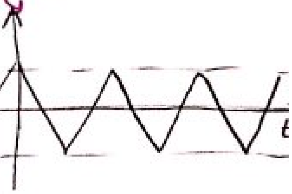
ex $m(t)$ = digital and periodic

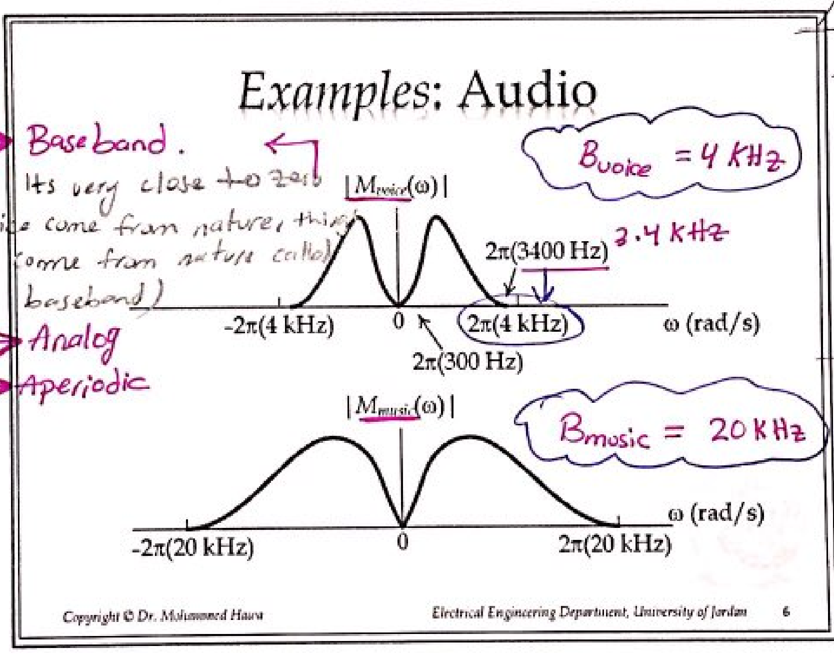


ex $m(t)$ = digital and aporiodic



$m(t)$ = Analog and Periodic





Examples: Audio

Baseband.
Its very close to zero
(voice come from nature, things come from nature called baseband)

Analog

Aperiodic

$B_{voice} = 4$ KHz

3.4 KHz

$B_{music} = 20$ KHz

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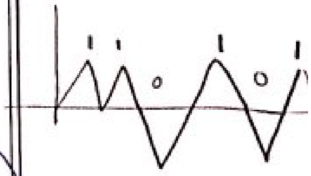
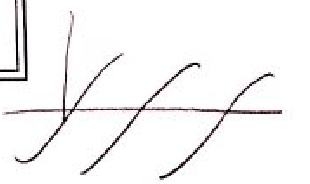
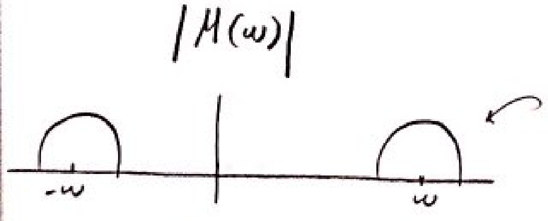
$m(t)$ = Digital and aperiodic

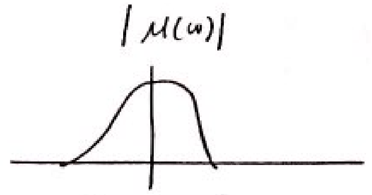


$m(t)$ = analog and periodic





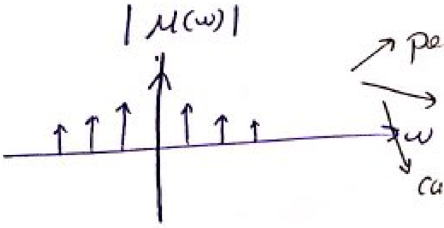
Carrier → Far away from zero



Baseband

→ Find Fourier Inverse $F^{-1}\{M(\omega)\} = m(t)$ to decide If it's analog or digital

→ aperiodic (smooth curve but Not sum of cosines)



→ periodic (sum of cosines)

→ Baseband (around zero)

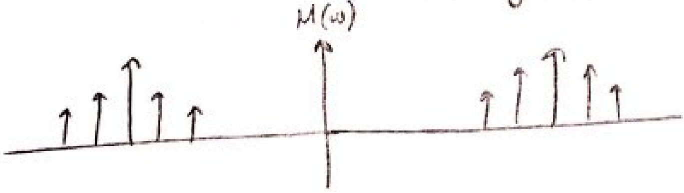
→ cannot decide If Its analog or digital only If we find $F^{-1}(M(\omega))$

---

* Show an example of carrier and periodic signal :-

carrier: Far away from zero

periodic: ↳ impulses Not smooth curves



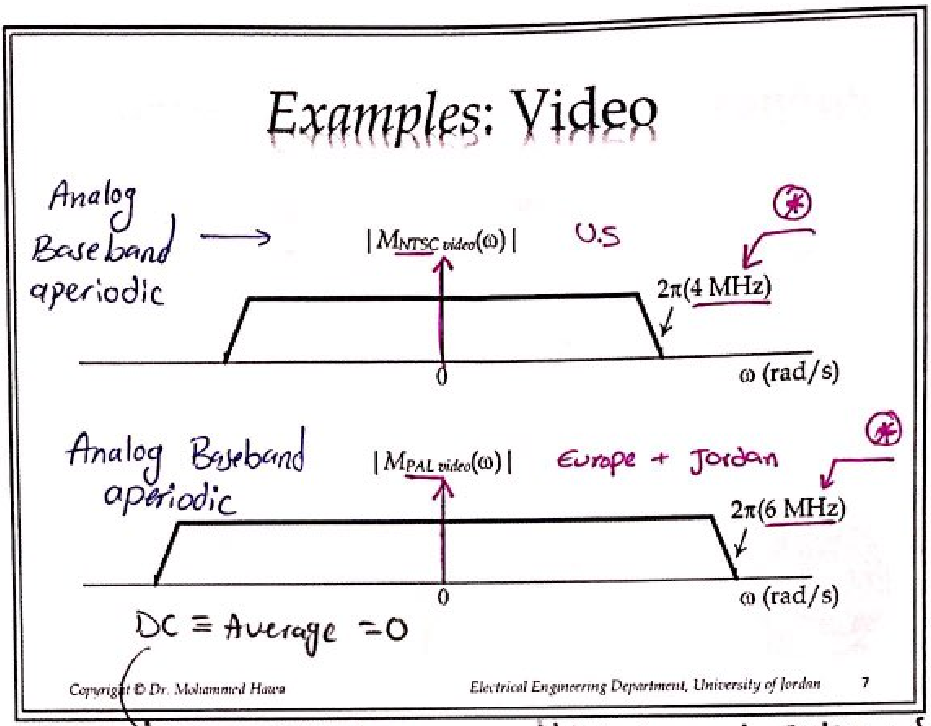
↳

$x(t) = \sum$ cosines

$F\{x(t)\} = F\{\sum \text{cosines}\}$

$= \sum F\{\text{cosine}\}$

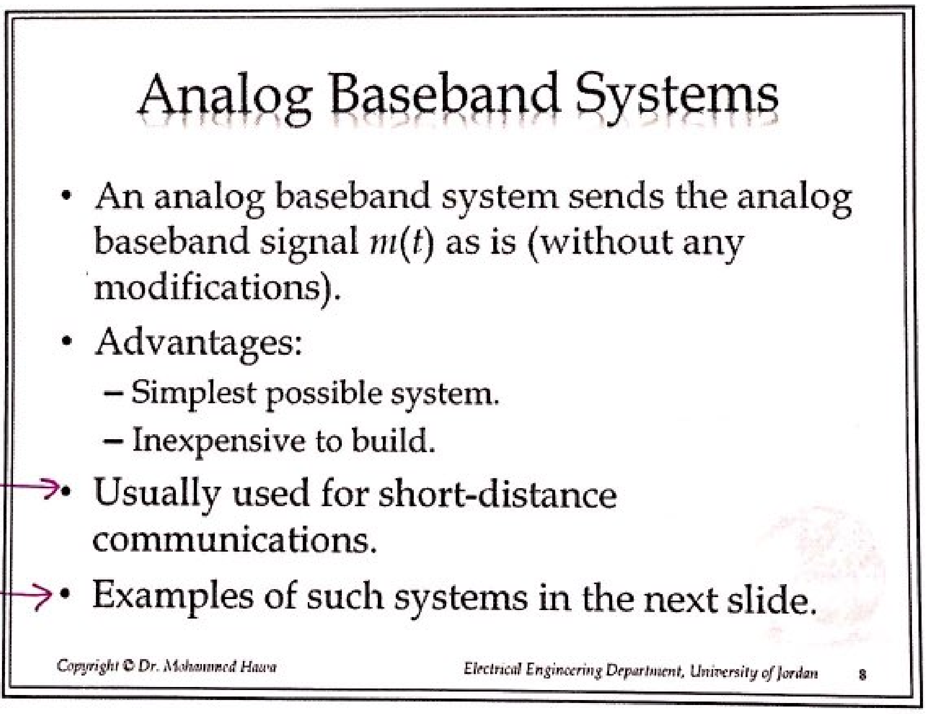
$=$ impulses .



Examples: Video

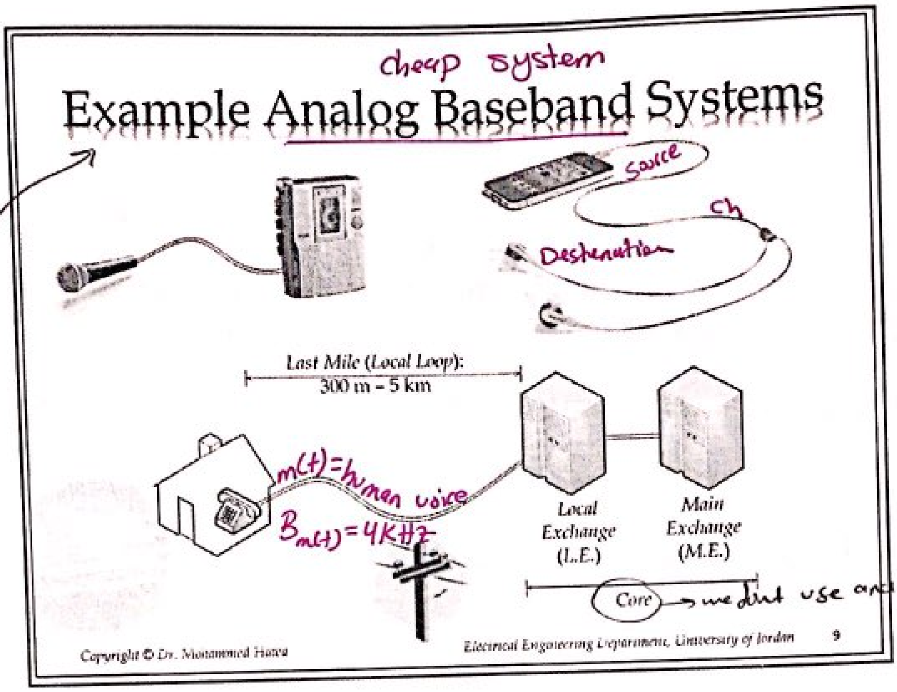
DC ≡ Average = 0

the impulse at 0 → and there is no impulse, so DC = 0



Analog Baseband Systems

- An analog baseband system sends the analog baseband signal $m(t)$ as is (without any modifications).
- Advantages:
  - Simplest possible system.
  - Inexpensive to build.
- Usually used for short-distance communications.
- Examples of such systems in the next slide.



cheap system

Example Analog Baseband Systems

source

ch

Destenation

Last Mile (Local Loop): 300 m – 5 km

m(t)=human voice

$B_{m(t)}=4KHz$

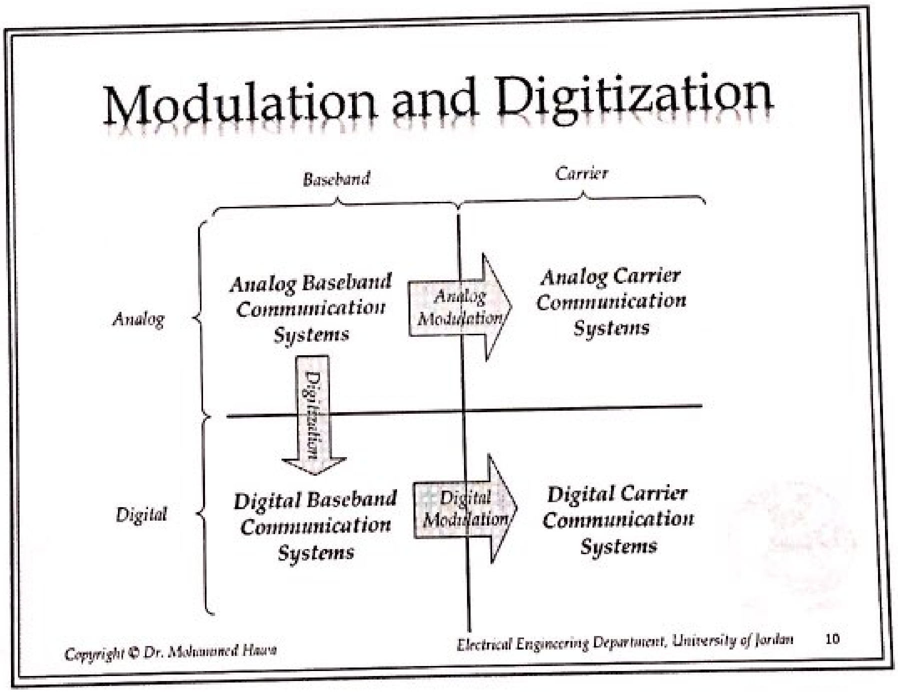
Local Exchange (L.E.)

Main Exchange (M.E.)

Core → we dont use anelog baseband in the core (because it's a long distance) (alot of noise, alot of attenuation)

PSTN

POTS



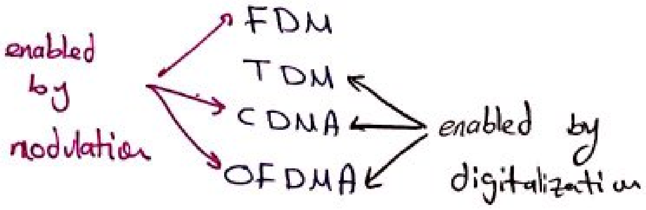
Modulation and Digitization

	Baseband	Carrier
Analog	Analog Baseband Communication Systems	Analog Carrier Communication Systems
Digital	Digital Baseband Communication Systems	Digital Carrier Communication Systems

Analog Modulation

Digitization

Digital Modulation

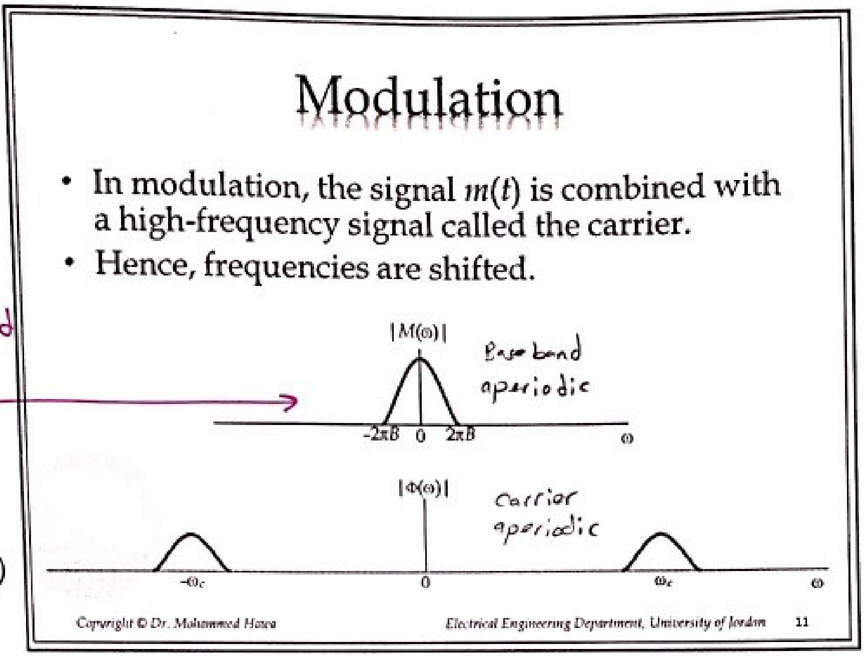


m(t) : Baseband

$F\{m(t)\} = M(\omega)$

↕

carrier $c(t) = \cos(\omega_c t)$



Modulation

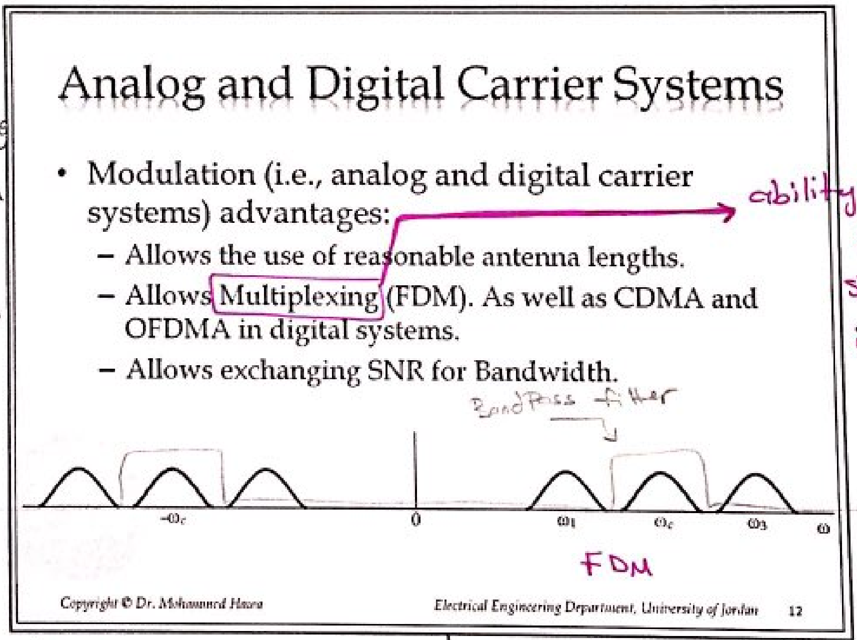
- In modulation, the signal $m(t)$ is combined with a high-frequency signal called the carrier.
- Hence, frequencies are shifted.

FDM: frequency division multiplexing

TDM : Time division multiplexing

CDMA: code division multiple access

OFDMA: orthogonal frequency " "



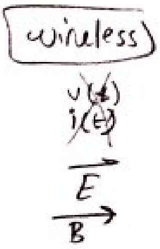
Analog and Digital Carrier Systems

- Modulation (i.e., analog and digital carrier systems) advantages:
  - Allows the use of reasonable antenna lengths.
  - Allows Multiplexing (FDM). As well as CDMA and OFDMA in digital systems.
  - Allows exchanging SNR for Bandwidth.

ability to send multiple signals simultaneously in the same channel.

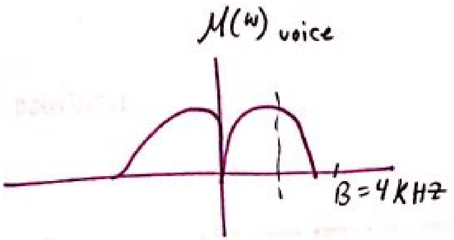
we need to convert voltage and current to $\vec{E}$ and $\vec{B}$

length of the antenna $= \frac{\lambda}{2}$



$L_a = \frac{\lambda}{2}$ → wavelength of signal

$$\lambda = \frac{c}{f} = \frac{\text{speed of light}}{\text{freq of signal}} = \frac{3\times10^{8}\ m/s}{f_{Hz}}$$



↳ $L_a = \frac{\lambda}{2}$ → $\lambda_{voice} = \frac{c}{f} = \frac{\cancel{3}\times 10^{8}}{\cancel{3}\times 10^{3}}$

$= 1\times 10^{5} = 100\ Km$

$L_a = \frac{100k}{2} = 50k$ → this is Not Practical.

Because of that we cannot send baseband by wireless.

---

wifi → $f = 2.4\ GHz \simeq 3GHz$

$\lambda_{wifi} = \frac{c}{f} = \frac{3\times 10^{8}}{3\times 10^{9}} = 1\times 10^{-1} = 10\ cm$

$L_a = \frac{\lambda}{2} = 5cm$ ✓ Practical

Practical system uses modulation → wireless
wifi
Radio
Multeplixing

Example Carrier Systems

Amplitude modulator

Frequency modulation

- Examples of **analog carrier** systems:
  - AM and FM radio broadcasting.
  - Analog TV broadcasting (NTSC and PAL).

US Europe

- Examples of **digital carrier** systems:
  - Digital radio broadcasting (DAB). → Digital Audio Broadcasting
  - Digital TV broadcasting (DVB-S, DVB-T, ATSC) → Homework (Appreciation)
  - WiMAX metropolitan area network. ↳ Digital video Broadcasting
  - Wi-Fi wireless local area network.
  - Cellular Telephony (2nd, 3rd and 4th generations).
  - Bluetooth, Zigbee and NFC
  - Old dial-up modems.
  - ADSL modems.

copper wires

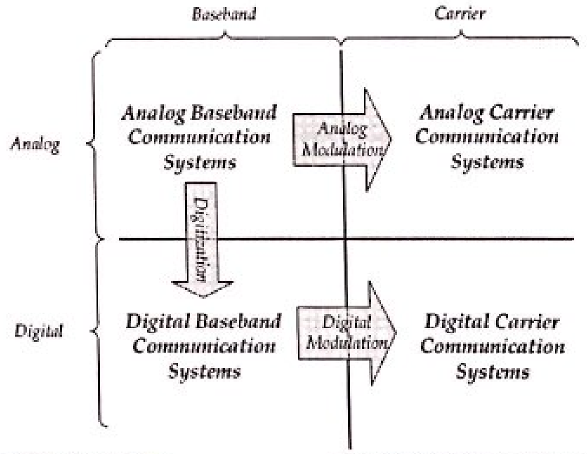
why we need modulation while its not wireless ?!

→ multiplexing

(we need it to use the internet)

also to make a phone call

Modulation and Digitization



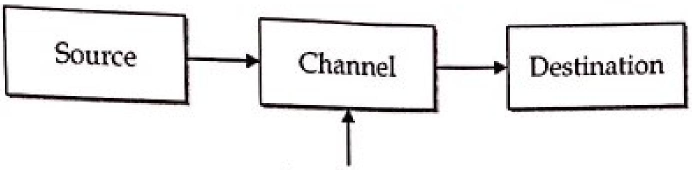
Digitization

- To convert the analog baseband signal into a digital baseband signal :
  - Sampling.
  - Quantization.
  - Mapping.
  - Encoding (coding).
  - Pulse Shaping.
- Digital baseband Advantages:
  - Immunity to Noise. (threshold detection, regenerators, FEC ---)
  - Allows Multiplexing at baseband level (TDM).
  - Immunity to Attenuation
  - Allows Multiplexing at carrier level (CDMA and OFDMA)

Example Digital Baseband Systems

- Digital baseband Advantages (*Continue*):
  - More bandwidth efficient (compression and line coding).
  - Allows exchanging SNR for Bandwidth at the baseband level.
  - For more, see Handout.
- Examples of digital baseband systems: → Universal Serial Bus
  - Serial (RS-232) and USB port connections.
  - Ethernet (a popular local area network). to connect computers to each others
  - Telephony (between local exchanges), such as the T-1, T-2, …, E1, E2, … etc PDH carriers.

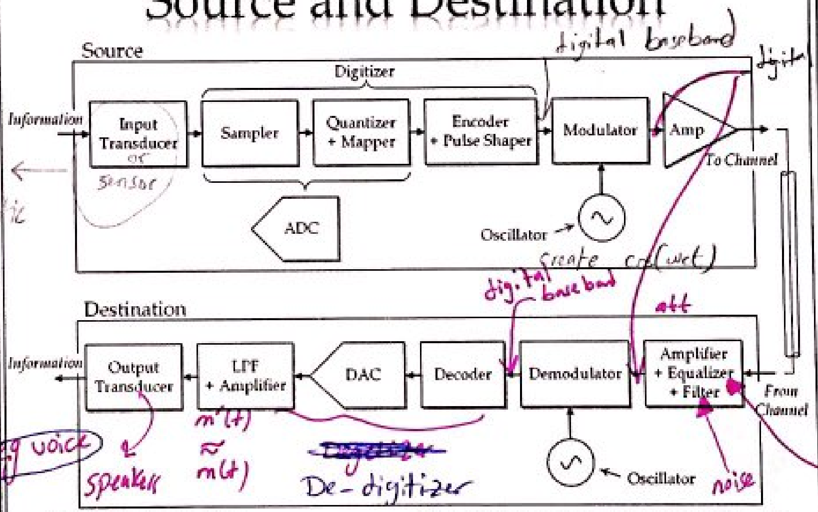
Block Diagram of a Communication System



Impairments:
Attenuation, Distortion,
Noise, etc

Source and Destination

ex
Microphone
convert voice
into electromagnetic
system



distortion
(linear and non-linear)

digital
baseband
block
diagram

analog
Baseband
- cheap
- simple to build

Lecture 3: Review of Signal Analysis Basics

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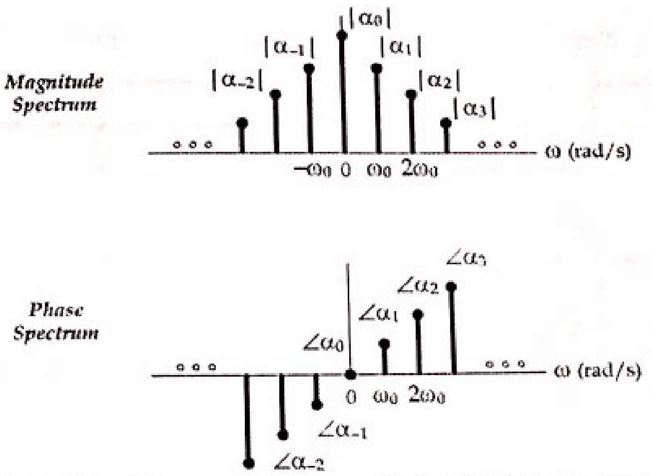
Exponential/Trigonometric/Compact

$$x(t) = \sum_{n=-\infty}^{\infty} a_n \cdot e^{jn\omega_0 t}, \quad \omega_0 = \frac{2\pi}{T}$$

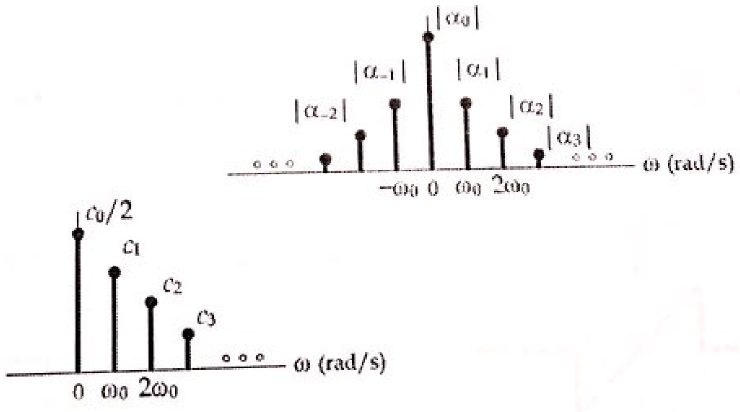
$$x(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} \left(a_n \cos(n\omega_0 t) + b_n \sin(n\omega_0 t)\right), \quad \omega_0 = \frac{2\pi}{T}$$

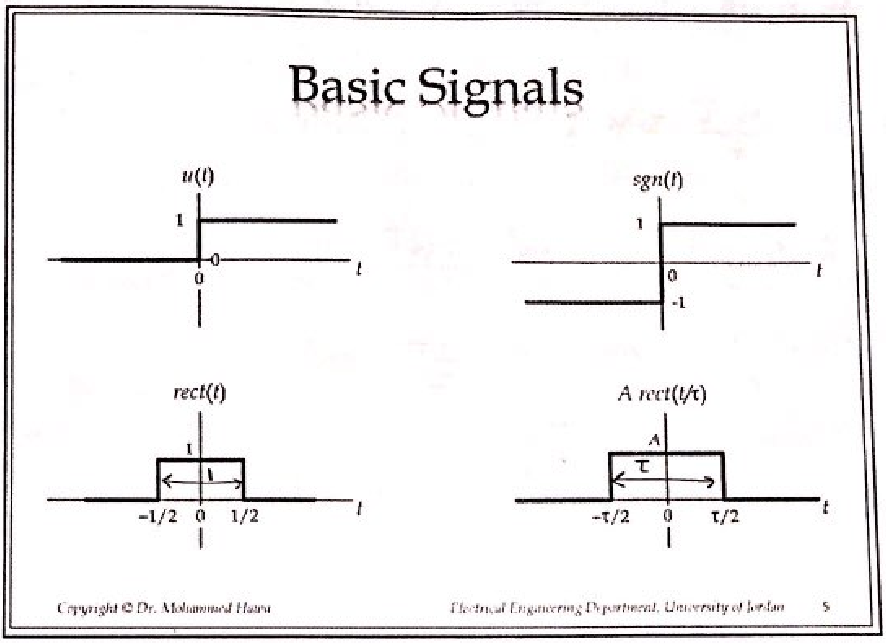
$$x(t) = \frac{c_0}{2} + \sum_{n=1}^{\infty} c_n \cos(n\omega_0 t - \theta_n), \quad \omega_0 = \frac{2\pi}{T}$$

Exponential Fourier Series



Single-Sided vs. Double-Sided





Basic Signals

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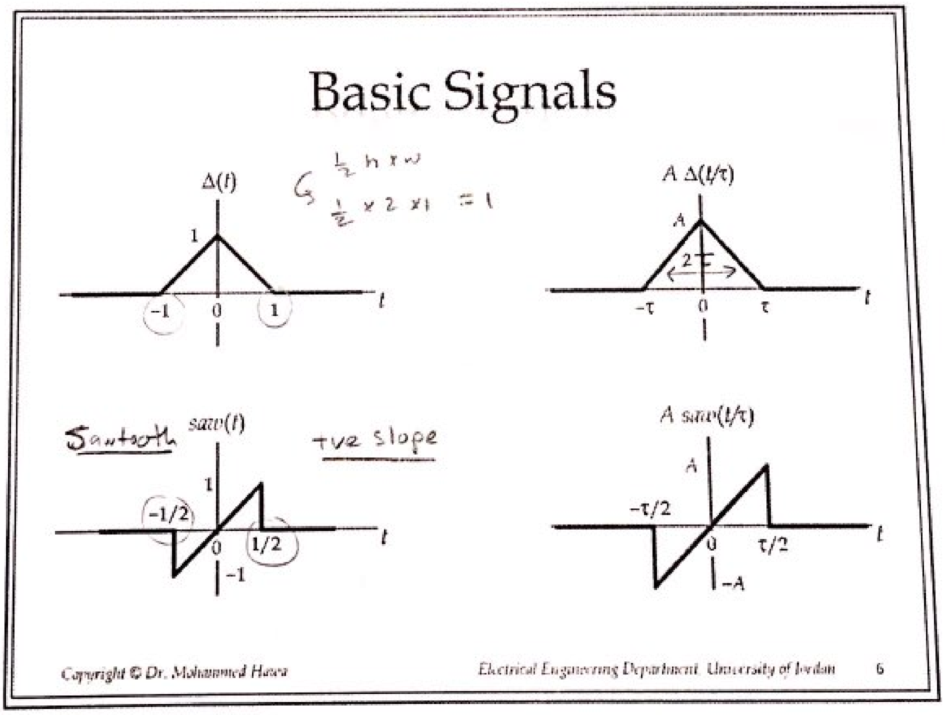

Basic Signals

$\hookrightarrow \frac{1}{2} h \times w$

$\frac{1}{2} \times 2 \times 1 = 1$

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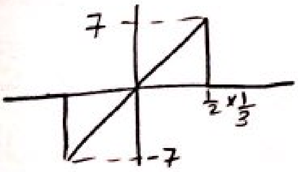
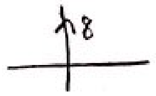
7 saw (3t)

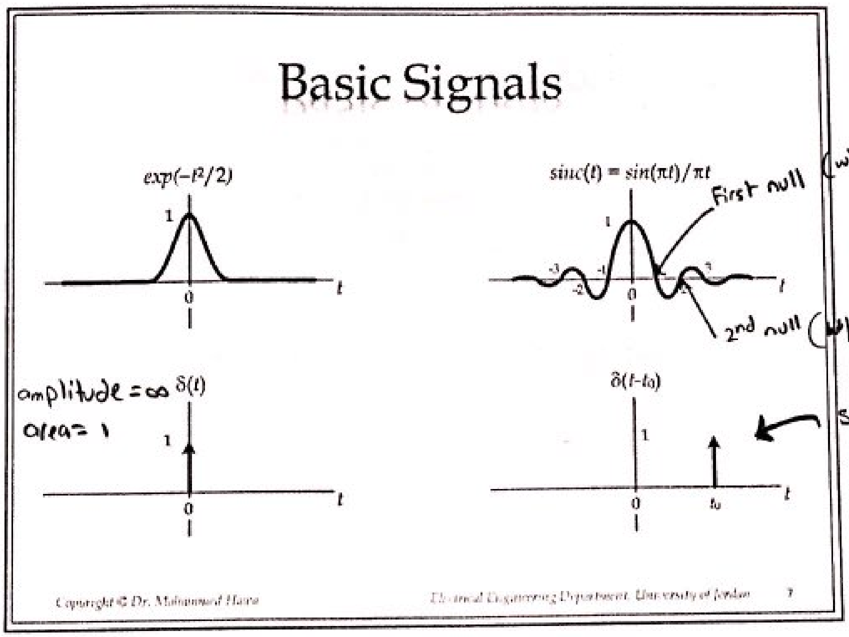


$\boxed{\mathrm{sinc}(t) = \frac{\sin \pi t}{\pi t}}$ ✓

$\boxed{\mathrm{sinc}(t) = \frac{\sin t}{t}}$

$8\,\delta(t)$





Basic Signals

First null (when the function reaches 0 first time) $\boxed{\text{when } t=1}$

2nd null (when t=2)

amplitude = ∞

area = 1

shift right

τ: pulse width

t: period

f: fundamental frequency: $\frac{1}{T}$

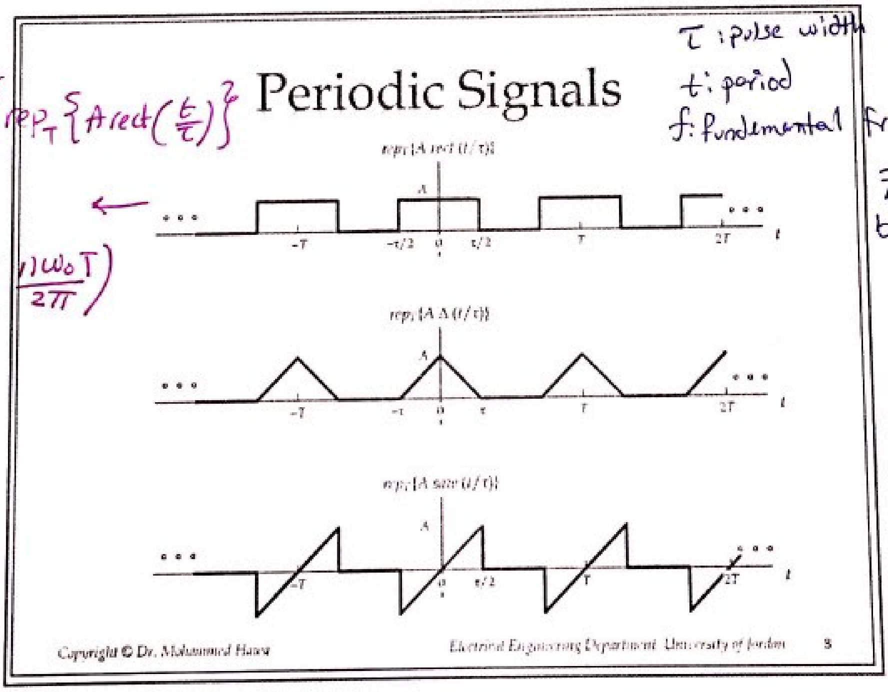
≠

bandwidth of $x(t) = B_x(t)$

$$F_{\text{Fourier series}}\{x(t)\} = F_{\text{Fourier series}}\{rep_T\{A\,\mathrm{rect}(\tfrac{t}{\tau})\}\}$$

↓

$$a_n = \frac{A\tau}{T}\,\mathrm{sinc}\left(\frac{n\omega_0 T}{2\pi}\right)$$



Periodic Signals

ex Find the bandwidth of $x(t) = rep_T\{A\,rect\left(\frac{t}{\tau}\right)\}$

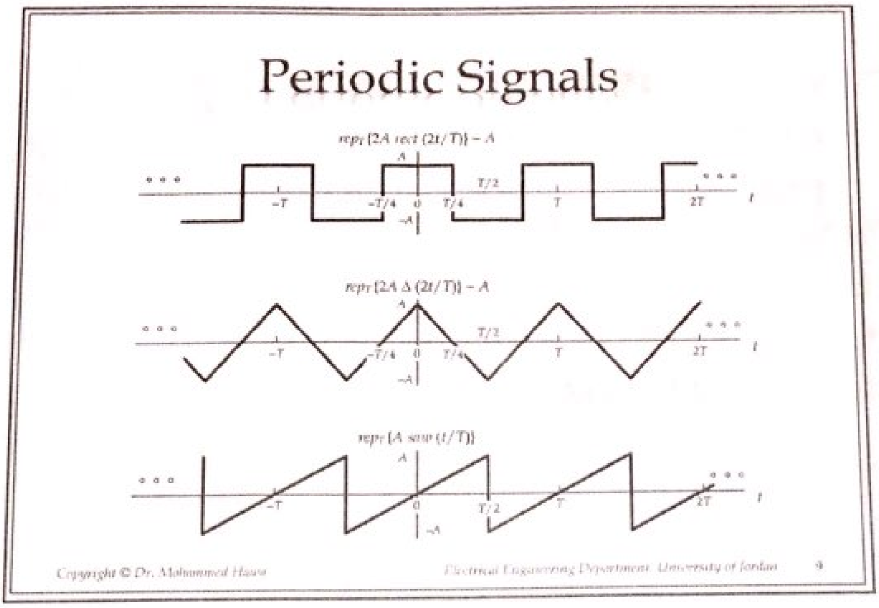
$$\alpha_n = \frac{A\tau}{T}\,\text{sinc}\left(\frac{n\omega_0\tau}{2\pi}\right) = 1$$

to get first null, you need $\frac{n\omega_0\tau}{2\pi} = 1$

So, the frequncy $= n\omega_0 = \frac{2\pi}{\tau}\ \frac{rad}{s}$

$$\boxed{\text{or } B = \frac{1}{\tau}\ \text{Hz}}$$

$nf_0 = \frac{1}{\tau}$



Periodic Signals

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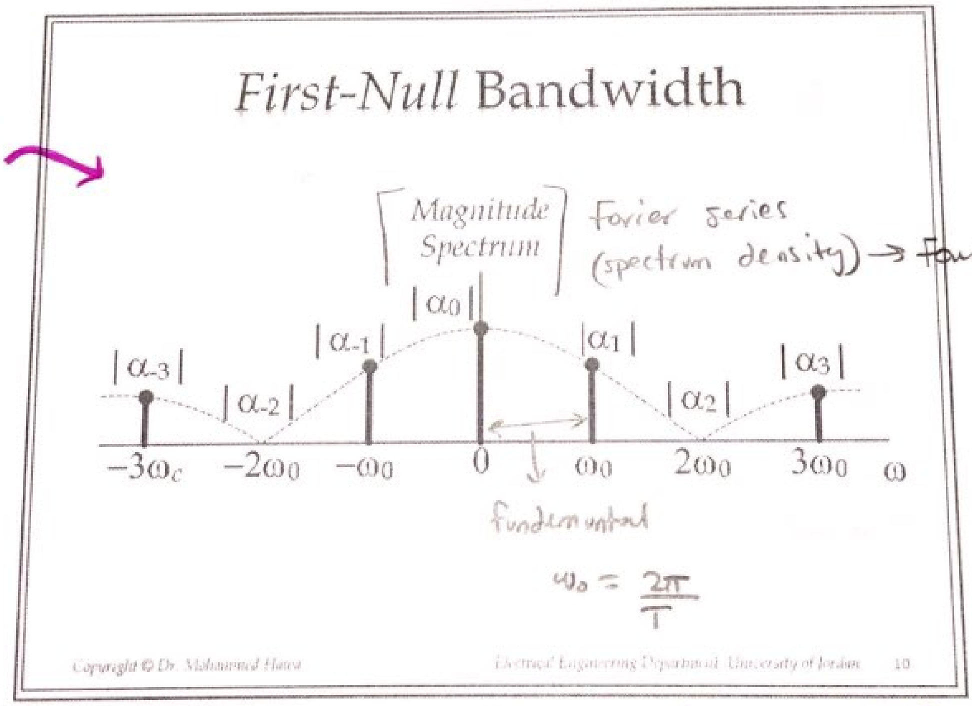
n this example bandwidth is $2\omega_0$



First-Null Bandwidth

Magnitude Spectrum

Forier series (spectrum density) → Fourier transform

fundemental

$\omega_0 = \frac{2\pi}{T}$

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* IF Farier series/transform has $sinc(\cdot)$ or $sinc^2(\cdot)$ or $sinc^3(\cdot)$ or $sinc^n(\cdot)$, then bandwidth of signal is 1st null frequency.

① $F\{\cos(\omega_0 t)\} = \pi\delta(\omega-\omega_0) + \pi\delta(\omega+\omega_0)$

② $F\{\sin(\omega_0 t)\} = -j\pi\delta(\omega-\omega_0) + j\pi\delta(\omega+\omega_0)$

③ $F\{\delta(t)\} = 1$

④ $F\{rect(t)\} = sinc(\frac{\omega}{2\pi})$

⑤ $F\{\Delta(t)\} = sinc^2(\frac{\omega}{2\pi})$

works for both

- periodic (and looks like fourier series)
- Aperiodic

← Fourier Transform

$$X(\omega) = \mathcal{F}\{x(t)\} = \int_{-\infty}^{\infty} x(t)e^{-j\omega t}dt$$

$$x(t) = \mathcal{F}^{-1}\{X(\omega)\} = \frac{1}{2\pi}\int_{-\infty}^{\infty} X(\omega)e^{j\omega t}d\omega$$

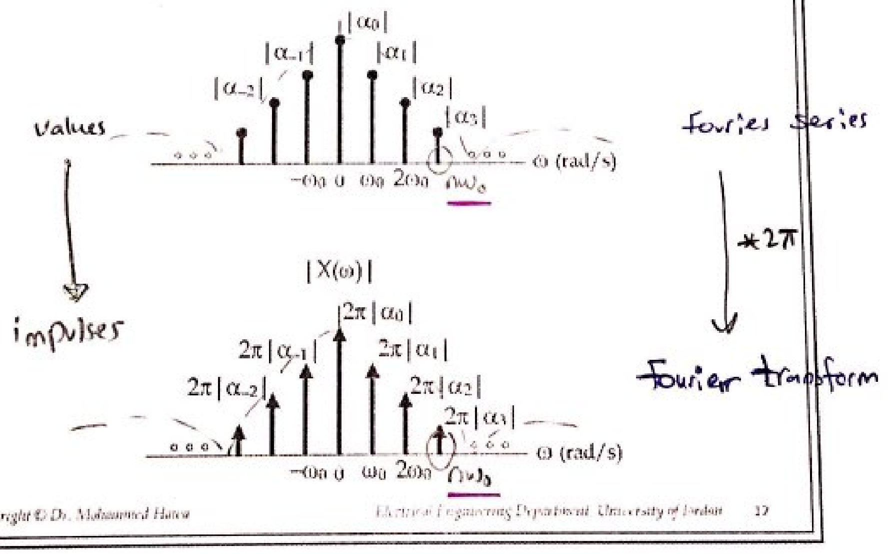
* $F\{A\, rect(\frac{t}{\tau})\} = A|T|\, sinc(\frac{\omega T}{2\pi})$

* $F\{A\, rect(t)\} = A\, sinc(\frac{\omega}{2\pi})$

* $F\{x(t) + y(t)\} = X(\omega) + Y(\omega)$

superposition

Fourier Series vs. Tranform

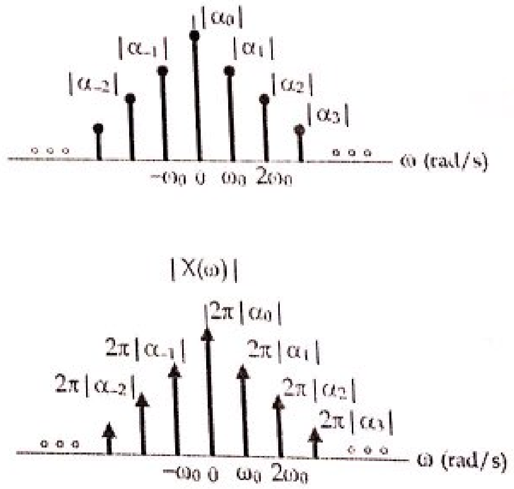


Fourier Transform

$$X(\omega) = \mathcal{F}\{x(t)\} = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt$$

$$x(t) = \mathcal{F}^{-1}\{X(\omega)\} = \frac{1}{2\pi} \int_{-\infty}^{\infty} X(\omega) e^{j\omega t} d\omega$$

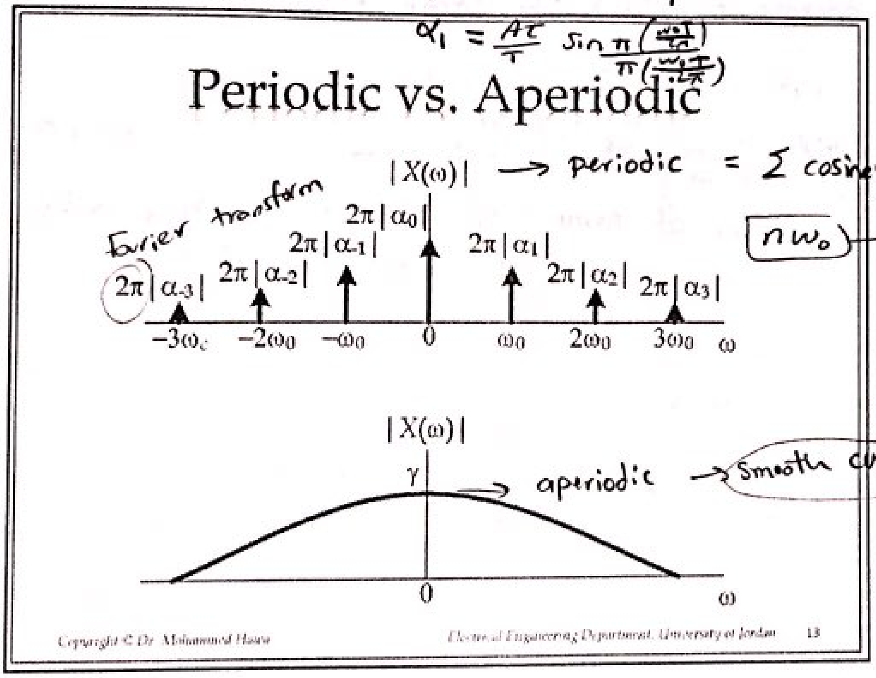
Fourier Series vs. Tranform



fourier series $\{x(t)\} = \{rep_T\{A\ rect(\frac{t}{\tau})\}\}$

$$\rightarrow \alpha_n = \frac{A\tau}{T}\ \text{sinc}\left(\frac{n\omega_0\tau}{2\pi}\right) \rightarrow \alpha_0 = \frac{A\tau}{T}\ \text{sinc}\left(\frac{0\times\omega_0\tau}{2\pi}\right)$$

$$= \frac{A\tau}{T}$$



$$\alpha_1 = \frac{A\tau}{T}\ \frac{\sin\pi\left(\frac{\omega_0\tau}{2\pi}\right)}{\pi\left(\frac{\omega_0\tau}{2\pi}\right)}$$

Periodic vs. Aperiodic

$|X(\omega)|$ → periodic = Σ cosines

Fourier transform

$n\omega_0$ → Discrete impulses.

→ aperiodic → Smooth curve

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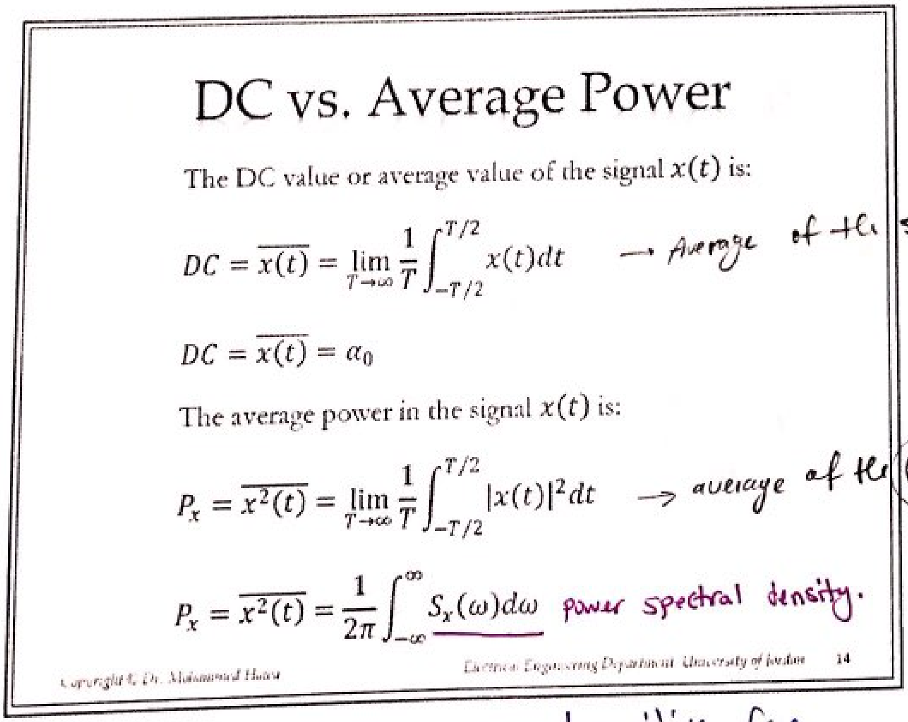

DC vs. Average Power

The DC value or average value of the signal $x(t)$ is:

$$DC = \overline{x(t)} = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x(t)dt$$ → Average of the signal

$$DC = \overline{x(t)} = \alpha_0$$

The average power in the signal $x(t)$ is:

$$P_x = \overline{x^2(t)} = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} |x(t)|^2 dt$$ → average of the (signal)² Power

$$P_x = \overline{x^2(t)} = \frac{1}{2\pi}\int_{-\infty}^{\infty} \underline{S_x(\omega)d\omega}$$ power spectral density.

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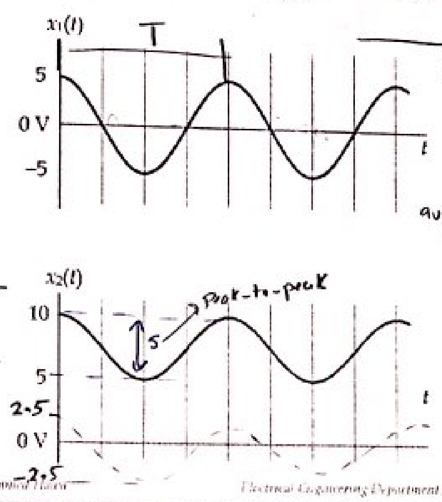
* For power consider both negative and positive freq.

Ex: $x(t) = rep_T\{A\ rect(\frac{t}{\tau})\}$

Area → $\overline{x(t)} = \frac{A\tau}{T}$

$\overline{x^2(t)} = \frac{A^2\tau}{T}$

DC vs. Average Power



$? \frac{2\pi}{T}$

$5\cos\left(n\,\cancel{\omega_0}\,\frac{t}{\cancel{2\pi}}\right)$

$x_1(t) = 5\cos(\omega_0 t)$

avg or mean:

$x_1(t) = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x(t)\,dt = 0$

avg power for $x_2(t)$:-

$= \frac{5^2}{2}$ ←

$x_2(t) = 2.5\cos(\omega_0 t) + 7.5$

$\overline{x_2(t)} = 0 + 7.5 = 7.5$

they are orthogonal $\overline{x_2^2(t)} = \frac{(2.5)^2}{2} + 7.5^2$ ✓

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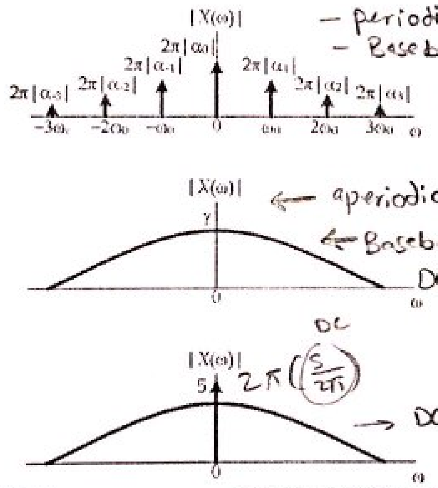
~~Ex: $x(t) = rep_T\{A\ \Delta(\frac{t}{\tau})\}$~~

→ we cannot use superposition for power except if the signals are orthogonal.

DC from Frequency Domain



- periodic
- Baseband

. DC = $\overline{x(t)} = \alpha_0$

← aperiodic

← Baseband

DC = 0 → fourier transform.

DC ≠ Y (there is No area around 0)

DC

$2\pi\left(\frac{5}{2\pi}\right)$

→ DC = $\frac{5}{2\pi}$

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* Examples of orthogonal Signals :—

① DC + AC ex: $7.5 + 5\sin(\omega_0 t)$

② multiple cosines (or sines) at different freq. → $\cos(50t) + \cos(70t)$

③ cos and sin at same frequency but 90° phase shift

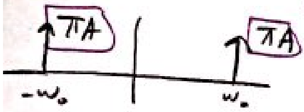
$\cos(600t) + \sin(600t)$

$x(t) \rightarrow$ voltage

$x^2(t) \rightarrow$ Power

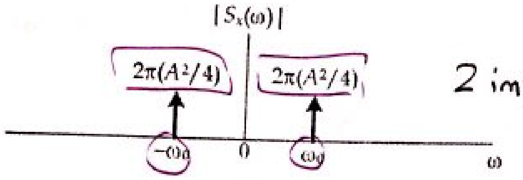
Power Spectral Density

$F\{A\cos(\omega_0 t)\}$



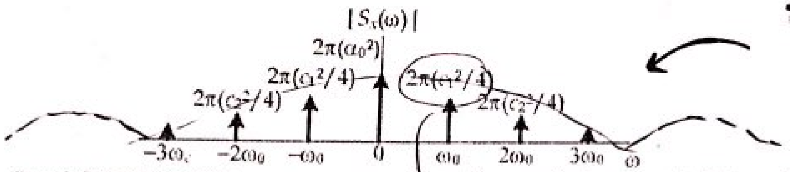
$$\underline{\text{PSD}} = S_x(\omega) = \lim_{T\to\infty}\frac{1}{T}|X_T(\omega)|^2 = \mathcal{F}\{\underbrace{R_{xx}(\tau)}_{}\}$$

auto-correlation.



2 impulses

impulses with $a(\text{sinc}^2)$ envelope



$2\pi(2\alpha_1^2/4) = 2\pi\alpha_1^2$ $\boxed{c_1 = 2\alpha_1}$

Quick Review of Filters

Devices Not signals

- There are four main filter types that you studied in signal analysis:
  - ① **LPF: Low-Pass Filter**
  - ② **BPF: Band-Pass Filter**
  - ③ HPF: High-Pass Filter
  - ④ Band-Stop Filter / Notch Filter.

very effective and cheap solutions for Noise

Find $R_{xx}(\tau)$ and then $S_x(\omega)$, then $P_{av} = \overline{x^2(t)}$ for :

① $x(t) = A\cos(\omega_0 t)$

② $x(t) = rep_T\left\{A\ rect\left(\frac{t}{\tau}\right)\right\}$ → any periodic $x(t)$

$$P_{av} = \frac{1}{2\pi}\int_{-\infty}^{\infty} S_x(\omega)\, d\omega$$

$$= \cancel{\frac{1}{2\pi}}\left(\cancel{2\pi}\frac{A^2}{4} + \cancel{2\pi}\frac{A^2}{4}\right) = \boxed{\frac{A^2}{2}}$$

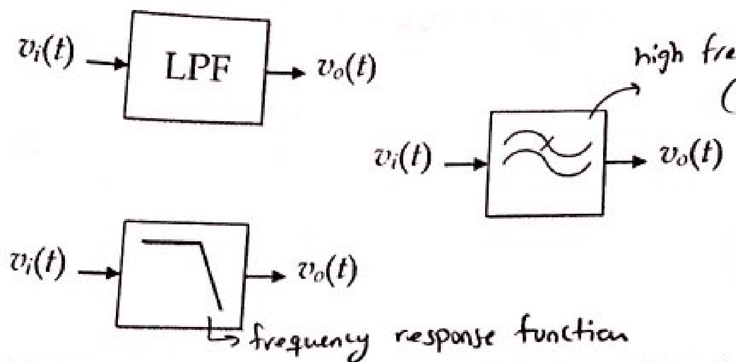
$\sum$ cosines$(n\omega_0 t)$

↳ orthogonal

$$\overline{x^2(t)} = P_{av} = \frac{A^2\tau}{T}$$

Low-Pass Filter (LPF)

- Symbol:



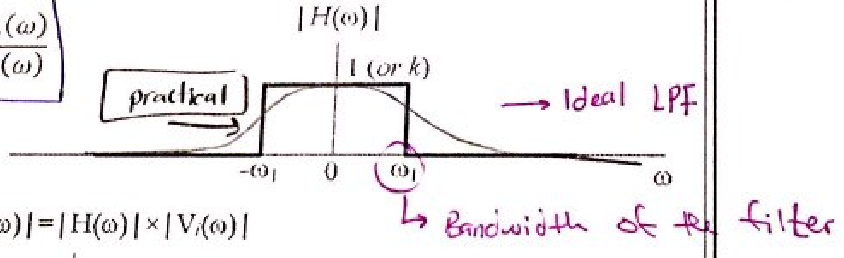
high frequencies are rejected (low freq. are passed)

frequency response function

Frequency-response function ≡ Frequency Transfer function.

$$H(\omega) = \frac{V_o(\omega)}{V_i(\omega)}$$

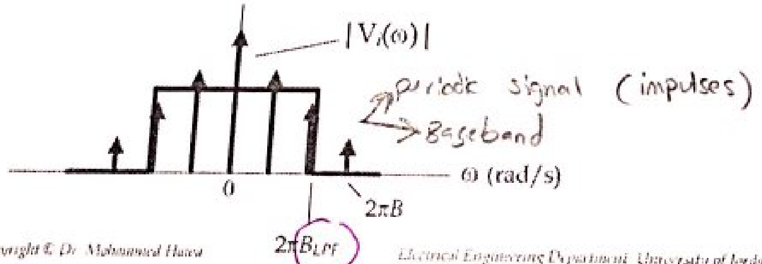
$V_o(\omega) = H(\omega)\, V_i(\omega)$



→ Ideal LPF

Bandwidth of the filter

$|V_o(\omega)| = |H(\omega)| \times |V_i(\omega)|$



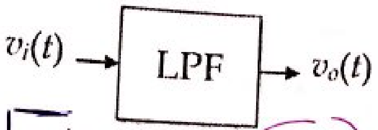
periodic signal (impulses)

Baseband

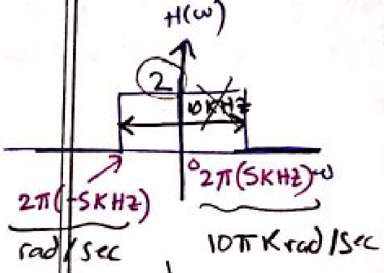
Bandwidth of the LPF

Characteristics/Specifications

- Always centered at 0 rad/s.
- Bandwidth = Cut-off frequency = ω_1 rad/s
- Gain = k.



⊛ w/ Bandwidth = 5 kHz
& Gain = 2

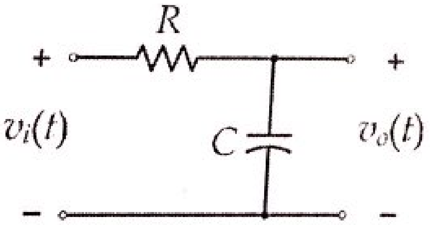


The Bandwidth = 5KHz
Not 10KHz

For Bandwidth calculations consider only positive freq.

Example Circuit

* first order low pass filter :-



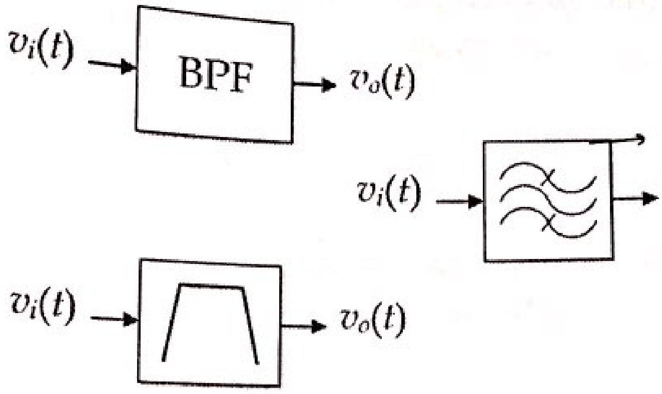
low freq → C → open circuit
high freq → C → short c

$$B_{LPF} = \frac{1}{2\pi RC}\,\text{Hz}$$ ← $\frac{1}{RC}$ → Rad/s

$$Gain = 1$$

Band-Pass Filter (BPF)

- Symbol:

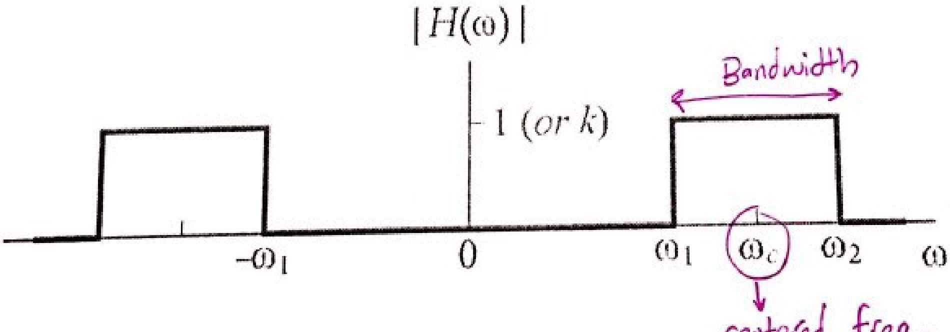


high and low freq. are rejected

Frequency-response function

*Ideal BPF

$$H(\omega) = \frac{V_o(\omega)}{V_i(\omega)}$$



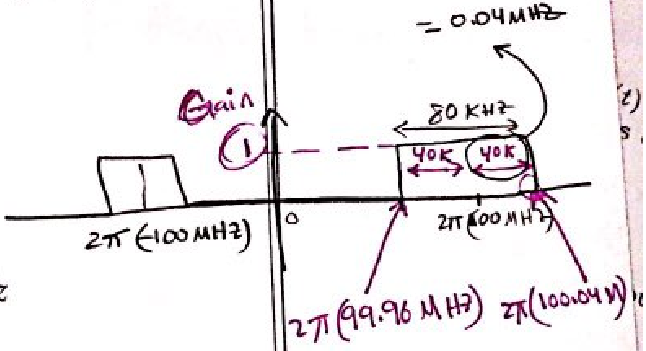
Bandwidth

centered freq.

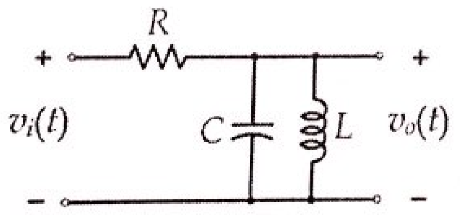
Characteristics/Specifications

- Centered around center frequency ω_c rad/s.
- Bandwidth of Filter = $\omega_2 - \omega_1$ rad/s
- Gain = k.

w/ Bandwidth = 80 kHz
Center Frequency = 100 MHz
& Gain = 1



Example Circuit



centered freq.

$$f_c = f_{res} = \frac{1}{2\pi\sqrt{LC}}\ \text{Hz}$$

fresonant

$$B_{BPF} = \Delta f = \frac{R}{2\pi L}\ \text{Hz}$$

$$Gain = 1$$

Lecture 4: Amplitude Modulation (Double Sideband *Suppressed Carrier*, DSB-SC)

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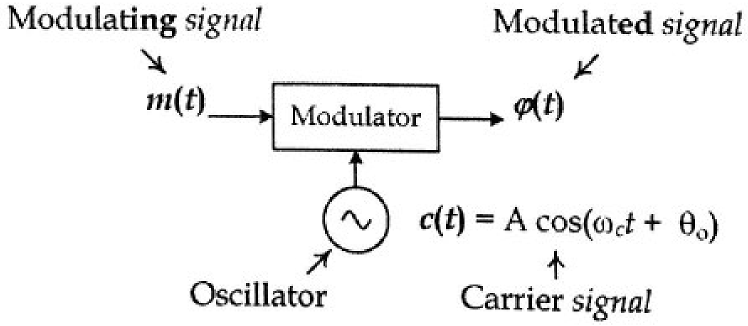
Notation



Modulating *signal*

$m(t)$

Modulator

$\varphi(t)$

Modulated *signal*

Oscillator

$c(t) = A\cos(\omega_c t + \theta_o)$

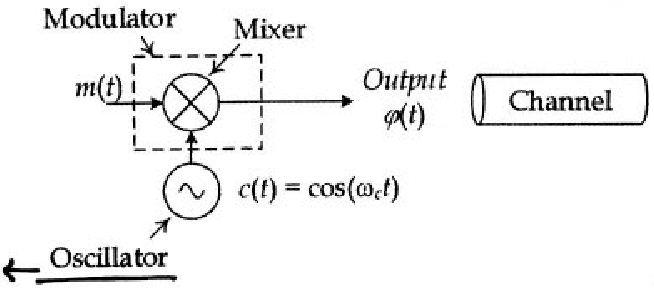
Carrier *signal*

Three Modulation Types

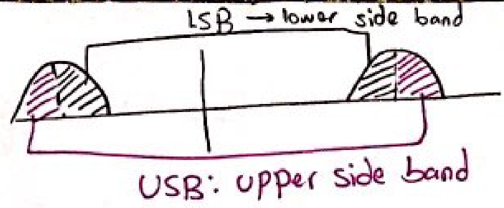
- $A \propto m(t)$; $\omega_c = constant$; $\theta_0 = constant$
  - Amplitude Modulation (AM)
  - Amplitude Shift Keying (ASK)
- $A = constant$; $\omega_c \propto m(t)$; $\theta_0 = constant$
  - Frequency Modulation (FM)
  - Frequency Shift Keying (FSK)
- $A = constant$; $\omega_c = constant$; $\theta_0 \propto m(t)$
  - Phase Modulation (PM)
  - Phase Shift Keying (PSK)

DSB-SC Modulator: Mixer

$\phi(t)_{DSB-SC} = m(t) . \cos(\omega_c t)$



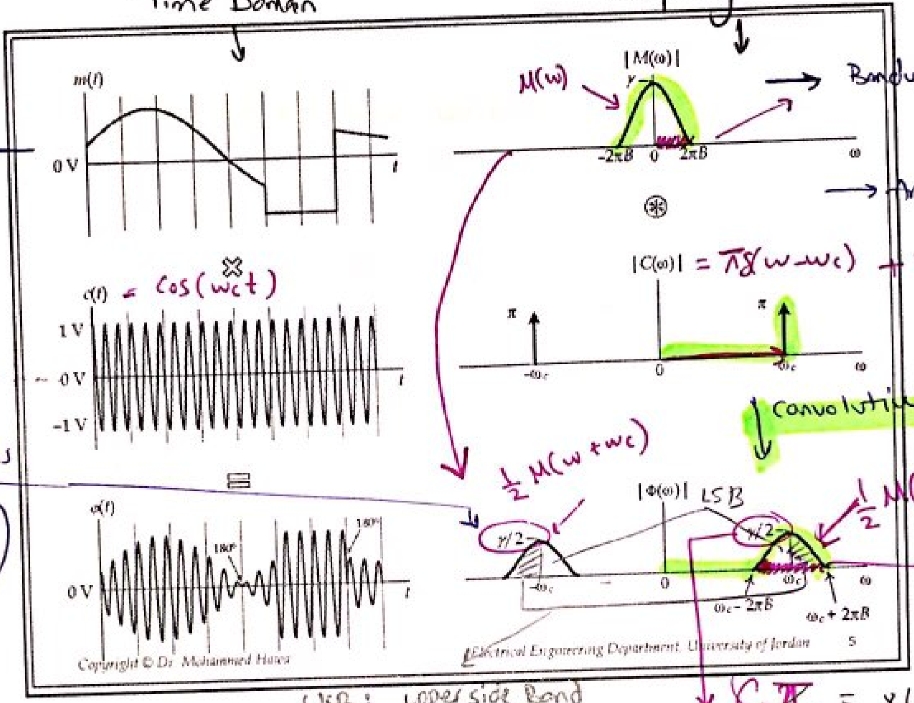
usually outside ← of the modulator



DSB : double side Band

Time Domain

Frequency Domain



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Bandwidth = 2πB rad/s

$\boxed{\text{OR}}$ = B Hz

→ Analog signal

There is no impulses

(~~they are~~ suppressed carrier)

→ Bandwidth of Φ(t)

= 4πB rad/s

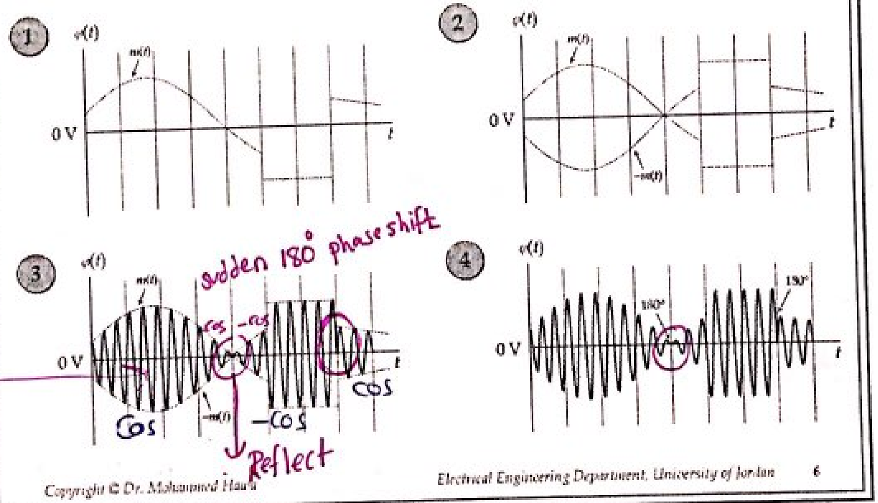
= 2B Hz

USB : upper side Band

$\frac{\gamma.\cancel{\pi}}{2\cancel{\pi}} = \gamma/2$

→ فقانونة Convolution.

Drawing a DSB-SC modulated signal



High frequency

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$\boxed{\text{HW}}$ rep{saw}

* In modulation, we require $W_c \gg 2\pi B$

$\boxed{\text{slide 5}}$

* For the first signal :-

Q1:- Find $\Phi_{DSB-SC}(\omega)$

Sol 1: math.

$$\Phi(\omega) = \mathcal{F}\{\phi_{DSB-SC}(\omega)\} = \mathcal{F}\{m(t)\cdot\cos(\omega_c t)\}$$

$$= \mathcal{F}\left\{m(t)\ \frac{e^{j\omega_c t} + e^{-j\omega_c t}}{2}\right\}$$

$$= \mathcal{F}\left\{\frac{1}{2}m(t)e^{j\omega_c t} + \frac{1}{2}m(t)e^{-j\omega_c t}\right\}$$

$$= \mathcal{F}\{\frac{1}{2}\overset{\text{shift}}{m(t)}e^{j\omega_c t}\} + \mathcal{F}\{\frac{1}{2}m(t)e^{-j\omega_c t}\}$$

* There is shift in frequency domain

$$\Phi_{DSB-SC}(\omega) = \frac{1}{2}M(\omega-\omega_c) + \frac{1}{2}M(\omega+\omega_c)$$

Sol 2: Graphical sol

$$\Phi(\omega) = \mathcal{F}\{\phi(t)\} = \mathcal{F}\{m(t)\cdot c(t)\}$$

$$= \frac{1}{2\pi}M(\omega) * C(\omega) \quad \text{((convolution))}$$

→ Conv(signal, δ) = same signal shifted by shift of Impulse. and scaled by area of Impulse

---

[illegible] *when multiplying by $c(t) = \cos(\omega_c t)$:-

① shift right by ω_c

② shift left by ω_c

③ multiply by $\frac{\pi}{2\pi} = \frac{1}{2}$

④ Bandwidth of m(t) multiplied by 2 (X2) bandwidth of $\phi(t)$

⑤ Power of m(t) $(\times\frac{1}{2})$ avg power in $\phi(t)$

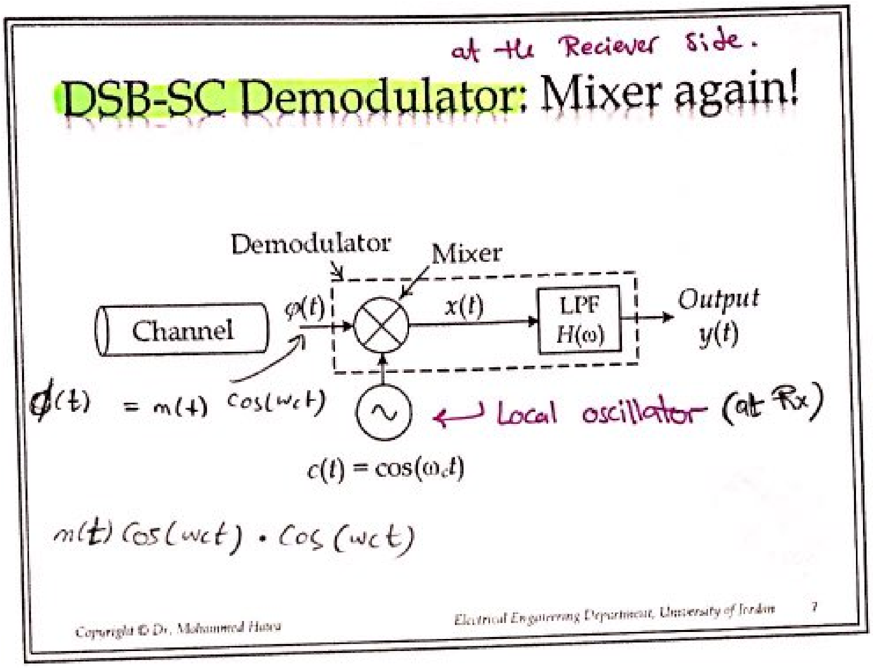
↳ $\boxed{\text{HW}}$ Find P_{avg} in $m(t) = 2\cos(10t) \longrightarrow P = \frac{(2)^2}{2} = 2$

$$\phi(t) = \underbrace{\cos(10t)}_{m(t)}\ \underbrace{\cos(2000t)}_{c(t)} \longrightarrow \overline{\phi^2}$$ [illegible]

sol ① $F\{x(t)\} = F\{\phi(t) \cdot c(t)\}$

$$= \frac{1}{2\pi} \Phi(\omega) \circledast C(\omega) = X(\omega)$$

← sol ②



at the Reciever side.

DSB-SC Demodulator: Mixer again!

$\phi(t) = m(t)\cos(w_c t)$

← Local oscillator (at Rx)

$c(t) = \cos(\omega_c t)$

$m(t)\cos(w_c t) \cdot \cos(w_c t)$

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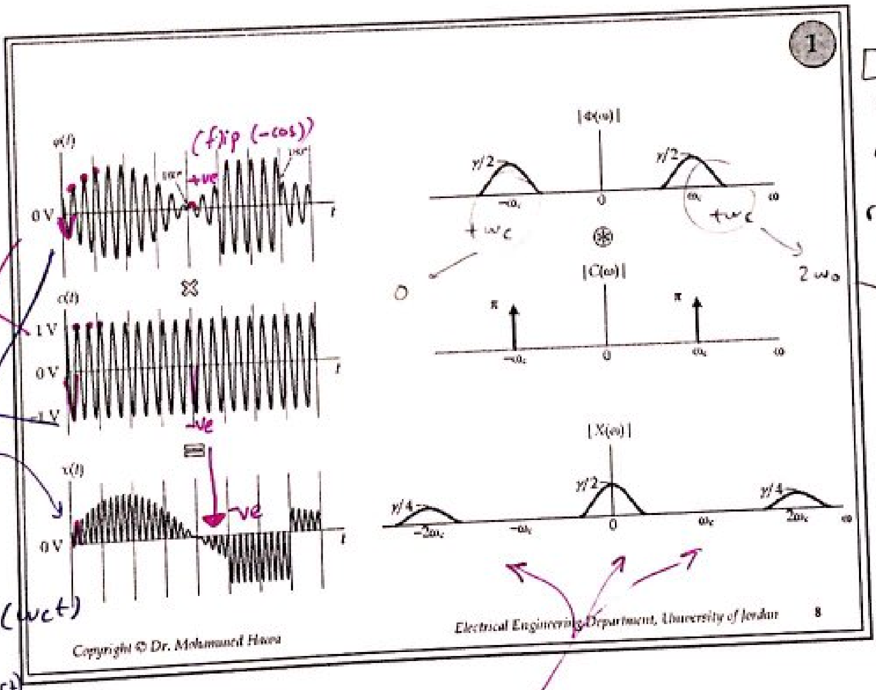

(flip (−cos))

+ve

−ve

$+w_c$

$+w_c$

0

$2w_o$ → Next slide

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8

HW

rep{rect}

rep{saw}

rep{tri}

Same frequency and phase

+ve X +ve = +ve

−ve X −ve = +ve

↓

$m(t)\cos(w_c t) \times \cos(w_c t)$

$= m(t)\cos^2(w_c t)$

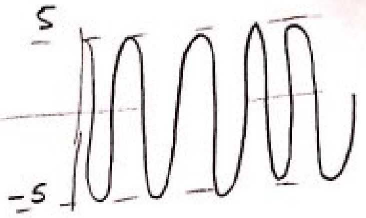
always +ve

↳ the fourier of this is 3 copies

Slide 5

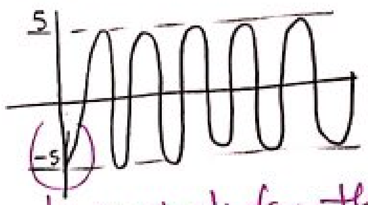
Q2 : sketch $\phi_{DSB-SC}(t) = m(t) \cdot \cos(w_c t)$

→ sketch $5\cos(wt)$



↳ Remember to erase the guide lines .

$-5\cos(wt)$



↳ It starts from the <u>-ve</u>

Sol ② :-

$$F\{\phi(t) \cdot c(t)\}$$

$$= F\{m(t) \cos(w_c t) \cos(w_c t)\}$$

$$= F\{m(t) \cos^2(w_c t)\}$$

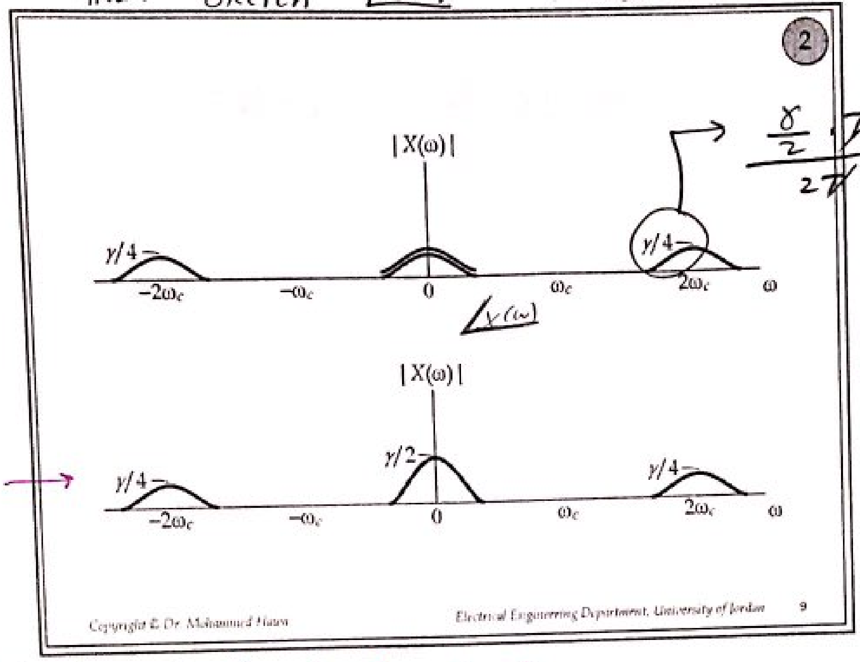
$$= F\{m(t) \{\tfrac{1}{2} + \tfrac{1}{2}\cos(2w_c t)\}\}$$

$$= F\{\tfrac{1}{2} m(t)\} + \tfrac{1}{2} F\{m(t) \cos(2w_c t)\} + \tfrac{1}{2} F\{m(t) \frac{e^{j2w_c t} + e^{-j2w_c t}}{2}\}$$

$$= \tfrac{1}{2} F\{m(t)\} + \tfrac{1}{4} F\{m(t) e^{j2w_c t}\} + \tfrac{1}{4} F\{m(t) e^{-j2w_c t}\}$$

$$= \tfrac{1}{2} M(w) + \tfrac{1}{4} M(w - 2w_c) + \tfrac{1}{4} M(w + 2w_c)$$

HW:- sketch $\angle X(\omega)$



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$$\frac{\frac{\gamma}{2}\cdot\cancel{\pi}}{2\cancel{\pi}} = \boxed{\frac{\gamma}{4}}$$

$5\angle 180$ ← $5\angle 0$ →

$5\angle 30°$ →

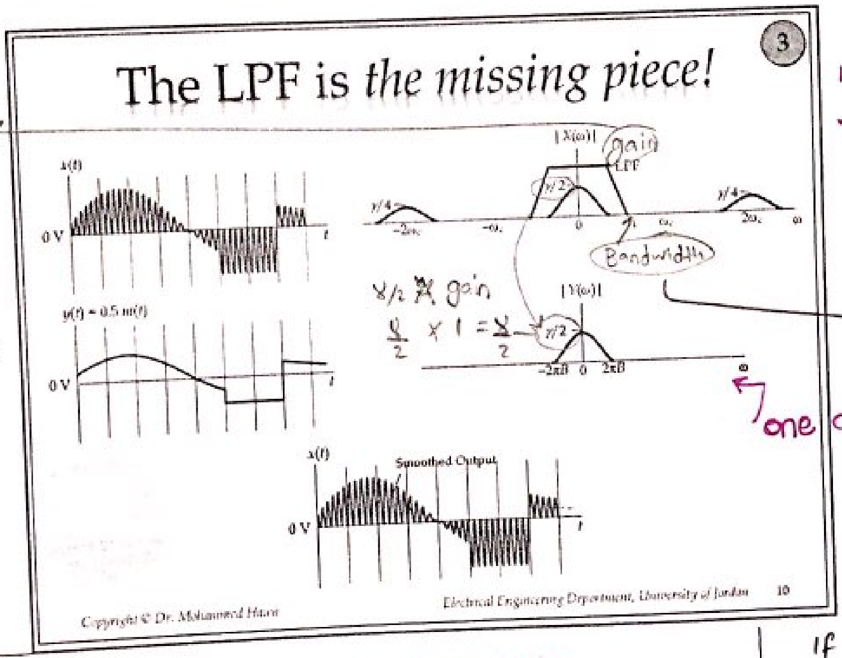
$5\angle 30°$ →

How many copies ?!

③

$$\Phi(\omega) = \frac{1}{2}M(\omega) + \frac{1}{4}M(\omega - 2w_c) + \frac{1}{4}M(\omega + 2w_c)$$

The LPF is *the missing piece!*



$\gamma/2 \times$ gain

$\frac{\gamma}{2} \times 1 = \frac{\gamma}{2}$

one copy

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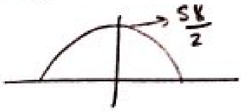
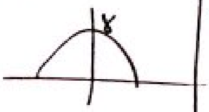
we use gain = 1

the gain must be corresponded to the specifications

Ex gain = 5



gain = 2



It's not easy to work with filters in the time domain

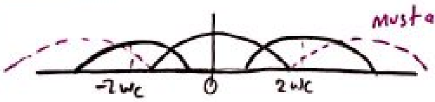
(Do fourier)

Bandwidth of the LPF must = Bsignal

Because If it was smaller, some of the signal will be distorted

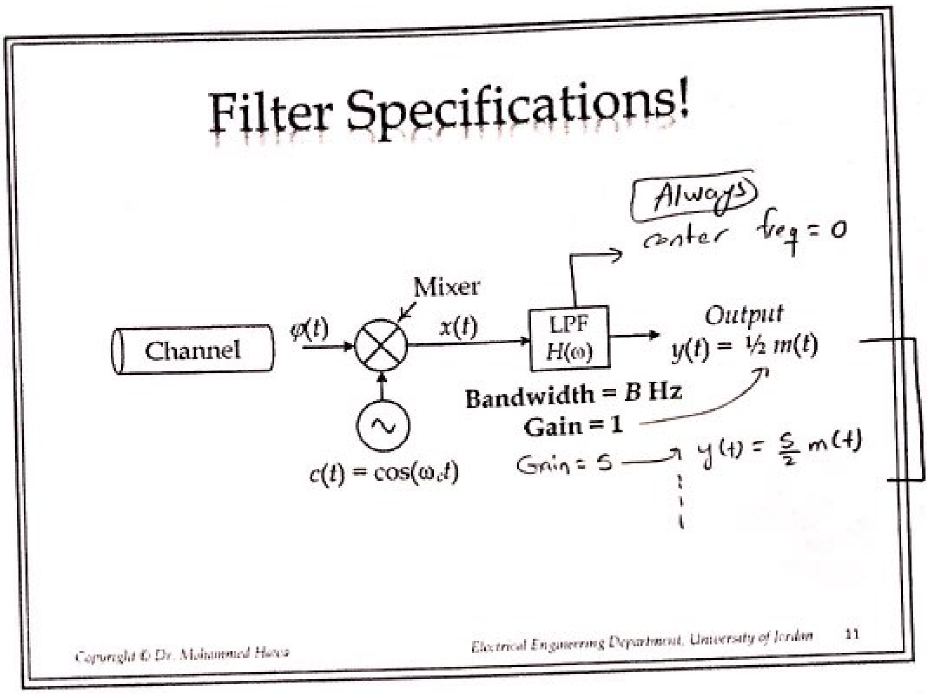
and if it was bigger more noise will happen

must avoid the overlap



$$2w_c \geq 2\pi B + 2\pi B$$

$$w_c \geq 2\pi B$$



Filter Specifications!

Always center freq = 0

Gain = 5 → $y(t) = \frac{5}{2} m(t)$

Be Careful!!

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φ(t) has sudden 180° phase shifts
DSB-SC

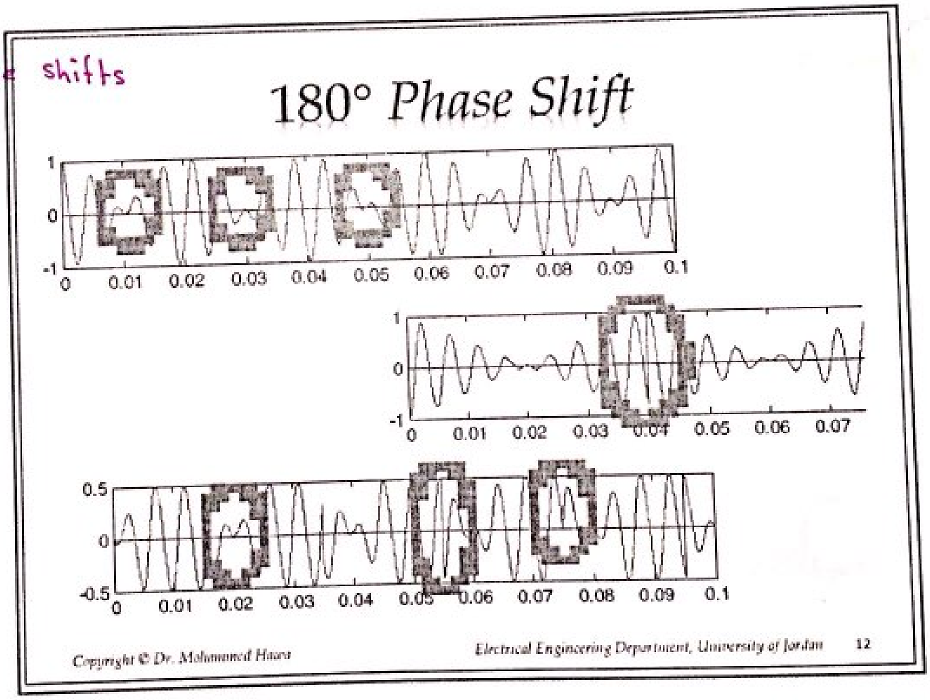
when

m(t) +ve → -ve

or

m(t) -ve → +ve

(disadvantage)



180° *Phase Shift*

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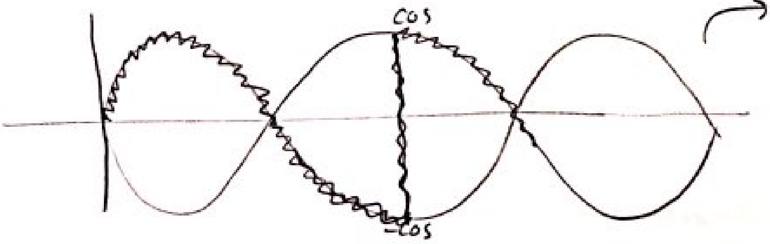


→ 180° phase shift (Jump)

Example

- Assume we perform DSB-SC modulation for the baseband signal $m(t) = \alpha \cos(\omega_m t)$ [the case of tone modulation], where $\omega_c >> \omega_m$:
  - Sketch the **time-domain** modulated signal $\varphi(t)$.
  - Sketch the **Fourier transform** of the modulated signal $\Phi(\omega)$ [frequency domain].
  - Find the **bandwidth** of $m(t)$ and $\varphi(t)$. $= \omega_m$
  - Find the **average power** in both $m(t)$ and $\varphi(t)$.
  - Show the demodulator hardware.
  - Sketch $x(t)$ and $y(t)$ in the demodulator.

tone modulation means $m(t) = \alpha \cos(\omega_m t)$

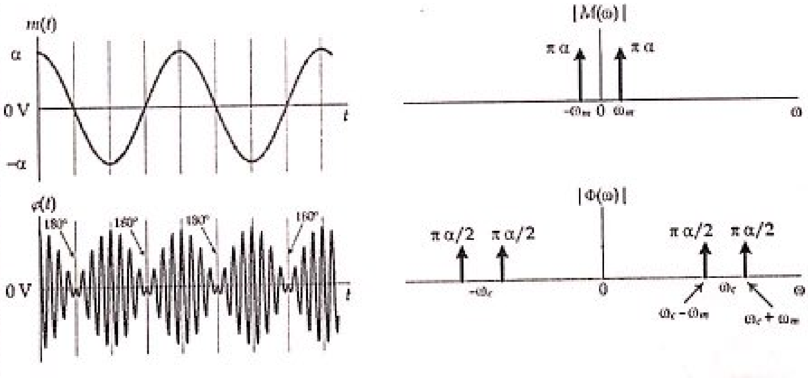
small freq

the carrier and the signal are both (cos)

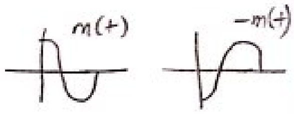
From the freq domain

$$\overline{\phi^2(t)} = \frac{1}{2}\overline{m^2(t)} = \frac{1}{2}\frac{\alpha^2}{2} = \frac{\alpha^2}{4}$$

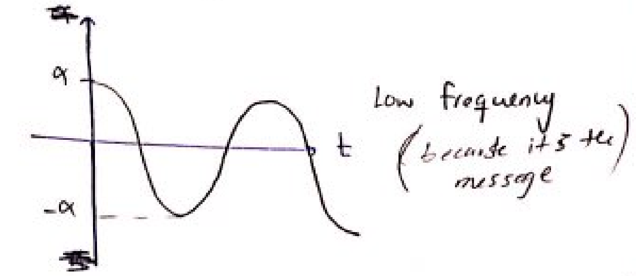
Solution

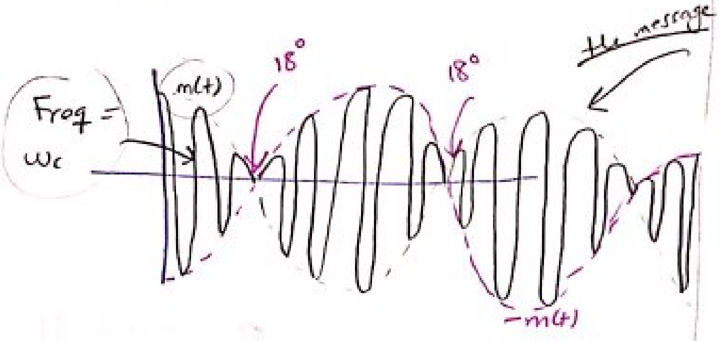


لازم ننتبه إذا كانت -m(t) أو m(t) مترسة

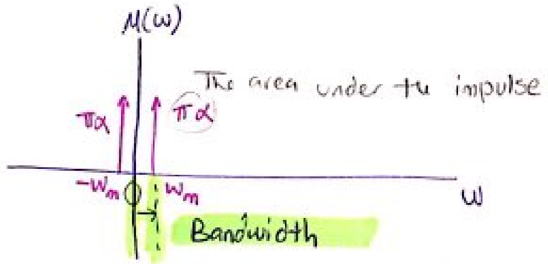


⑨ $\phi(t)$ vs t





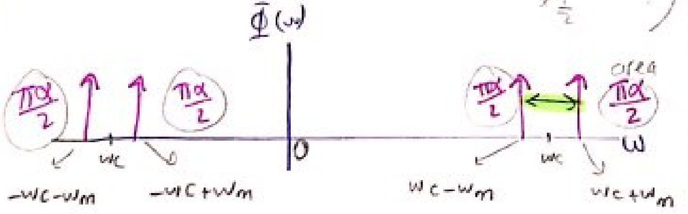
$\bar{\Phi}(\omega)$ → mathematical (Hw)
↓ Graphical ✓



$$M(\omega) = \mathcal{F}\{m(t)\} = \mathcal{F}\{\alpha \cos(\omega_m t)\}$$

$$= \pi\alpha\,\delta(\omega - \omega_m) + \pi\alpha\,\delta(\omega + \omega_m)$$

↓ convolution with another cosine (shift Right, shift left) $\times \frac{1}{2}$



* Bandwidth of $m(t) = \omega_m$ rad/s

$= f_m = \frac{\omega_m}{2\pi}$ Hz

* Band width of $\phi(t) = 2\omega_m$ rad/s

$= 2f_m$ Hz

Homework

- For the following signals $m(t)$, sketch:
  - The modulated signal $\varphi(t)$ at the modulator
  - The Fourier transform $\Phi(\omega)$
  - The signals $x(t)$ and $y(t)$ at the demodulator
  - The Fourier transform $X(\omega)$ and $Y(\omega)$
- Find the average power and bandwidth for the signals $\varphi(t)$ and $y(t)$.
- Are there any phase shifts in $\varphi(t)$? If so, where?
- Determine the DC value in $m(t)$, $\varphi(t)$ and $y(t)$.

$\mathcal{F}\{x(t)\} = X(\omega)$

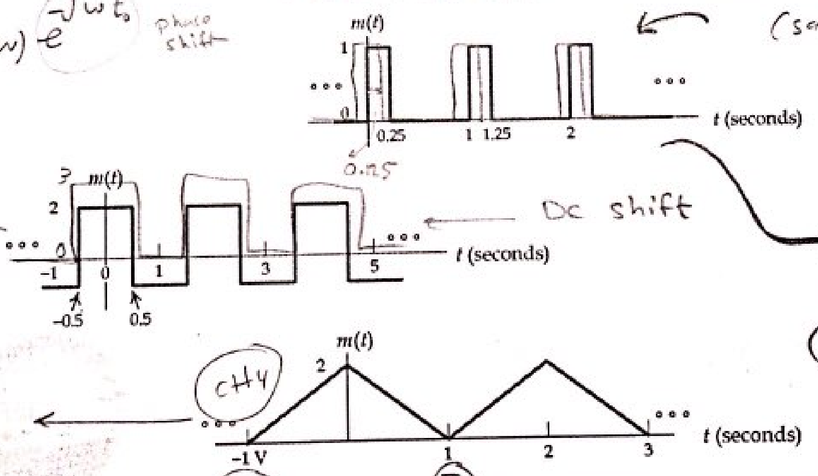
$\mathcal{F}\{x(t-t_0)\} = X(\omega)\, e^{-j\omega t_0}$ phase shift

Homework

Time shifted by 0.125

(same power as rect)
↳ it won't affected

* phase shift also won't be affected



there is no sudden phase shift
[illegible]
([illegible])

[illegible] avg, a₀ DC value will be affected

Bandwidth = $\frac{1}{\tau}$

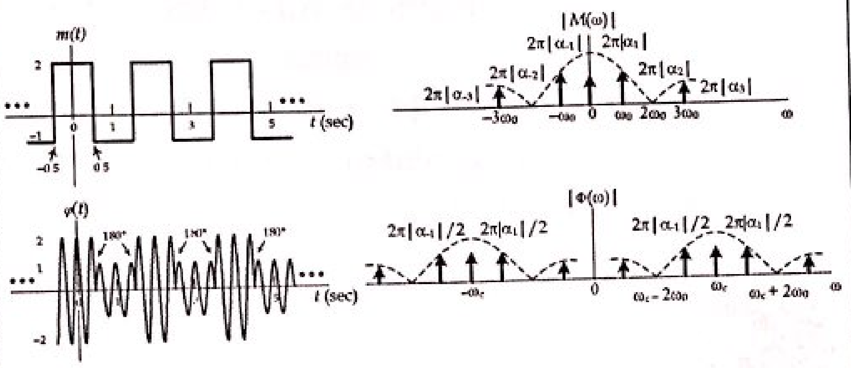
$\boxed{\tau=1}$

$\boxed{B = 1\ \text{Hz}}$

$= 2\pi$ rad/s

← Be careful!

Solution: Part(b)

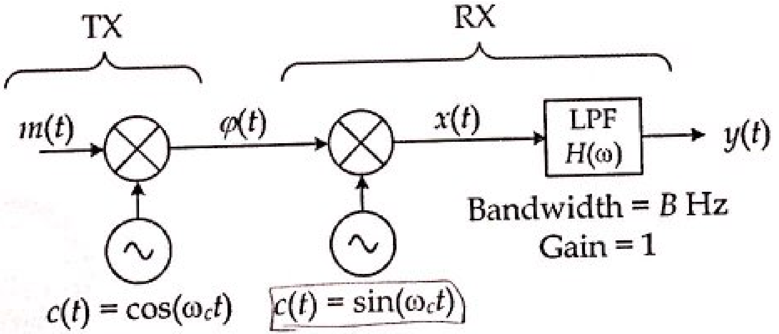


Exam problem

DSB-SC

Homework

- For the following circuit, sketch $x(t)$ and $y(t)$, along with the Fourier transform $X(\omega)$ and $Y(\omega)$.



$= \cos(\omega ct - 90^\circ)$ → It affects the phase spectrum density.