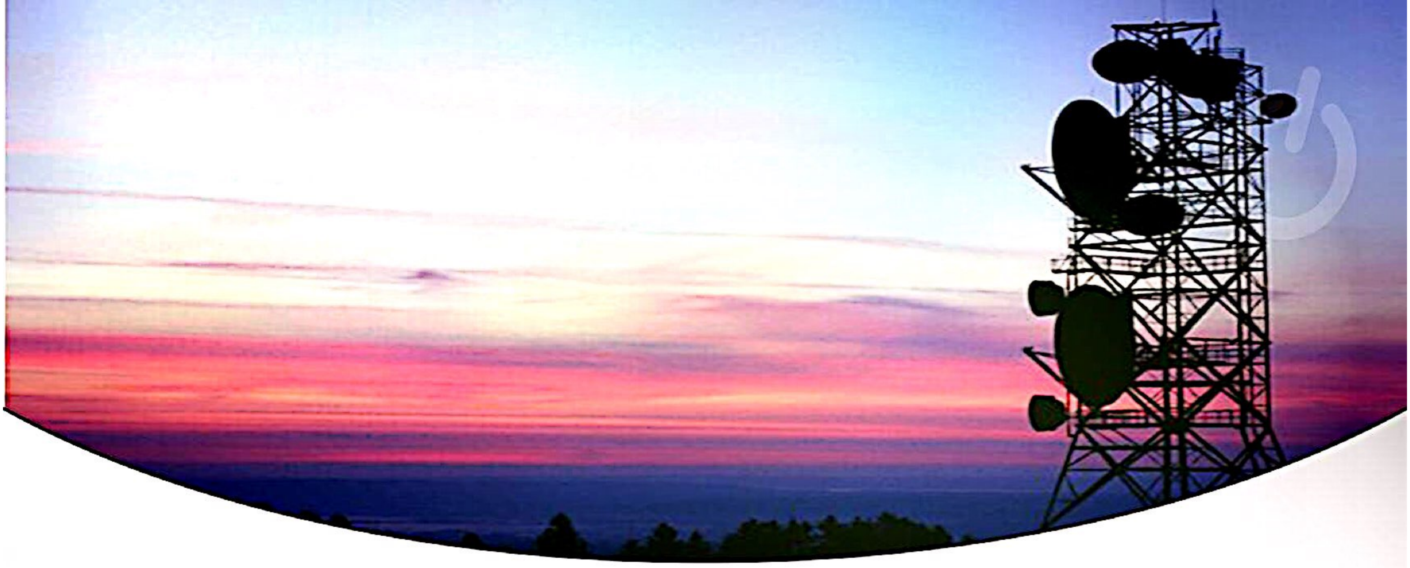

Communications1

Fall017

Dr. Mhmd Hawa

By: Mhmd Abuhashya

Lecture 6: Amplitude Modulation (QAM, SSB, VSB and Analog TV)

Dr. Mohammed Hawa
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→ DSB-SC + orthogonality.

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

EE421: Communications I

Orthogonality

Memorize.

- In Modulation: → it is the most popular one.
  - **QAM modulation** (sin/cos)
  - Used in DVB, Wi-Fi, WiMAX, 3G, 4G LTE
- In Multiplexing:
  - **CDMA** (Walsh codes, GOLD codes)
  - Used in 3G cellular telephony
  - **OFDMA** (multiple cosines) → with multiple freq.
  - Used in Wi-Fi, WiMAX, 4G LTE

CDMA: Code Division Multiple Access.
OFDMA: orthogonal Freq. Division Multiple Access.

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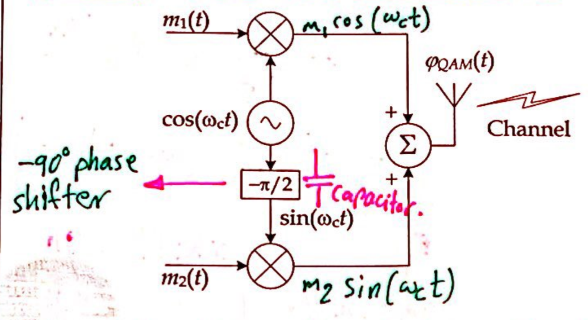
for x(t) & y(t) to be orthogonal it must satisfy: $\overline{x(t) \cdot y(t)} = 0$

orthog. : Needs Perfect Synchronization.

QAM (Quadrature Amplitude Modulation)

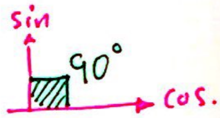


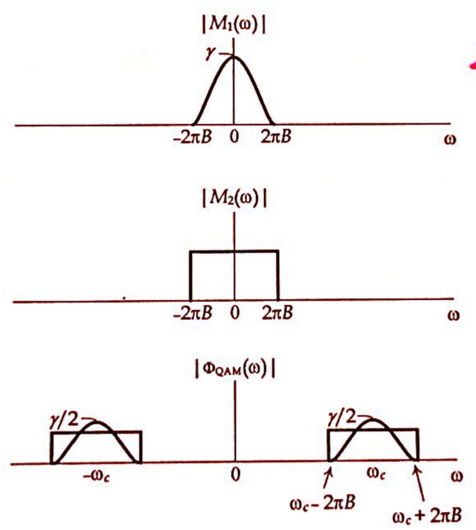
$-90°$ phase shifter

we use it since it is easier and inexpensive comparing with using another oscillator.

$$\phi_{QAM}(t) = m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)$$

$\sin(\omega_c t) = \cos(\omega_c t - 90°)$





Not necessary To have same B.

⇒

* What is B_{DSB-SC}? $B_{DSB-SC} = 2B$ Hz.
* What is B_{QAM}? $B_{QAM} = 2B$ Hz.

Same Bandwidth BUT B_{QAM} is More Efficient. (it send 2 signals)

if M_1 & M_2 different in B. ⇒ $B_{QAM} = 2B_{max}$ Hz.

$$\mathcal{F}\{m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)\}$$

$$= \mathcal{F}\{m_1(t)\cos(\omega_c t)\} + \mathcal{F}\{m_2(t)\sin(\omega_c t)\}$$

$$\frac{1}{2}M_1(\omega-\omega_c) + \frac{1}{2}M(\omega+\omega_c)$$

shift right by ω_c
" left by ω_c
$* \frac{1}{2}$

$$\mathcal{F}\left\{m_2(t)\,\frac{e^{j\omega_c t} - e^{-j\omega_c t}}{j2}\right\}$$

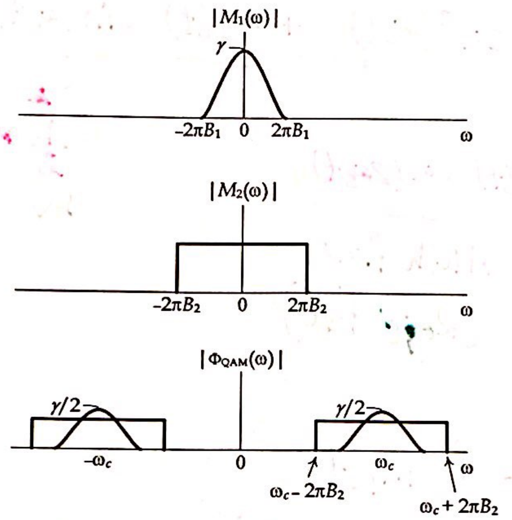
$$= \frac{-j}{2}\mathcal{F}\{e^{j\omega_c t} - e^{-j\omega_c t}\}$$

$$= \frac{-j}{2}M_2(\omega-\omega_c) + \frac{j}{2}M_2(\omega+\omega_c)$$

$-90°$ phase shift.

shift right
" left.
$* \frac{1}{2}$
extra phase shift.

$+90°$ phase shift.



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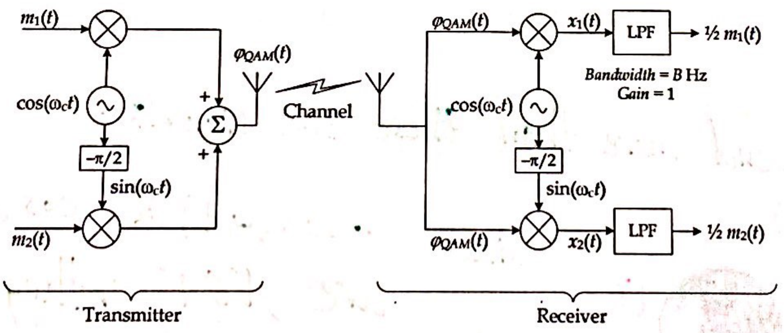
QAM Transmitter and Receiver



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→ Question: find $y_1(t)$?

Q:

$$\underset{QAM}{\phi(t)} = m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)$$

$$X_1(t) = [m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)] \cdot \cos(\omega_c t)$$

$$= m_1(t)\cos^2(\omega_c t) + m_2(t)\sin(\omega_c t)\cos(\omega_c t)$$

$m_1(t)\cos^2(\omega_c t) \rightarrow \frac{1}{2}m_1(t) + \frac{1}{2}m_1(t)\cos(2\omega_c t)$

- $\frac{1}{2}m_1(t)$: Low freq. (passes)
- $\frac{1}{2}m_1(t)\cos(2\omega_c t)$: High freq. (Rejected)

$m_2(t)\sin(\omega_c t)\cos(\omega_c t) \rightarrow \frac{1}{2}m_2(t)\sin(2\omega_c t)$

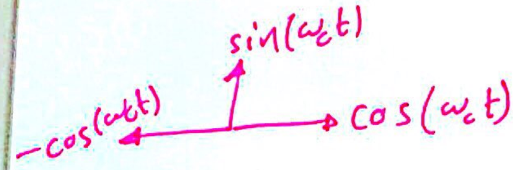
- High freq. (Rejected).

so $$y_1(t) = \frac{1}{2}m_1(t)$$

* H.W: prove it again using graphical solution.

* H.W: Do the Same To find $y_2(t)$?

***Note:**
We can't send more than these two signals.



since $-\cos(\omega_c t)$ & $\cos(\omega_c t)$ are NOT orthog.

QAM vs. DSB-SC

- **Advantages of QAM:**
  - QAM is more bandwidth efficient than DSB-SC, allowing us to send two signals on the same channel (of bandwidth 2*B*).
- **Disadvantages of QAM:**
  - When synchronous detection is used for QAM with errors in synchronization, attenuation, distortion and **co-channel interference** show up.

→ when $y_1(t) = K_1 m_1(t) + K_2 m_2(t)$

$y_2(t) = K_3 m_2(t) + K_4 m_1(t)$

Co-channel interference.

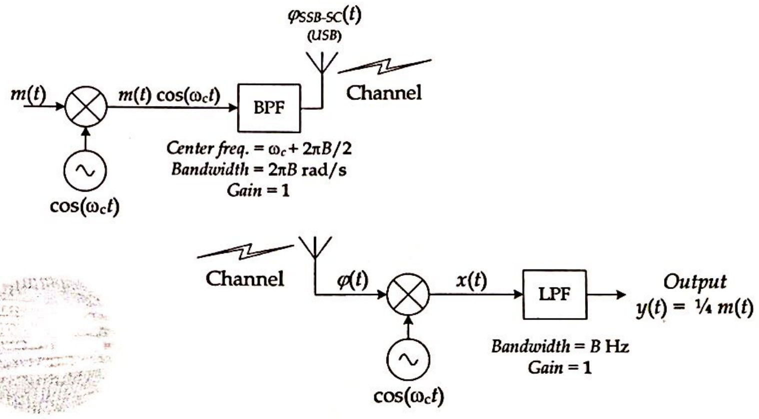
Applications

- Analog QAM is used to carry *chrominance* (color) information in Analog TV broadcasting.
- Digital QAM (to be discussed later) is very popular nowadays: DVB, DAB, Wi-Fi, WiMAX, 3G, 4G, ADSL, etc.
- DSB-SC is used in analog instrumentation, and as part of multiplexing in Stereo FM broadcasting.

SSB-SC < SSB-SC (USB) / SSB-SC (LSB)   SSB-LC < SSB-LC (USB) / SSB-LC (LSB)

Single Side Band

SSB-SC (USB) Modulation



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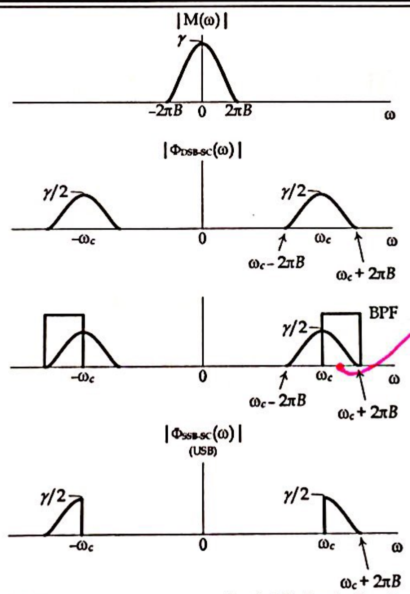
* SSB disadvantage: very sharp. ⇒ Very expensive BPF.



what is the center freq? for BPF ⇒ $\omega_c + \frac{2\pi B}{2} = \boxed{\omega_c + \pi B}$

$B_{SSB\text{-}SC\,(USB)} = B$ Hz.

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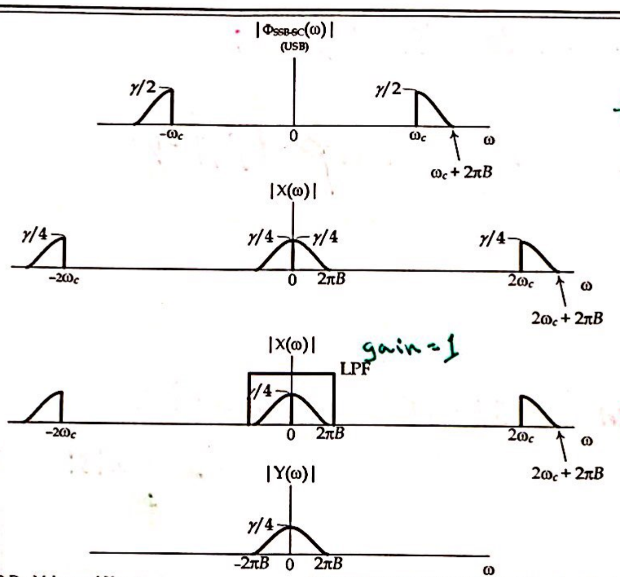
HW: Do SSB-SC (LSB) !!



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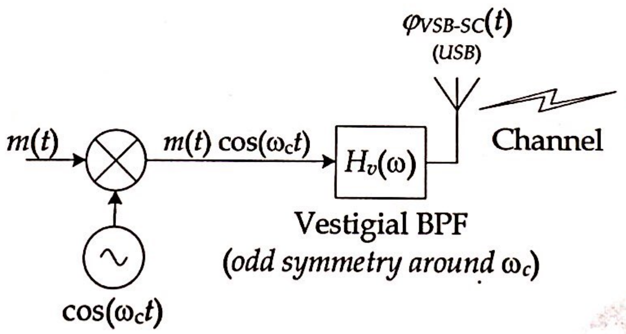
* $\cos \omega_c t$
shift right by ω_c
" left by ω_c
* $\frac{1}{2}$

Vestigial Side Band.

VSB-SC (USB) Transmitter



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VSB-SC →
- VSB-SC (USB)
- VSB-SC (LSB)
- VSB-LC (USB)
- VSB-LC (LSB)

* Adv of SSB vs. DSB:

Smaller Bandwidth (Need $\underline{B}$ Hz.).

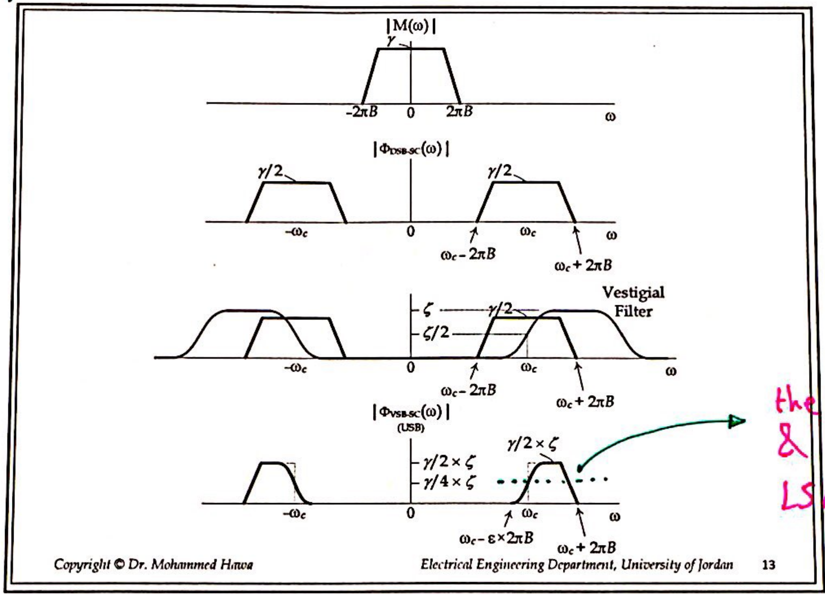
* Disadv. of SSB vs. DSB:

Needs a very sharp filter

difference between DSB-SC – DSB-LC

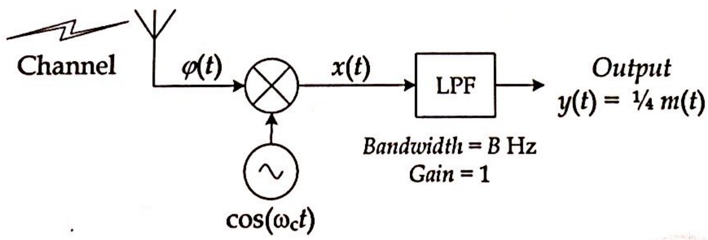
↳ exist of impulses.

* in VSB-(USB) filter: • we pass most of the USB, however, some of that USB is rejected (attenuated).
• we reject most of the LSB, however, some of that LSB passes.



the rejected of USB & the passed of LSB are odd symmetrical.

VSB-SC (USB) Receiver



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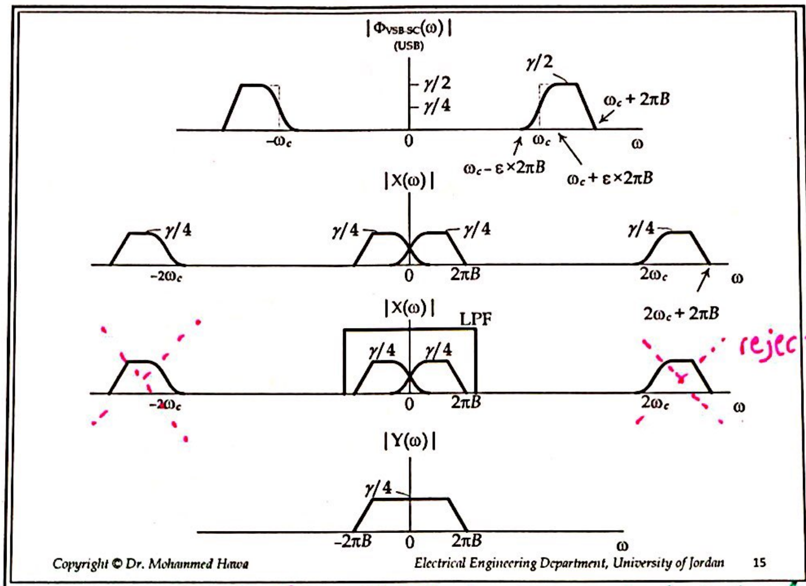
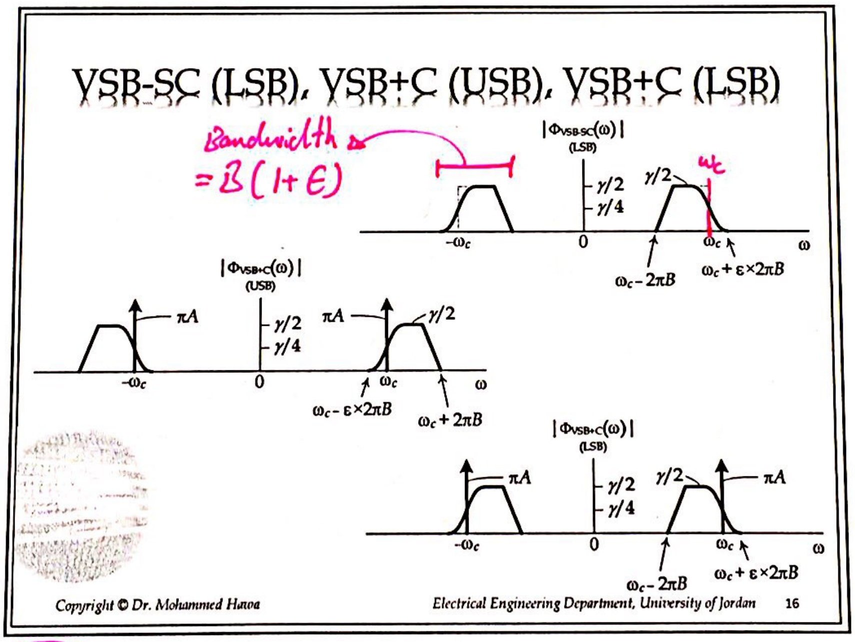


*Whatever we lost from USB it is substituted from LSB.



Bandwidth of $\phi(t)$ VSB-SC (USB) $= \epsilon B + B = B(1+\epsilon)$

Memorize.

$0 \le \epsilon \le 1$ ⇒ *** Typical ϵ = 0.1 – 0.25

0 → SSB, 1 → DSB

* in freq. selective fading: (Best) to (worst) [SSB → VSB → DSB → QAM.]

* Synch. Errors: [SSB → VSB → DSB → QAM] (Best) to (worst)

VSB

(memorize).

- **Advantages of VSB:**
  - Simple to generate (no need for sharp filters). ← Vs. SSB
  - Can vary the VSB filter bandwidth (flexibility). ← Vs. SSB / Vs. DSB
    $0 \le \epsilon \le 1$ → save BW But more exp. / more BW But cheaper.
  - VSB transmission bandwidth is smaller than DSB.
  - Smaller bandwidth means more immunity to frequency-selective fading compared to DSB.
  - In case of synchronization errors, VSB-SC suffers less attenuation and distortion compared to DSB-SC.

$B_{SSB} = B$, $B_{DSB} = 2B$

VSB

(memorize).

- **Disadvantages of VSB:**
  1. – VSB-SC require synchronous detection.
  2. – VSB+C (which allows envelope detection) is less power efficient compared to AM (since we need $A >> -m(t)_{min}$) → DSB-LC.
- **Applications:**
  - VSB+C is used to send luminance (B & W) information in Analog TV broadcasting.
  - VSB-SC is used in facsimile (fax) machines.

→ Disadvantages:

3. – Need Perfect Symmetry.
4. – Bandwidth Efficiency is higher than SSB & QAM.

orthogonal.

$\phi_{QAM}(t) = m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)$

so $P = P_1 + P_2$

$= \frac{1}{2}\overline{m_1^2(t)} + \frac{1}{2}\overline{m_2^2(t)}$

Summary

- QAM
  - Bandwidth is $2B$ (but we send two signals)
  - Average power is $\overline{\varphi^2(t)} = \frac{1}{2}\overline{m_1^2(t)} + \frac{1}{2}\overline{m_2^2(t)}$
- SSB-SC (USB or LSB)
  - Bandwidth is B (one signal)
  - Average power is $\overline{\varphi^2(t)} = \frac{1}{4}\overline{m^2(t)}$
- VSB-SC (USB or LSB)
  - Bandwidth is $(1+\epsilon)B$ (one signal)
  - Average power is $\overline{\varphi^2(t)} = \frac{1}{4}\overline{m^2(t)}$

$\overline{\phi^2_{SSB}(t)} = \frac{1}{2}\overline{\phi^2_{DSB}(t)}$

$= \frac{1}{2} \cdot \frac{1}{2}\overline{m^2(t)}$

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

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Analog Television Standards

Memorize.

	U.S. Standard	*European Standard*
Analog TV	***NTSC:*** *National Television System Committee* *(VSB+C, QAM, FM; FDM)*	***PAL:*** *Phase Alternating Line* *(VSB+C, QAM, FM; FDM)*
Digital TV	***ATSC:*** *Advanced Television System Committee* *(MPEG-2; VSB-8 or QAM; TDM+FDM)*	***DVB-T, DVB-S, DVB-S2, ...:*** *Digital Video Broadcasting* *(MPEG-2; QPSK, QAM; TDM+FDM)*

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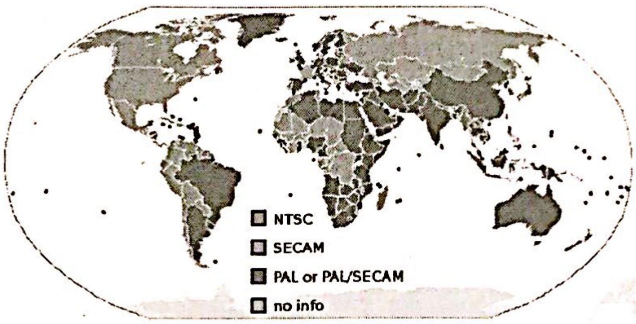
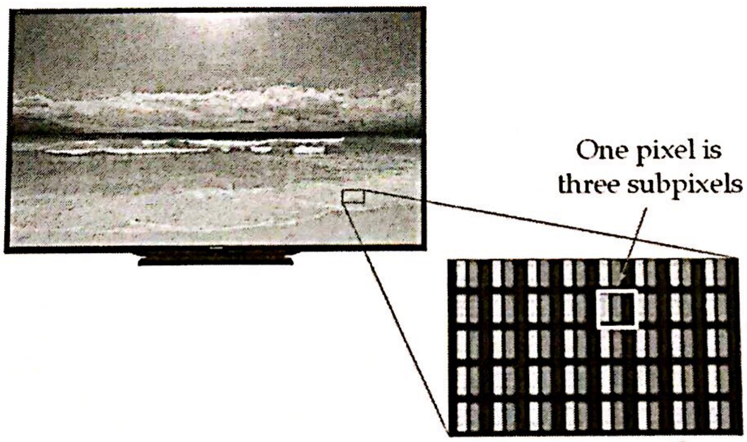
we will study Analog TV.

Analog Television (PAL/NTSC)



Jordan use PAL.

Television and Pixels

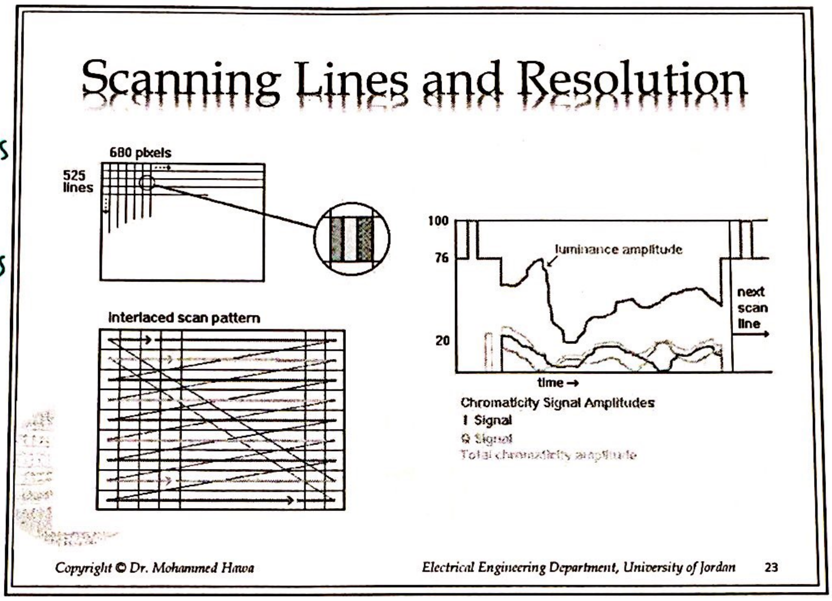


Main 3-colors:
Red
Green
Blue.

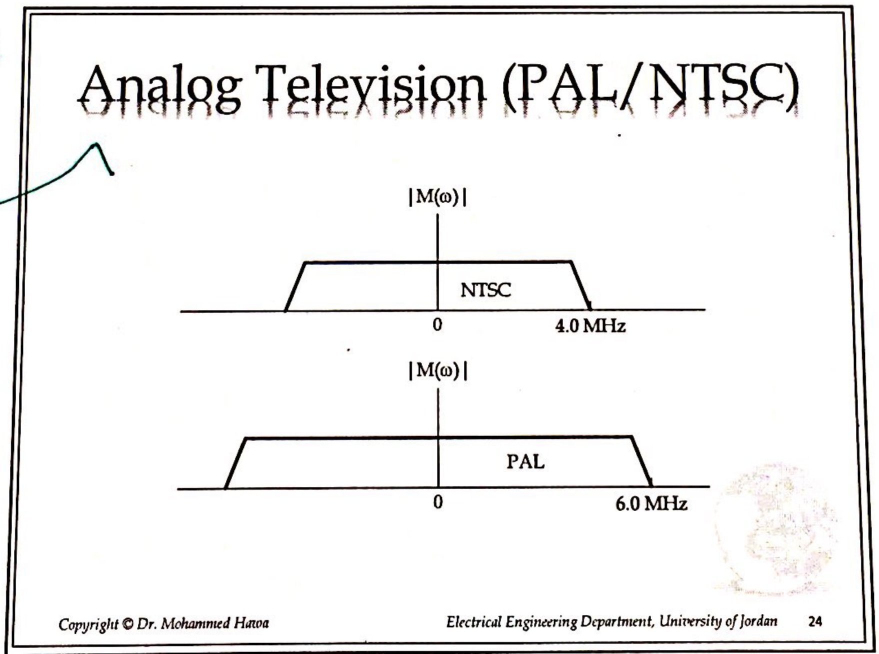
Pixels ↑ ⇒ Quality ↑ ⇒ info. ↑ ⇒ BW ↑
Pixels ↓ ⇒ Quality ↓ ⇒ info. ↓ ⇒ BW ↓

* Memorize:
PAL has 625 lines of Resolution.
NTSC has 525 Lines of Resolution.

* Quality ↑ for PAL.
so BW higher for PAL.



why B_{PAL} ↑ > B_{NTSC} ?!



in Digital TV: we have Profiles → SDTV.
→ HDTV.

Standard Definition (SDTV)

Lines.
columns.

Resolution		Aspect ratio	Pixel shape	Form of scanning	Frame Rate (Hz)
Vertical	*Horizontal*				
480	640	4:3	square	interlaced	30 (60 fields/s)
				progressive	24 30 60
	704	4:3 or 16:9	non-square	interlaced	30 (60 fields/s)
				progressive	24 30 60

NTSC 525
PAL 625

- Many other profiles and frame rates are supported by ATSC and DVB, but the above are the most popular and the most likely to be supported by a digital TV set (monitor). The monitor profile name is called 480i and 480p.

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High Definition (HDTV)

Resolution		Aspect ratio	Pixel shape	Form of scanning	Frame Rate (Hz)
Vertical	*Horizontal*				
720	1280	16:9	square	progressive	24 30 60
1080	1920	16:9	square	interlaced	25 (50 fields/s) 30 (60 fields/s)
				progressive	24 25 30
2160	3840	16:9	square	progressive	30 60 120

1080i
1080p

HD
4K TV

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#of lines.
#of columns.

* which fram rate is typical? 30HZ.

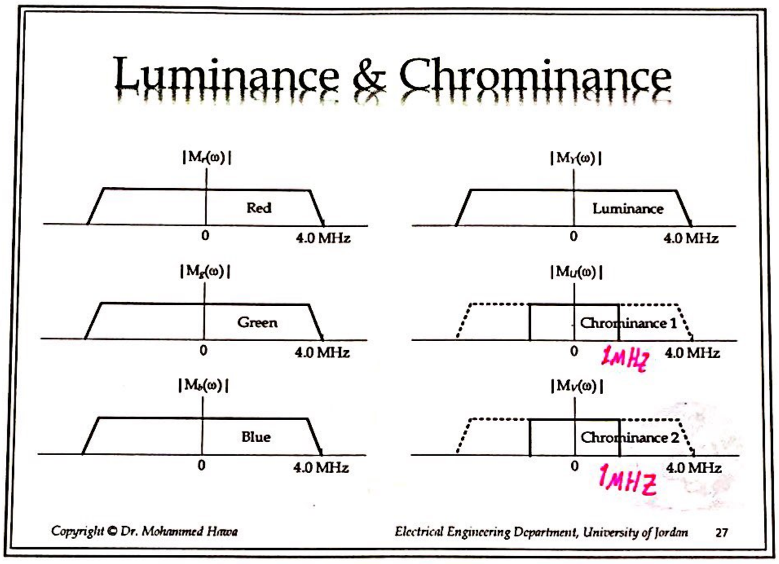
Before Transmitting we convert RGB → YUV. (why ?!)

Reasons: #1 Save Bandwidth.

#2 Backwards Compatibility.

※ for PAL:

RGB →	YUV
6MHZ	6MHZ
6MHZ	1MHZ
6MHZ	1MHZ

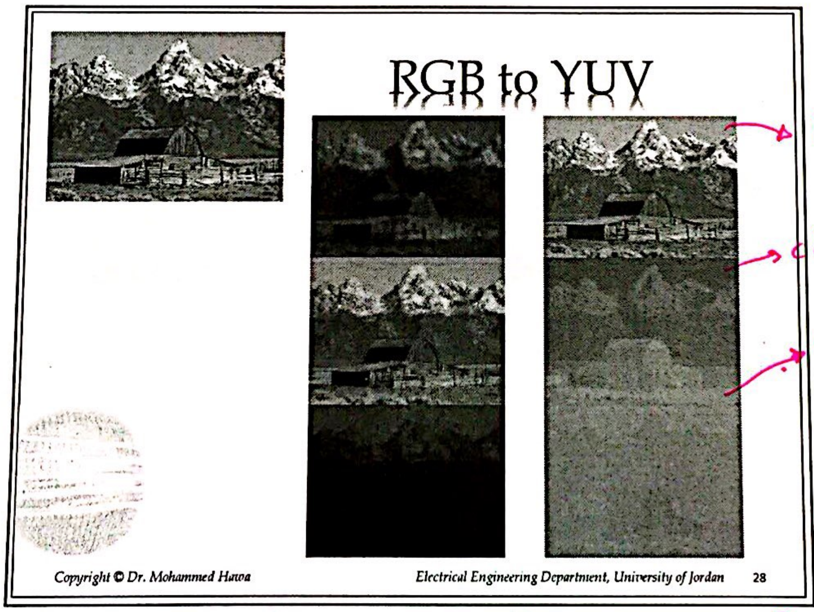


※ for NTC:

RGB →	YUV
NTC	
4MHZ	4MHZ
4MHZ	1MHZ
4MHZ	1MHZ

(save Bandwidth).

* Human Eye: insensitive to chrominance.



→ luminance.

→ chrominance1.

→ chrominance 2.

"Backward Compatiblity."

* To save BW & to be compatible with B&W TV's:

Red/Green/Blue signals are converted into luminance & chrominance signals.

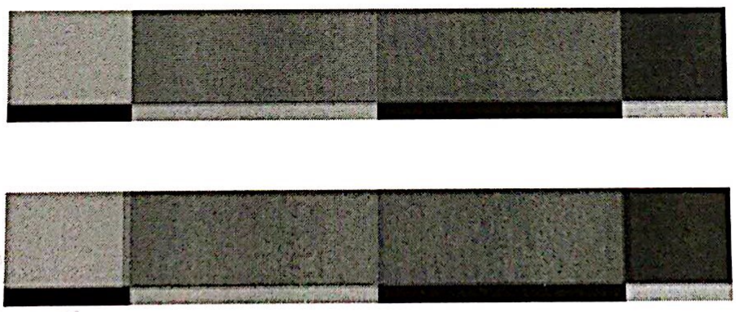
RGB to YUV Transformation

$$\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix} \begin{bmatrix} Y' \\ U \\ V \end{bmatrix}$$

See *http://en.wikipedia.org/wiki/YUV* for mode details.

Noticeable only in sharp images



$\epsilon = ?$

$(1+\epsilon)B = 5MHZ$

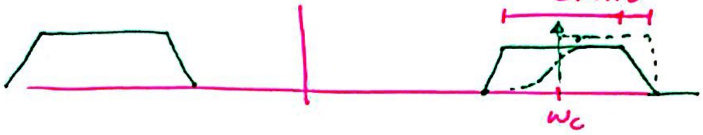
$(1+\epsilon)4 = 5$

$\epsilon = 0.25$

Luminance → VSB+C.

* $\cos(w_c t)$

8MHZ.



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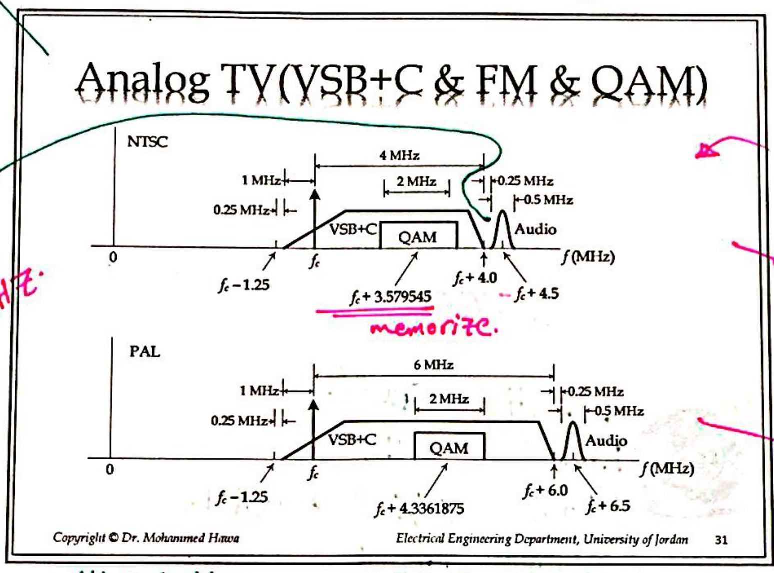


This called Guardband ⇒ allows practical BPF.

Guardband = 0.25MHZ.

memorize.

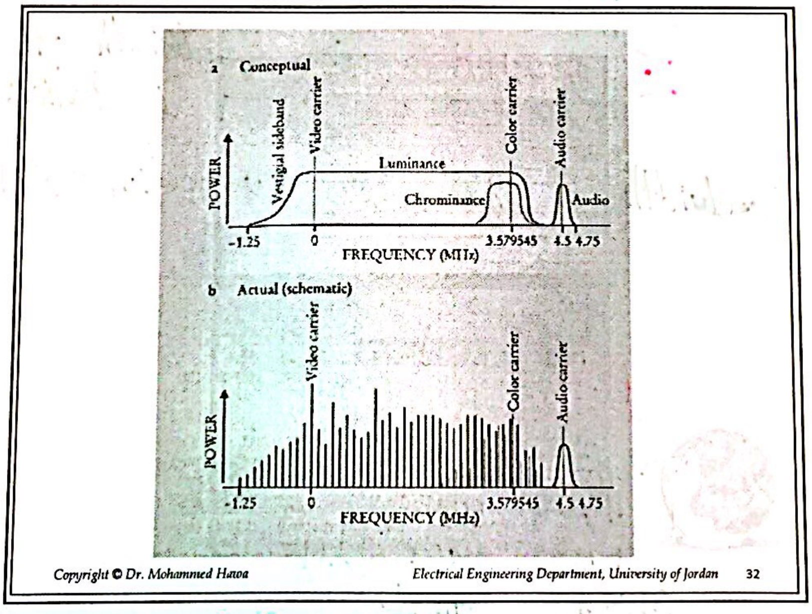
Memorize the Numbers.

sending vedio & audio This is FDM.

find $\epsilon = ?$ ⇒ smaller than ϵ_{NTSC}.

$\epsilon = 0.167$ PAL.

$m_v(t)\cos(w_s t) + m_v(t)\sin(w_s t)$ ⇒ Bandwidth of QAM = 2B = 2 × 1 MHZ.



※ what Modulation used for AUDIO? FM modulation.

※ TV is quasi-periodic (Not smooth – Not impulses).

Look like this ∩ ∩ ∩ ∩ ∩ ∩

NTSC

※Summarize:
0.25MHZ guard.
1MHZ LSB
4MHZ USB & QAM.
0.25MHz guard.
0.5MHZ Audio

Σ = 6MHZ. ⇒ Bandwidth of ONE NTSC TV station.

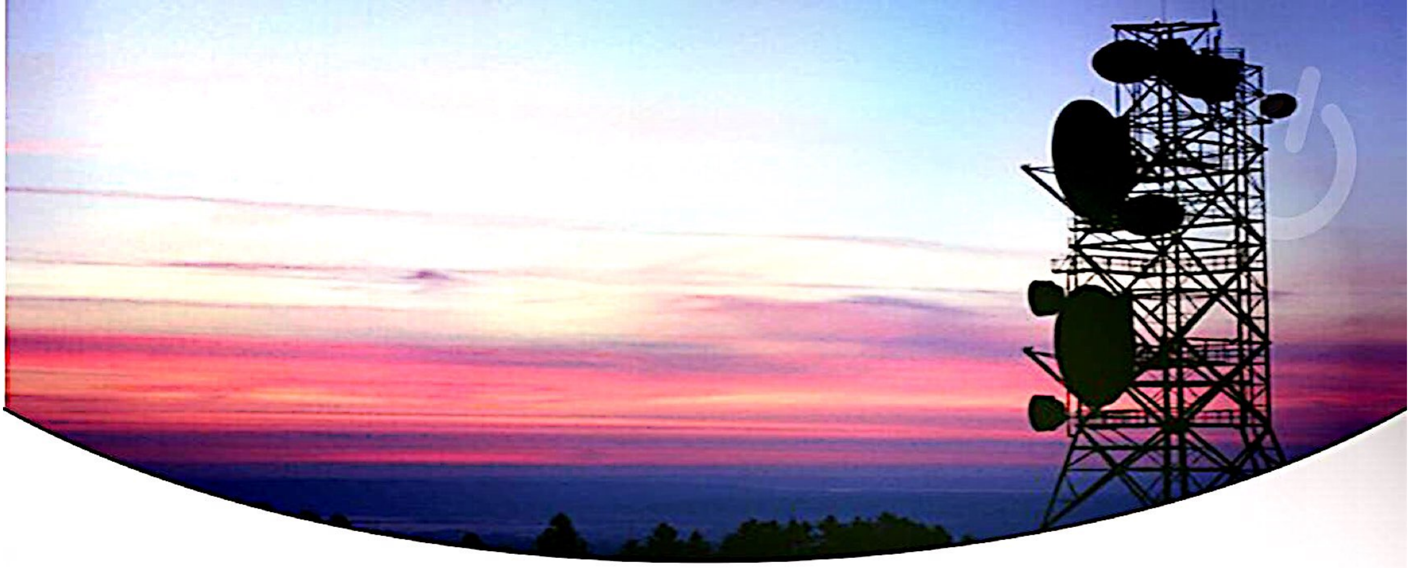
* Bandwidth of ONE ATSC TV station = 6MHZ.

PAL

0.25 MHZ guard
1 MHZ LSB
6 MHZ USB & QAM.
0.25 MHZ guard.
0.5M HZ audio

Σ = 8 MHZ. ⇒ Bandwidth of ONE PAL TV station.

* Bandwidth of each DVB-T TV station = 8 MHZ.



Communications1

Fall017

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By: Mhmd Abuhashya

www Powerunit-ju.com

Homdyne → Single Freq.

Multiple Freq.

Lecture 7: Heterodyning
(Up & Down Frequency Converter)

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EE421: Communications I

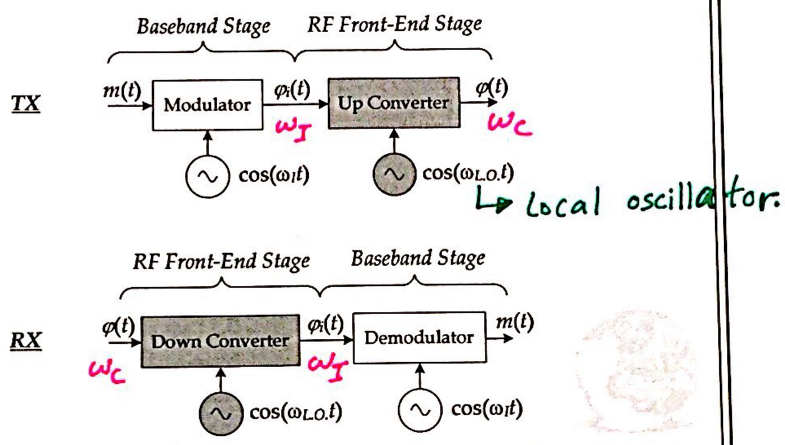
Baseband → Modulate.
0 → ω_c
$x\cos(\omega_c t)$
rather that we do:
0 → ω_I → ω_c
modulation, freq. converter (Heterodyne)

Heterodyne: Multiple Frequencies

- Typical **transmitters** do not modulate immediately from baseband to carrier frequency ω_c. Rather, they modulate to an *intermediate frequency* ω_I, then an up-converter shifts the frequency to the higher frequency ω_c.
- Also, real-life **receivers** do not demodulate immediately from carrier frequency ω_c to baseband. Rather, they use a down-converter to shift the modulated signal to an *intermediate frequency* ω_I, then demodulate to baseband.
- This has advantages, especially in FDM systems and digital systems (see: super-heterodyne receiver).

RF ≡ Radio Frequency.
≡ High freq.

Frequency Conversion



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Be careful!

- A frequency converter is also commonly called a **mixer,** but do not confuse it with a multiplication device.
- A frequency converter is **not** a demodulator.
- A frequency converter is **not** a modulator.
- **Up converter** takes you from *low* input frequency to *high* output frequency.
- **Down converter** takes you from *high* input frequency to *low* output frequency.

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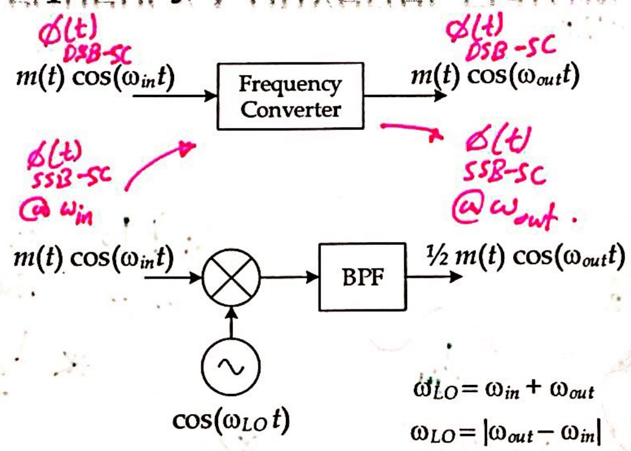
Frequency Converter Hardware



Examples

Input frequency f_{in}	Output frequency f_{out}	Device Type	L.O. frequency
300 MHz	100 MHz	Down converter (*sum*)	400 MHz
300 MHz	100 MHz	Down converter (*difference*)	200 MHz
100 MHz	300 MHz	Up converter (*sum*)	400 MHz
100 MHz	300 MHz	Up converter (*difference*)	200 MHz

$m(t)\cos(\omega_{in} t)$

$\Rightarrow m(t)\cos(2\pi \times 300M\, t)$

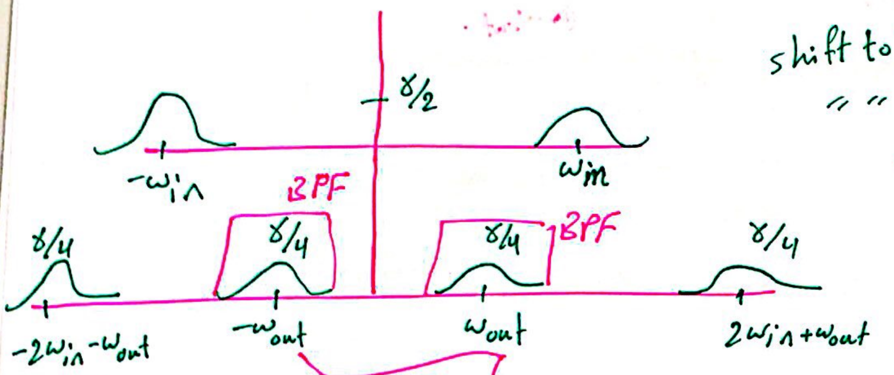
"Down Converter (Sum)"

$\cos(2\pi \times 400M\, t)$

$\cos((\omega_{in}+\omega_{out})t)$

$\downarrow$

ω_{LO}



shift to Left by $(\omega_{in}+\omega_{out})$

" " right " $(\omega_{in}+\omega_{out})$

$* \frac{1}{2}$

(4 copies).

$+\omega_{in} - (\omega_{in}+\omega_{out}) = -\omega_{out}$.

$-\omega_{in} - (\omega_{in}+\omega_{out}) = -2\omega_{in}-\omega_{out}$.

※ Specifications of BPF:

Center $= \omega_{out}$ rad/s.

Bandwidth $= 2B^{Hz} = 4\pi B$ rad/s.

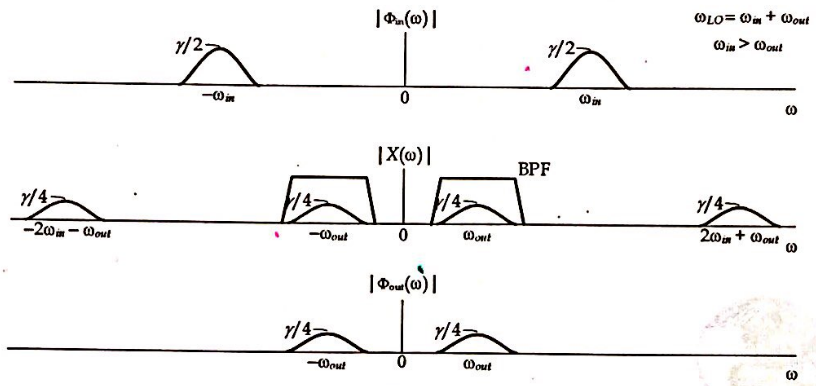
Gain = 1

$\hookrightarrow$ output $= \frac{1}{2} m(t)\cos(\omega_{out} t)$.

$B \equiv B_{m(t)}$ Bandwidth of the original signal $m(t)$.

$\Rightarrow$ Do the same for other converters.

Frequency Converter
(Down Converter, Sum)



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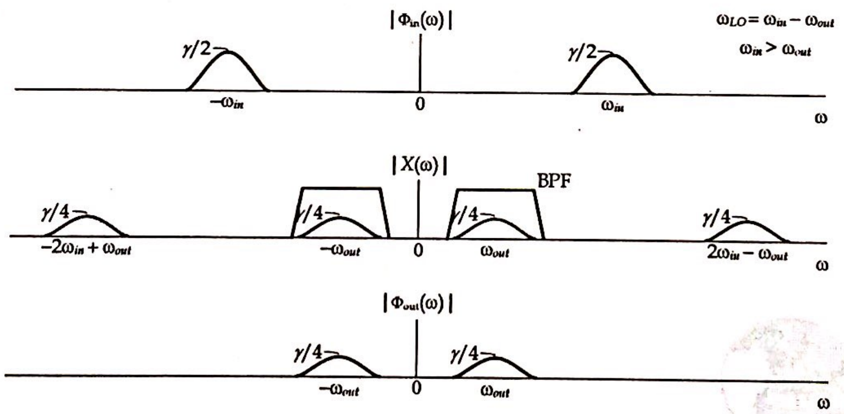
Frequency Converter
(Down Converter, Difference)



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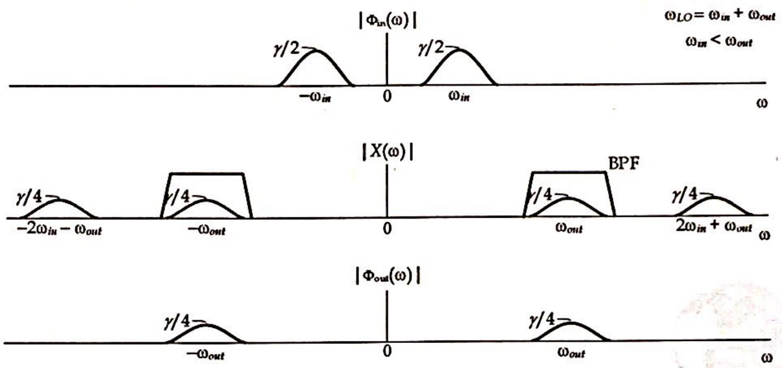
Frequency Converter
(Up Converter, Sum)



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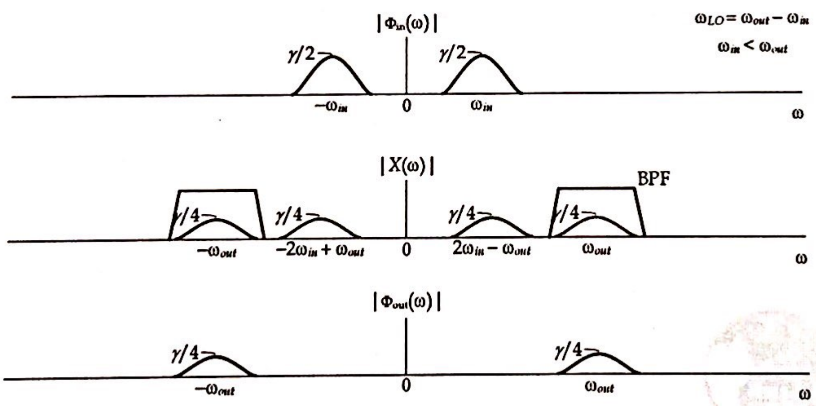
Frequency Converter
(Up Converter, Difference)



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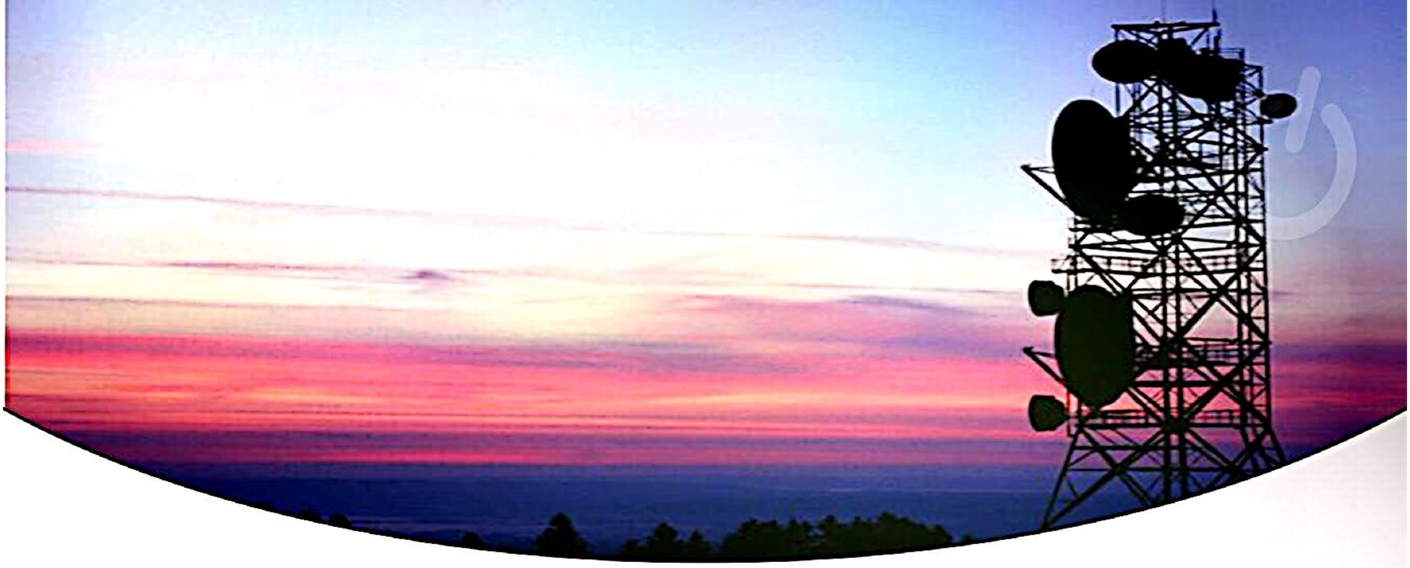
Homework 1

- Repeat the four cases above for SSB-SC (USB) input modulated signal:
  - Up converter, Sum
  - Up converter, Difference
  - Down converter, Sum
  - Down converter, Difference
- Find k in the output signal:
  $y(t) = k\,\varphi_{SSB-SC}(t)$
- Provide specifications for the BPF to be used.

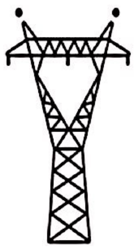
Homework 2

- Does the frequency converter (mixer) work if you use $p(t)$ instead of $\cos(\omega_{LO}t)$?
- If so, what is the necessary frequency(ies) for $p(t)$?
- Find k in the output signal:
  $y(t) = k\,m(t)\cos(\omega_{out}t)$
- Provide specifications for the BPF to be used.



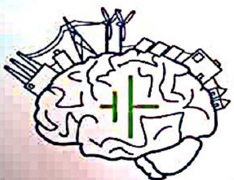
Communications1

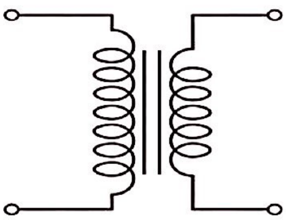
Fall017



Dr.Mhmd Hawa

By: Mhmd Abuhashya





Lecture 8: Performance of Communication Systems

Dr. Mohammed Hawa
Electrical Engineering Department
University of Jordan

EE421: Communications I. For more information read Section 9.9 in your textbook or visit http://wikipedia.org/.

Shannon's Limit

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

Shannon's Limit:

- C: Capacity of the channel in bits/second (bps)
- B_{ch}: Channel bandwidth (units of Hz)
- SNR: Signal-to-Noise Ratio (unitless)

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$m(t) \rightarrow$ ch. $\rightarrow m(t) + n(t)$ → we found $SNR = \frac{P_{signal}}{P_{noise}}$.

$\phi(t) \rightarrow$ ch. $\rightarrow \phi(t) + n(t)$

P_{signal} P_{noise}

Signal-to-Noise Ratio (SNR)

$$SNR = \frac{Signal\ \ Power}{Noise\ \ Power} = \frac{P_x}{P_n} \qquad (unitless)$$

→ since $\frac{Watt}{Watt}$

- **Noise:** all random and unpredictable signals added to the message by the channel.
- External and internal sources of noise.
- Solutions exist to reduce noise power (but noise can *never* be eliminated).
- In analog systems, SNR decides the *Quality* of the received *noisy* signal.
- In digital systems, SNR decides *BER*, i.e., *Quality*.

Quality

Good Quality due to High Power of the signal.

Bad Quality due to High noise power.

SNR → Related to Quality; (Higher SNR ⇒ Higher Quality)

SNR → BER ≡ Bit Error Rate. or Probability of Bit Error.

↳ Quality;

Ex. $BER = 10^{-7}$ (Good Quality).

$BER = 10^{-3}$ (Bad Quality).

$BER \leq 10^{-6}$ is good Quality digital system.

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SNR is usually expressed in dB

$$SNR = \frac{Signal\ Power}{Noise\ Power} = \frac{P_x}{P_n}\ (unitless)$$

$$SNR = 10 \times \log_{10}\left(\frac{P_x}{P_n}\right)\ (dB)$$

$$\frac{P_2}{P_1}[dB] = 10 \times \log_{10}\left(\frac{P_2}{P_1}[unitless]\right) = 10 \times \log_{10}\left(\left(\frac{V_2}{V_1}\right)^2[unitless]\right)$$

$$\frac{V_2}{V_1}[dB] = 20 \times \log_{10}\left(\frac{V_2}{V_1}[unitless]\right)$$

Be carful for the Base for the $\log_{\square}$ [ ]

if we deal with power use 10log

if voltage use 20log

Unitless vs. dB

$$\frac{P_2}{P_1}[dB] = 10 \times \log_{10}\left(\frac{P_2}{P_1}[unitless]\right)$$

$$\frac{P_2}{P_1}[unitless] = 10^{\left[\frac{\frac{P_2}{P_1}[dB]}{10}\right]}$$

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

$$30\ dB \Rightarrow 10^{\left[\frac{30}{10}\right]} = 10^3 = 1000\ unitless$$

Ex. $P_{signal} = 1000W$

$P_n = 1\ W$

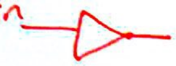
SNR = 1000 unitless

in dB:

$SNR = 10\log_{10} 10^3 = 30\ dB$

Ex. SNR = 30dB find unitless value?

$\Rightarrow 10^{\left(\frac{30dB}{10}\right)} = 10^3 = 1000$ unitless.

* Pin  Pout $Gain = \frac{P_{out}}{P_{in}}$ ⇒ $P_{out} > P_{in}$ for Amplifiers so we will get +ve dB value.

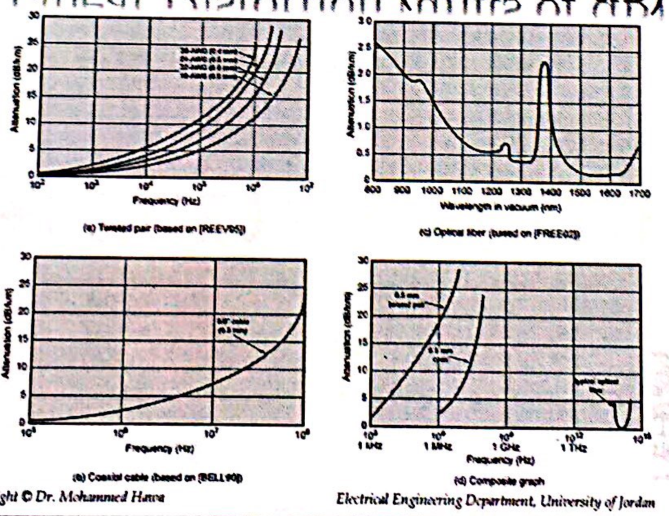
*  P_{tx} P_{rx} $P_{rx} < P_{tx}$ we will get -ve dB value. 11/5/2016

$10\log_{10}(<1) = (-)dB$

Gain, Power	Gain in dB
1 (no gain)	0 dB
2 (twice the power)	≈ +3 dB
10 (ten times the power)	+10 dB
100	+20 dB
1000	+30 dB
10000	+40 dB

Attenuation, Power	Attenuation in dB
0.5 (half the power)	≈ -3 dB
0.25 (quarter the power)	≈ -6 dB
0.1 (tenth the power)	-10 dB
0.01 (one hundredth)	-20 dB
0.001 (one in a thousand)	-30 dB
0.0001 (one in 10 thousand)	-40 dB

Linear Distortion (units of dB)



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

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

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

(d) Composite graph

$a \times b \Rightarrow \log_{10}(a \times b) = \log_{10} a + \log_{10} b$

$\frac{a}{b} \Rightarrow \log_{10}\frac{a}{b} = \log_{10} a - \log_{10} b$

dB, dBm and dBW

$$\frac{P_2}{P_1}[unitless] \rightarrow \frac{P_2}{P_1}[dB] = 10 \times \log_{10}\left(\frac{P_2}{P_1}[unitless]\right)$$

$$P_2[mW] \rightarrow P_2[dBm] = 10 \times \log_{10}\left(\frac{P_2[mW]}{1\,mW}\right)$$

$$P_2[W] \rightarrow P_2[dBW] = 10 \times \log_{10}\left(\frac{P_2[W]}{1\,W}\right)$$

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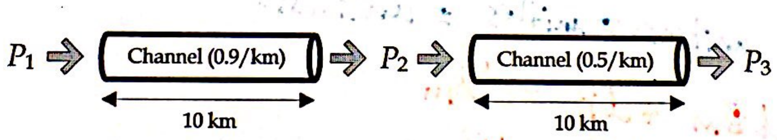
Example

- Assume P_1 is 100 mW. Find P_3 in dBm.



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for 1000 W:
⇒ 30 dBW
OR 1000W = 1000000 mW
⇒ 60 dBm

for 1000m W:
⇒ 30 dBm
OR 1000 m = 1 W
⇒ 0 dBW

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* For Previous Example:

- Using Unitless:

P_3 (mW) $= 100\,mW \times \underbrace{0.9 \text{ unitless} \times 0.9 \times 0.9 \times \cdots}_{10 \text{ times}} \times \underbrace{0.5 \times 0.5 \times \cdots}_{10 \text{ times}}$

$= 100\,mW \times (0.9)^{10} \times (0.5)^{10} = \boxed{0.0341}\ mW.$

- Using dB, dBm, dBW: (using proparties of log of multiplication)

$P_3 = \overset{\to 100mW}{20\,dB_m} + \underbrace{-0.46\,dB + -0.46 + \cdots}_{10 \text{ times.}} + \underbrace{-3\,dB + -3\,dB + \cdots}_{10 \text{ times.}}$

$= 20\,dB_m - 4.6\,dB - 30\,dB = \boxed{-14.6}\ dB_m.$

check: $10\log_{10}(0.0341)$ it must give $= -14.6\ dB_m$.

* Typically: Max power $20\,dB_m \Rightarrow 100\,mW$.

* Note: mW x unitless = mW. w x unitless = W.

unitless x unitles = unitless.

$\Rightarrow$ $dB_m + dB = dB_m$

$dB + dB = dB$

$dBW + dB = dBW$

$dBW - dBW = dB$ → $\frac{watt}{watt}$ = unitless ⇒ dB.

$dB_m + dBW =$ X (wrong to be added).

** $30\,dBW + 30\,dB = 60\,dB_m$

1000 W x 1000 unitless = 1000 000 mW.

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SNR vs. Quality

Memorize.

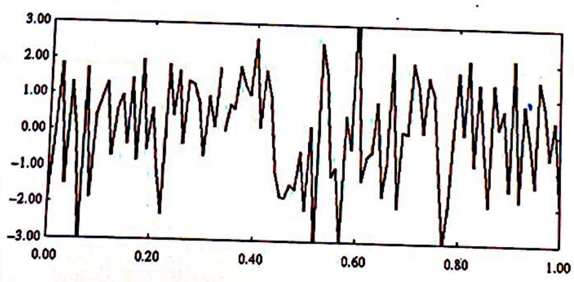
- For **voice** signals:
  - SNR = 5 dB to 10 dB at the receiver output implies a barely intelligible signal.
  - SNR = 25 dB to 35 dB is telephone quality signal.
  - **Summary:** If SNR ≥ 30 dB, good quality voice.

30.5 dB (Good)
29.5 dB (Bad).

- For **video** signals: ↳ 1000 unitless.
  - **Summary:** If SNR ≥ 50 dB, good quality video.
- For **digital** signals: ↳ 100000 unitless.
  - Need enough SNR for BER ≤ 10^{-6}, good quality.

Noise in Time Domain

- Noise is a purely **random** signal.
- Cannot be written as a deterministic equation.



* The Most Popular Model for Noise is : AWGN noise

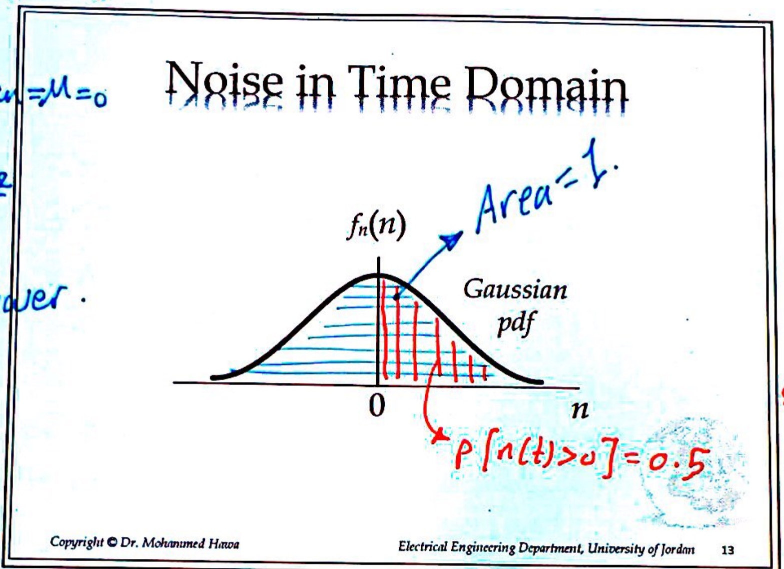
AWGN ≡ Additive White Gaussian Noise.

⇒ it is easier & fits well with internal noise (thermal).

11/5/2016

Gaussian : (t-domain)

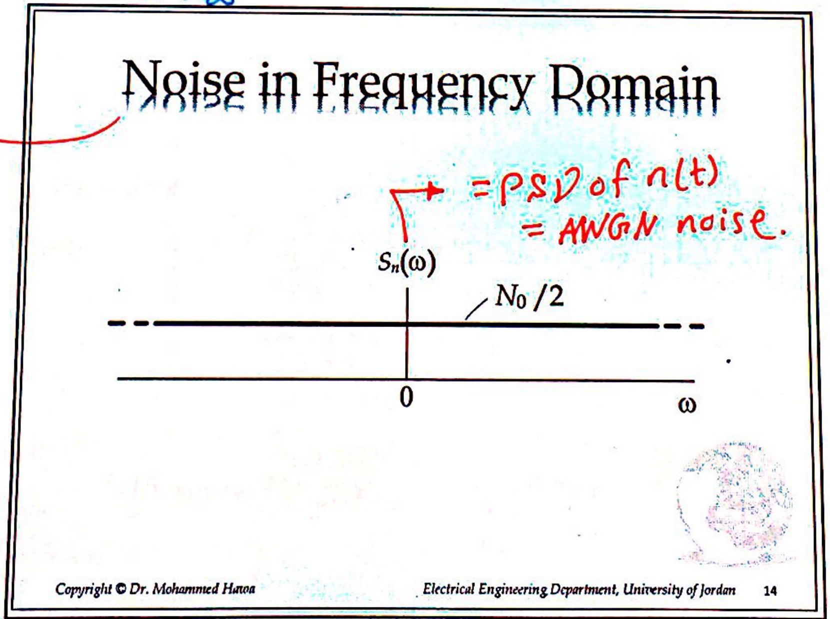
- average = mean = $\mu = 0$ = DC.
- Variance = σ^2 = RMS^2 = Average Power.



it is called Additive : Because it is added to the signal.

$\phi(t) \rightarrow \phi(t) + n(t)$

$P_n = \overline{n^2(t)} = \frac{1}{2\pi} \int_{-\infty}^{\infty} S_n(\omega)\, d\omega = \infty$ Watt. (Solved By filters).



Memorize : PSD of AWGN is Constant $= \frac{N_0}{2}$

$N_0 = 4KT$

$K \equiv$ Boltzman Constant $= 1.38 \times 10^{-23}$ J/K.

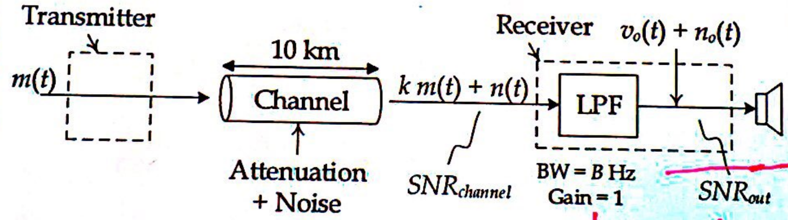
T = Temprature (in Kelvin).

$B_{m(t)} = B = 4KHz$. (memorize) if won't be mentioned in the Exam.

Example

- A voice signal $m(t)$ is transmitted without modulation through a 10 km long baseband channel with AWGN noise. Assume:
  - Average power in $m(t)$ at the TX is 1 kW
  - Channel Attenuation = –5 dB/km
  - $S_n(\omega) = 2 \times 10^{-9}$ W/Hz $= N_0 / 2$ $\Rightarrow N_0 = 4 * 10^{-9}$
- Show the block diagram of the receiver.
- Determine $SNR_{channel}$ and SNR_{out}.

Solution



→ $B = 4KHz$.

→ if Gain = 5 multiply by 25.

$\frac{25 * P_{signal}}{25 * P_n}$

$$SNR_{channel} = \frac{\overline{k^2 m^2(t)}}{\overline{n^2(t)}} \qquad SNR_{out} = \frac{\overline{v_o^2(t)}}{\overline{n_o^2(t)}}$$

$SNR_{channel} = \frac{10mW}{\infty} = 0$ unitless.

$SNR_{channel}$ (in dB) $= 10 \log_{10}(0) = -\infty$ dB.

$\Rightarrow SNR = \frac{10mW}{16\mu W} = \frac{10000\mu W}{16\mu W} = 625$ unitless $= 27.96$ dB $\ngtr 30$ dB (Bad Quality).

⇒ To find P_{signal} @ Rx :

dB

$$P_{rx,dBm} = P_{tx,dBm} + Att_{dB}$$

$P_{tx,dBm}$:

1KW = 1000 W

= 1000000 mW

= 60 dBm.

Att_{dB}:

−5dB + −5dB + ... 10 times.

$$\Rightarrow P_{rx,dBm} = 60dB_m - 50dB$$

$= 10 dBm$

$= 10 mW$ #

unitless

$$P_{rx,W} = P_{tx,W} \times Att_{unitless.}$$

$$P_{rx,W} = 1000 W \times \underbrace{10^{-5/10} \times 10^{-5/10} \cdots}_{10 \text{ times}}$$

$= 1000 W \times 10^{-5}$

$= 0.01 W = 10 mW.$ #.

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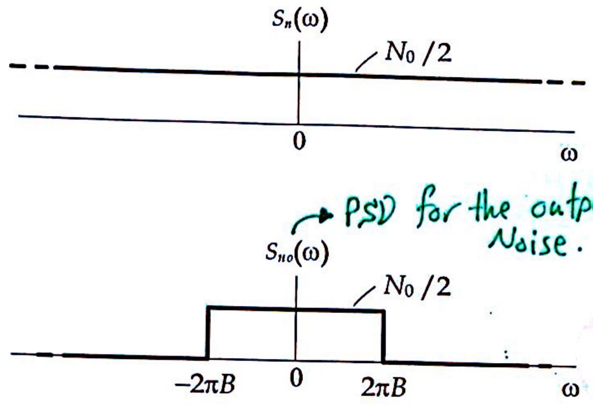
$$\overline{n^2(t)} = \frac{1}{2\pi}\int_{-\infty}^{\infty} S_n(\omega)\,d\omega = \frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{N_0}{2}\,d\omega = \infty \text{ Watt.}$$

Band-Limited Noise



$$\overline{n_o^2(t)} = \frac{1}{2\pi}\int_{-2\pi B}^{2\pi B} N_0/2\,d\omega = \frac{N_0/2 \cdot 4\pi B}{2\pi} = N_0 B = 4\times10^{-9}\,\frac{W}{Hz} * 4000\,Hz = 16\,\mu W$$

it was Limited from ∞ to 16 μW.

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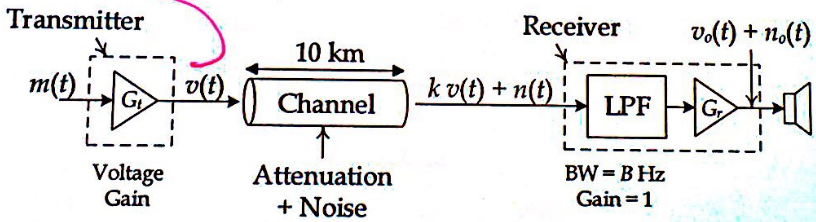
Homework

$\overline{v^2(t)} = G_t^2\,\overline{m^2(t)}$



- Is the gain G_r useful for improving quality? NO
- Is the gain G_r useful for anything else? Yes / for att. Not Quality.
- Determine the gain G_t to get good quality voice.
- *Or* determine the necessary cooling (temperature) to get good quality voice.

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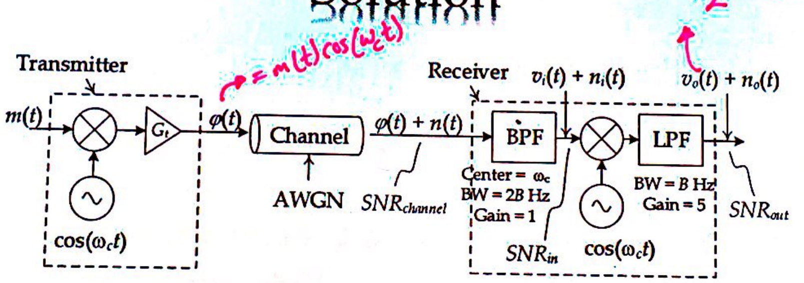
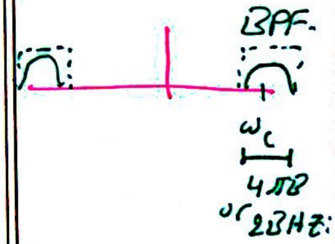
- Find Att. in chanel to get good quality voice?

Example 2

- A DSB-SC signal is sent though a channel with no attenuation. The channel is affected by AWGN noise. At the receiver side:
- Show the block diagram of the receiver.
- Determine $SNR_{channel}$.
- Determine SNR_{in}.
- Determine SNR_{out}.
- Determine NF for the demodulator.

Solution





$$SNR_{channel} = 0\,,\ SNR_{in} = \frac{\overline{m^2(t)}}{4N_0B}\ ,\ \ SNR_{out} = \frac{\overline{m^2(t)}}{2N_0B}$$

$\overline{n^2(t)} = \infty$ Watt.

$P_{signal} = \overline{\phi^2(t)} = \frac{1}{2}\overline{m^2(t)}$

*why we use BPF? To Reduce the Noise Power.

*SNR_{out} higher than SNR_{in} By a factor of 2 (Quality x2) Because of synch. Demodulator.

* Synch. receiver improves SNR. By factor of 2.

11/5/2016

- $P_{input\ signal} = \overline{\phi^2(t)} = \frac{1}{2}\overline{m^2(t)}$

$SNR_{in} = \frac{\overline{\phi^2(t)}}{\overline{n_i^2(t)}} = \frac{\frac{1}{2}\overline{m^2(t)}}{2N_0B}$

$\Rightarrow SNR_{in} = \frac{\overline{m^2(t)}}{4N_0B}$ Memorize.

- $P_{input\ Noise} = \overline{n_i^2(t)} = \frac{1}{2\pi}\int_{-\infty}^{\infty} S_{n_i}(\omega)\,d\omega$

$= \frac{1}{2\pi}$ (+ve & -ve Area)

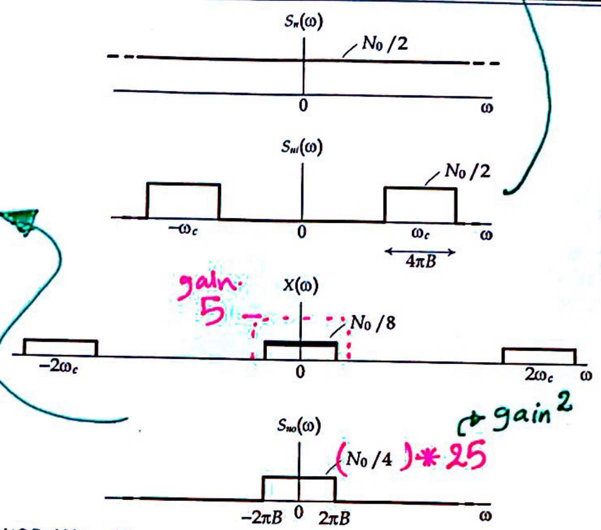
$= \frac{4\pi B * \frac{N_0}{2} * 2}{2\pi}$

$= 2N_0B$

in F: $* \frac{1}{2}$

in PSD: $* (\frac{1}{2})^2 = \frac{1}{4}$

when use $* \cos(\omega_c t)$.



- $P_{output\ Noise} = \overline{n_o^2(t)}$

$= \frac{1}{2\pi}\left(4\pi B * \frac{N_0}{4} * 25\right)$

$= \frac{N_0B}{2} * 25$

- $P_{output\ signal} = \overline{v_o^2(t)}$

$= \left[\frac{5}{2} m(t)\right]^2$

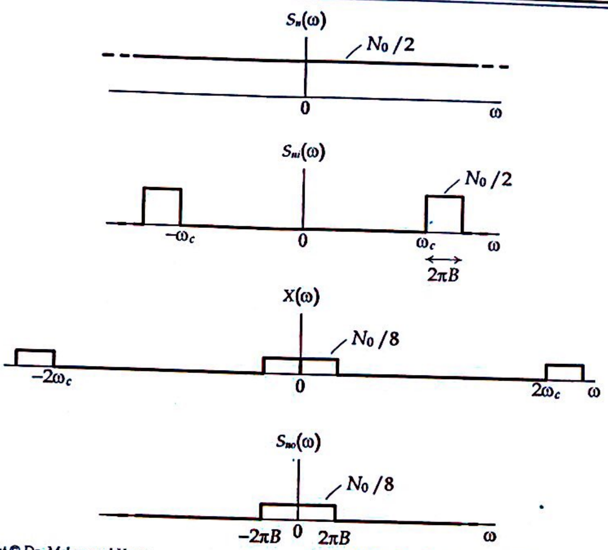
$= \frac{25}{4}\overline{m^2(t)}$

$\Rightarrow SNR_{out} = \frac{\overline{v_o^2(t)}}{\overline{n_o^2(t)}} = \frac{\frac{25}{4}\overline{m^2(t)}}{\frac{N_0B * 25}{2}} \Rightarrow SNR_{out} = \frac{\overline{m^2(t)}}{2N_0B}$

Homework 1

- A SSB-SC (USB) signal is sent though a channel with no attenuation. The channel is affected by AWGN noise. At the receiver side:
- Show the block diagram of the receiver.
- Determine $SNR_{channel}$.
- Determine SNR_{in}.
- Determine SNR_{out}.
- Determine NF for the demodulator. = 0dB

NF = 0dB (means No improvements).



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Homework 2

- A QAM signal is sent though a channel with no attenuation. The channel is affected by AWGN noise. At the receiver side:
- Show the block diagram of the receiver.
- Determine $SNR_{channel}$.
- Determine SNR_{in}.
- Determine SNR_{out}.
- Determine NF for the demodulator.

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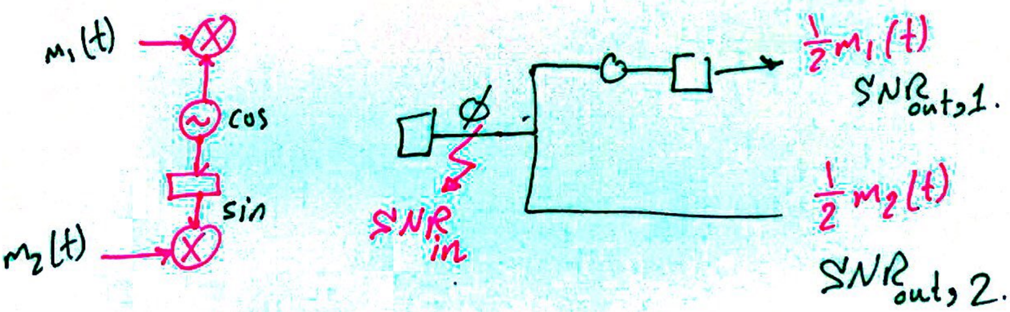


$S_{in} \equiv$ Power of signal @ input of Rx.
= Power of $\phi(t)_{DSB\text{-}SC}$ = $\frac{1}{2}\overline{m^2(t)}$ → substitute it in SNR_{out}.

Memorize

Modulation Technique	Modulated Signal Bandwidth	SNR_{out}	Noise Figure NF, dB	Typical Applications
DSB-SC	$2B$	$\frac{S_{in}}{N_0 B}$	−3	Analog instrumentation; multiplexing as part of FM stereo
SSB-SC	B	$\frac{S_{in}}{N_0 B}$	0	Point-to-point voice
VSB-SC	$B \sim 2B$	$\frac{S_{in}}{N_0 B}$	−3~0	Facsimile (Fax machines)
QAM	$2B$ for two signals	$\frac{S_{in,effective}}{N_0 B}$	0	Transmit color information in TV broadcasting; digital data
AM	$2B$	$\eta \frac{S_{in}}{N_0 B}$	$-10\log(2\eta)$	Broadcast AM radio; point-to-point voice
SSB+C	B	$\eta \frac{S_{in}}{N_0 B}$	$-10\log(\eta)$	Multiplexing in old telephony systems; point-to-point voice
VSB+C	$B \sim 2B$	$\eta \frac{S_{in}}{N_0 B}$	$-10\log(2\eta) \sim -10\log(\eta)$	Analog Television broadcasting
FM	$2\Delta f + 2B$	$\left(\frac{3\beta^2}{k_m^2}\right)\frac{S_{in}}{N_0 B}$	$10\log\left(\frac{k_m^2}{6(\beta+1)\beta^2}\right)$	Broadcast FM radio; analog microwave links
PM	$2\Delta f + 2B$	$\left(\frac{(\Delta\theta)^2}{k_m^2}\right)\frac{S_{in}}{N_0 B}$	$10\log\left(\frac{k_m^2 B}{2(\Delta\theta)^2(\Delta f + B)}\right)$	Telemetry; digital data

⇒ To find SNR_{in}:

$NF_{dB} = SNR_{in_{dB}} - SNR_{out_{dB}}$

Noise Figure, NF

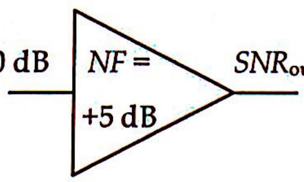
- A number by which the performance of a device can be specified. It measures the *degradation* of the quality (SNR) caused by components in this device.

$$NF \triangleq SNR_{in}(dB) - SNR_{out}(dB)$$

+ve means worse.
−ve means Good.

Example:

$SNR_{in} = 20$ dB



$SNR_{out} = 15$ dB

worse By 5dB
OR
Degradation By 5dB.
since it decrease the SNR.

NF for the Example in slide (19):

$SNR_{in} = \frac{\overline{m^2(t)}}{4N_oB}$ unitless.

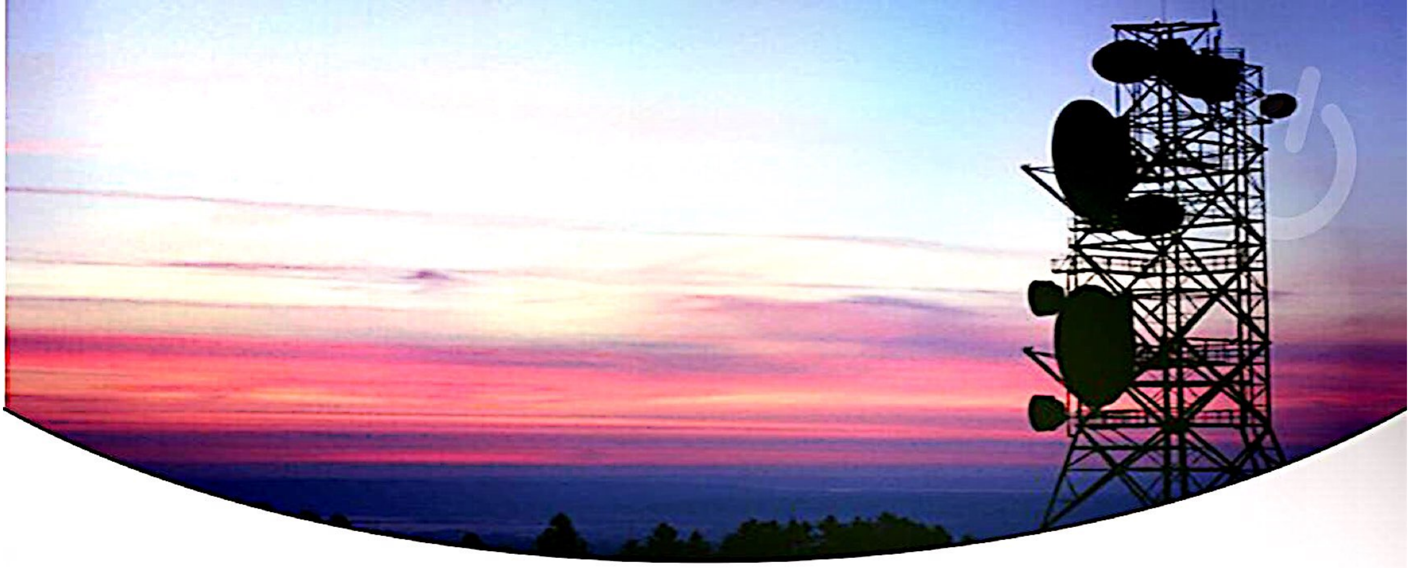
$SNR_{in,dB} = 10\log_{10}\left(\frac{\overline{m^2(t)}}{4N_oB}\right) = 10\log_{10}\left(\frac{1}{2}\cdot\frac{\overline{m^2(t)}}{2N_oB}\right)$

$= 10\log_{10}\left(\frac{1}{2}\right) + 10\log_{10}\left(\frac{\overline{m^2(t)}}{2N_oB}\right)$

$\Rightarrow SNR_{in,dB} = -3\,dB + SNR_{out,dB}$

$\Rightarrow NF = SNR_{in,dB} - SNR_{out,dB} = -3\,dB$

Good since we used synch Receiver.



Communications1

Fall017

Dr.Mhmd Hawa

By: Mhmd Abuhashya

DSB-SC → DSB-LC (AM) (DSB+C)
SSB-SC → SSB-LC (SSB+C)
VSB-SC → VSB-LC (VSB+C)
QAM → ~~QAM-LC~~ (doesn't exist)

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

$\phi_{DSB-LC\,(AM)}(t) = m(t)\cos(\omega_c t) + A\cos(\omega_c t) = [m(t)+A] \cdot \cos(\omega_c t)$

Extra Carrier.

Lecture 10: Amplitude Modulation (Double Sideband *Large Carrier*, DSB-LC or AM)

OR DSB+C

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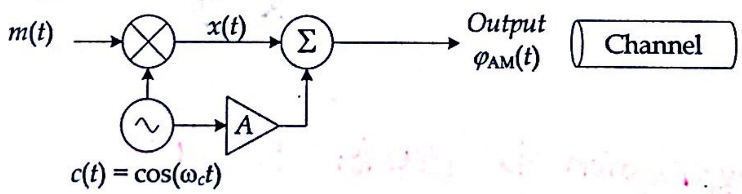
EE421: Communications I. For more information read Chapter 4 in your textbook or visit http://wikipedia.org/.

AM Modulator (*Method #1*)



- Three possibilities (based on the value of A):
  - *Under* modulation; $m < 1$
  - *Critical* modulation; $m = 1$
  - *Over* modulation; $m > 1$

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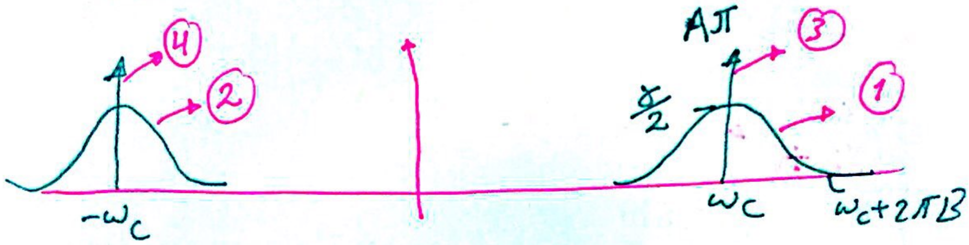
* sketch $\mathcal{F}\{\underset{\substack{DSB-LC \\ AM.}}{\phi(t)}\} = \underset{AM}{\Phi(\omega)}$

$$\mathcal{F}\{m(t)\cos(\omega_c t) + A\cos(\omega_c t)\} = \mathcal{F}\{m(t)\cos(\omega_c t)\} + \mathcal{F}\{A\cos(\omega_c t)\}$$

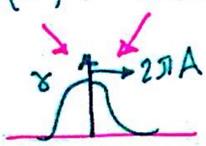
$$= \underbrace{\frac{1}{2}M(\omega-\omega_c)}_{①} + \underbrace{\frac{1}{2}M(\omega+\omega_c)}_{②} + \underbrace{A\pi\,\delta(\omega-\omega_c)}_{③} + \underbrace{A\pi\,\delta(\omega+\omega_c)}_{④}$$



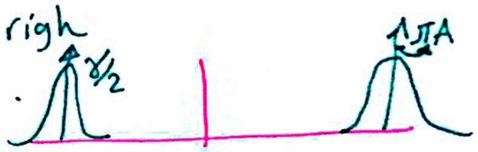
for the other expression you will get same answer.

$$\mathcal{F}\{[m(t)+A]\cdot\cos(\omega_c t)\}$$

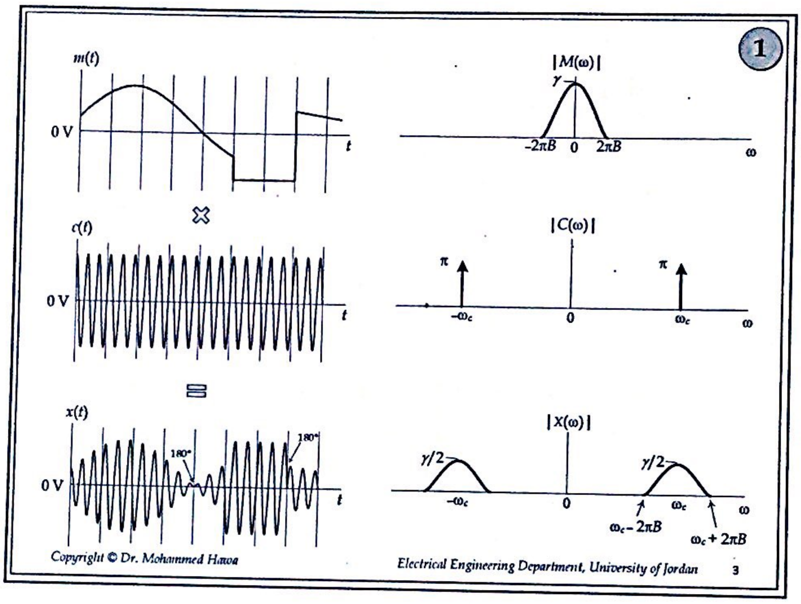
$M(\omega) + 2\pi A\delta(\omega)$



$\Rightarrow$ Then shift to left
shift to righ
$* \frac{1}{2}$.



This expression is easier to draw in Time Domain.


1
m(t)
0 V
t
|M(ω)|
γ
−2πB 0 2πB
ω
c(t)
|C(ω)|
π
−ωc
0
ωc
x(t)
180°
|X(ω)|
γ/2
ωc − 2πB
ωc + 2πB
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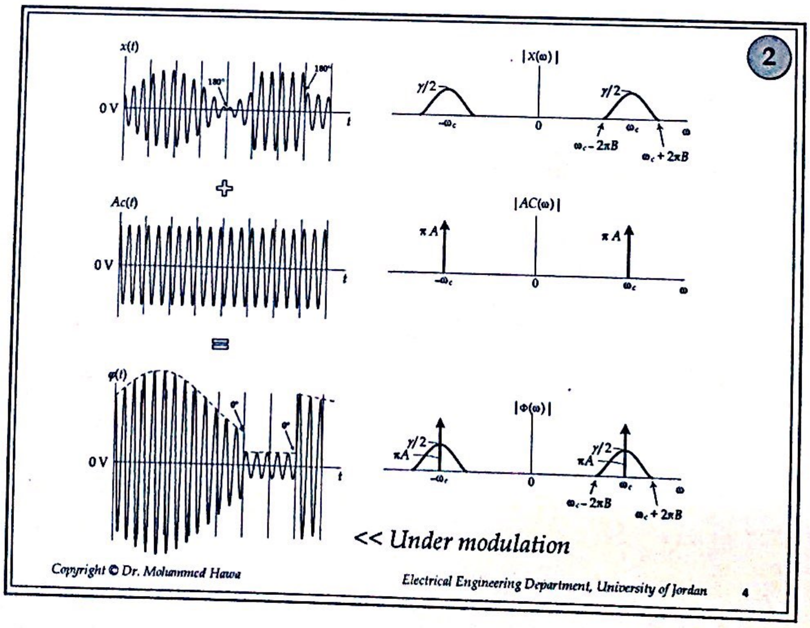
3


2
x(t)
0 V
|X(ω)|
γ/2
ωc − 2πB
ωc + 2πB
Ac(t)
|AC(ω)|
πA
φ(t)
|Φ(ω)|
<< Under modulation
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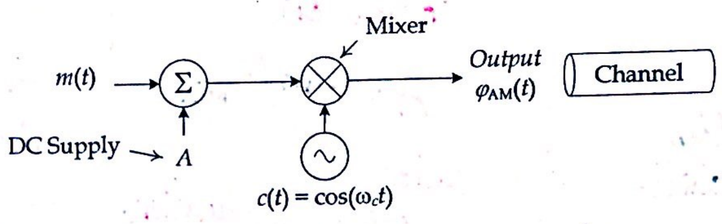
A
Small A — inbetween. — Big A

AM Modulator (*Method #2*)



- Three possibilities (based on the value of A):
  - *Under* modulation; $m < 1$
  - *Critical* modulation; $m = 1$
  - *Over* modulation; $m > 1$

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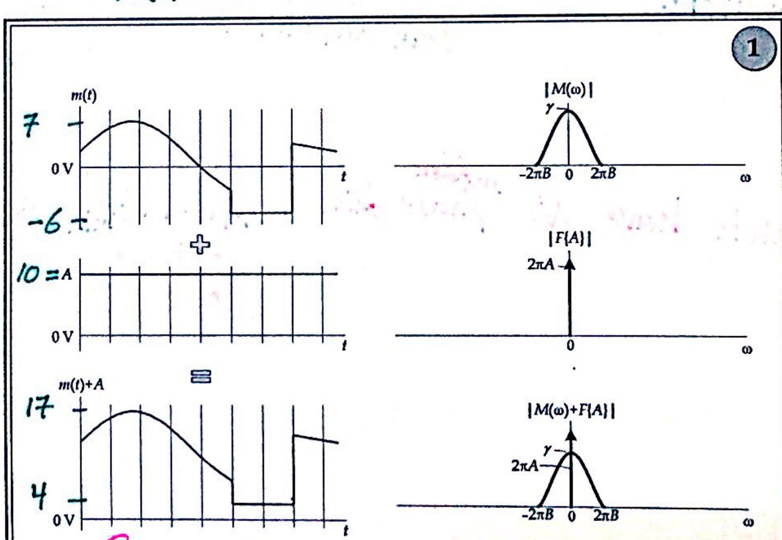
$m(t) + A = x(t)$.



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→ x(t) always +ve
means that: No-sudden phase shift.

A

small A

$A < -m(t)_{min}$

there is sudden 180° phase shift.

(when $x(t)$ +ve → -ve, -ve → +ve).

Called: Over Modulation.

⇒ only limited to synch. Demodulator.

inbetween.

$A = -m(t)_{min}$.

called: Critical Modulation.

No sudden 180° phase shift.

⇒ you can use asynch & synch. Demodulator.

Big A.

$A > -m(t)_{min}$.

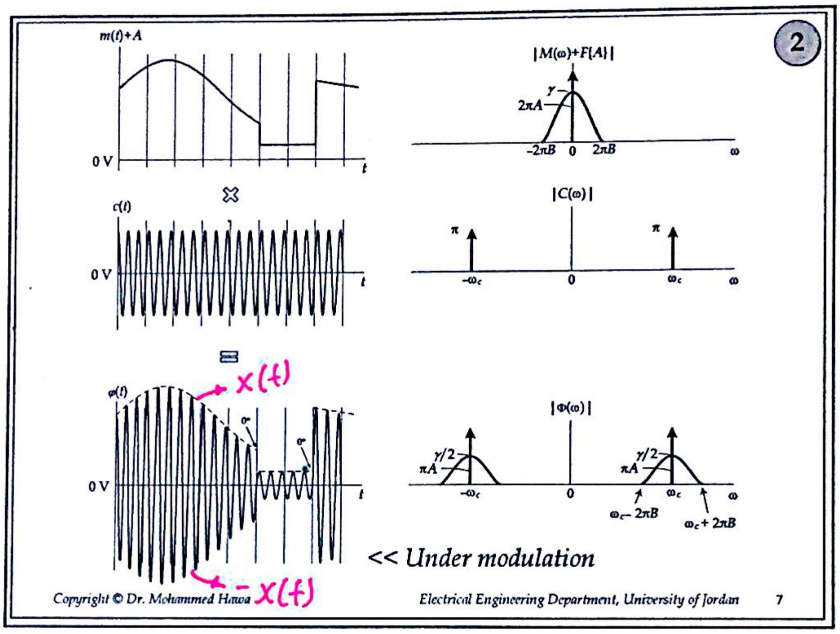
$A + m(t) > 0$

No sudden phase shift (180°). No sudden phase shift.

Called: Under modulation.

⇒ we can use asynch. & synch demodulator.

* Cases which have No sudden phase shift: $A = -m(t)_{min}$ & $A > -m(t)_{min}$.
critical modulation. & under modulation.


2
m(t)+A
0 V
t
|M(ω)+F{A}|
γ
2πA
-2πB
0
2πB
ω
c(t)
|C(ω)|
π
-ω_c
ω_c
φ(t)
x(t)
-x(t)
|Φ(ω)|
γ/2
πA
ω_c− 2πB
ω_c+ 2πB
<< Under modulation
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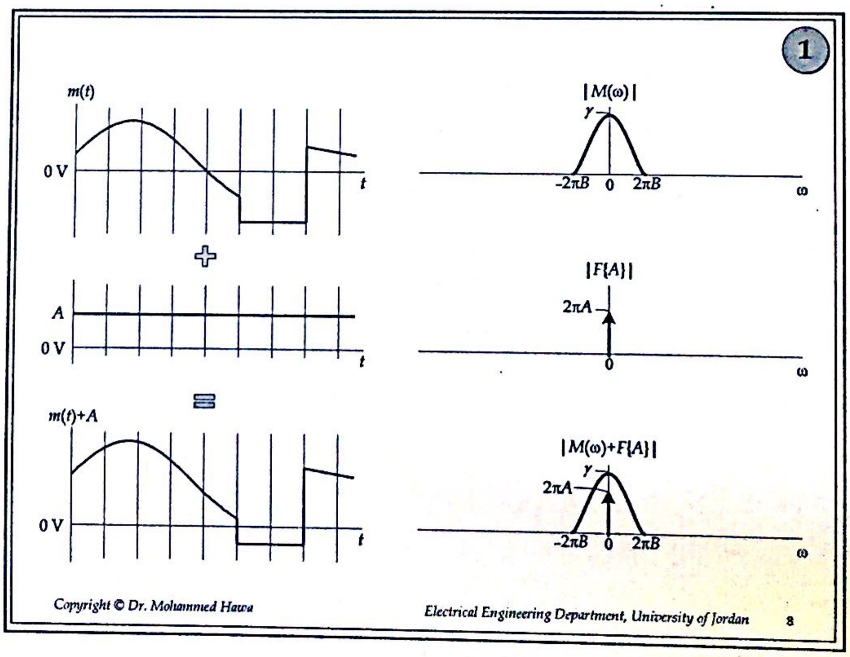
1
m(t)
0 V
t
|M(ω)|
γ
-2πB
0
2πB
ω
A
|F{A}|
2πA
m(t)+A
|M(ω)+F{A}|
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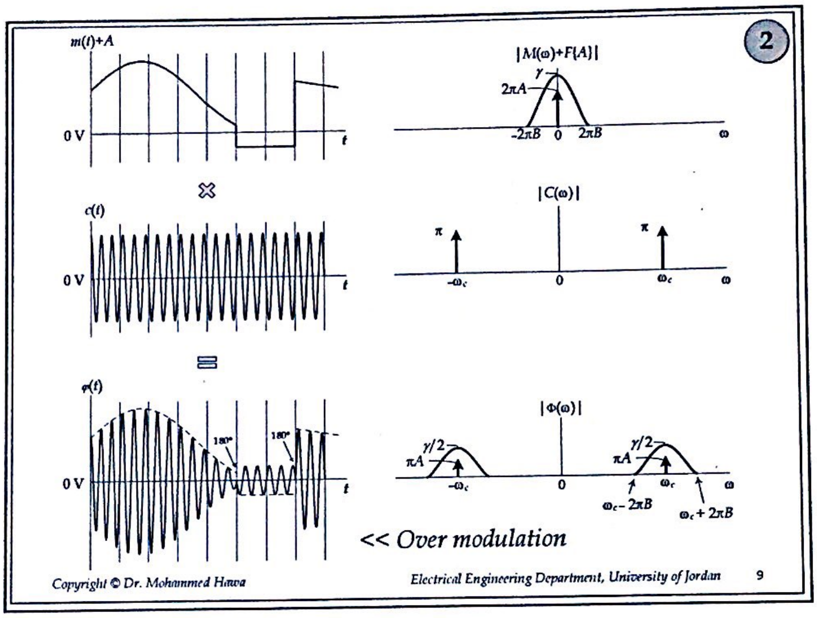
2
m(t)+A
0 V
t
|M(ω)+F{A}|
γ
2πA
-2πB 0 2πB
ω
c(t)
|C(ω)|
π
-ω_c
ω_c
φ(t)
180°
|Φ(ω)|
γ/2
πA
ω_c − 2πB
ω_c + 2πB
<< Over modulation
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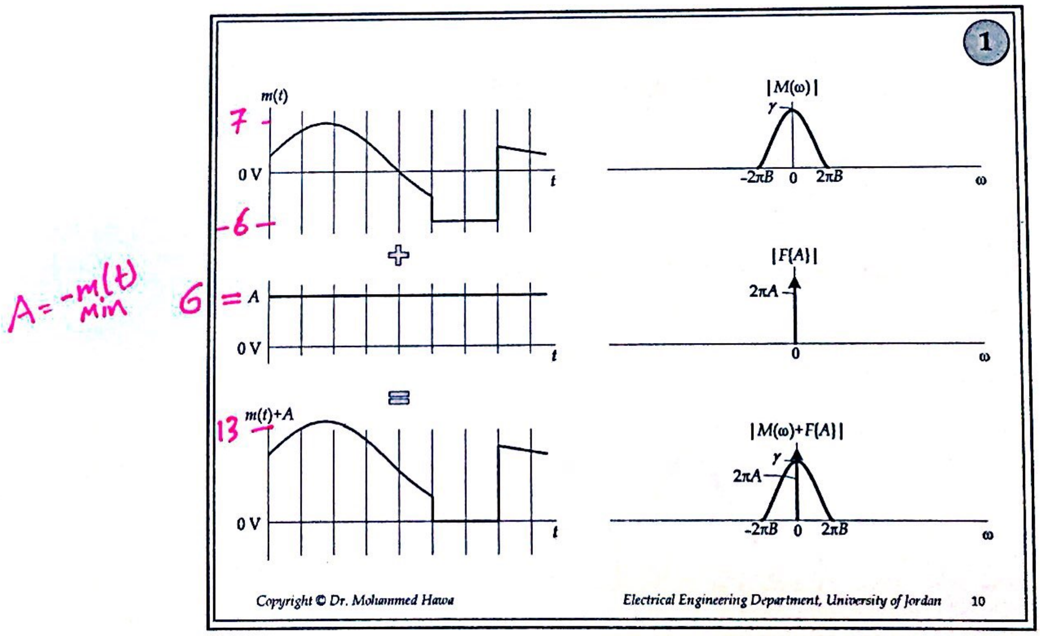
1
m(t)
7
-6
0 V
t
|M(ω)|
γ
-2πB 0 2πB
ω
A = -m(t) min
6 = A
|F{A}|
2πA
m(t)+A
13
|M(ω)+F{A}|
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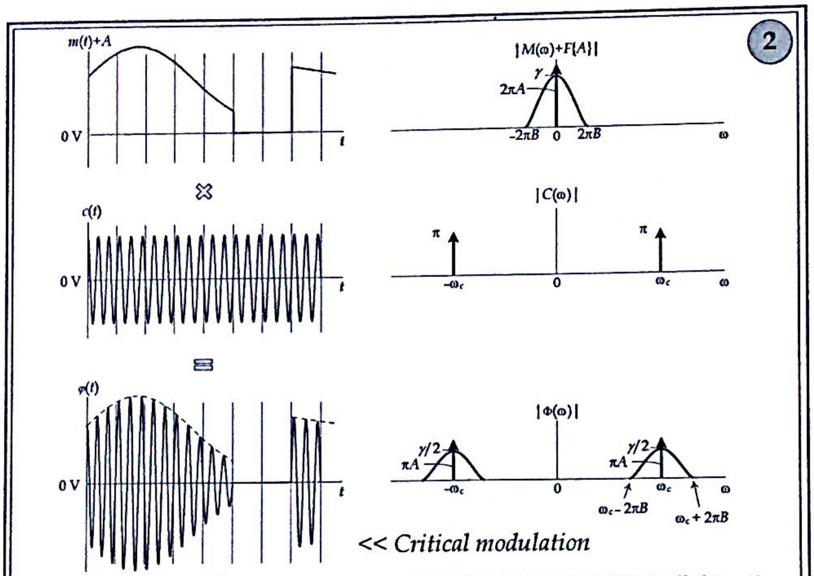
10



<< Critical modulation

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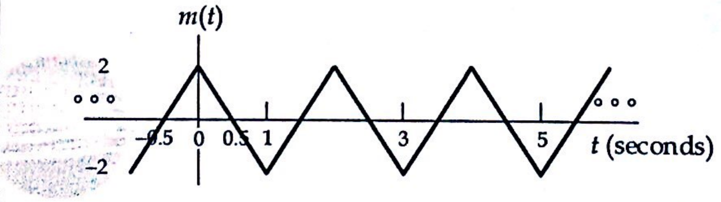
Homework

If we perform AM modulation on the following baseband message signal $m(t)$:

- Sketch the modulated signal in ***time domain*** $\varphi_{AM}(t)$
- Sketch the ***frequency domain*** Fourier Transform $\Phi_{AM}(\omega)$
- Determine the modulated signal ***bandwidth***. $= 2B$

$\Rightarrow B_{AM} = 2B$ Hz
$= 4\pi B$ rad/s

$B \equiv$ it is BW of the original signal.



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11/5/2016

A

small A	inbetween	Big A
$A < -m(t)_{min}$	$A = -m(t)_{min}$	$A > -m(t)_{min}$
⇒ $m > 1$ over modulation	⇒ $m = 1$ Critical Modulation	⇒ $m < 1$ under modulation.

"memorize"

AM Modulation Index, m

(more expensive) @ Tx.

More power needed from transmitter (Larger A)

$$m \triangleq \frac{-m(t)_{min}}{A}$$

- $m < 1$
- $m = 1$

} Asynchronous receiver can demodulate. (Very *simple* and very *inexpensive*)

- $m > 1$
- $m = \infty$ → when $A = 0$ in case DSB-SC.

} Only a *synchronous* receiver can demodulate. This RX requires using a PLL (*Expensive*)

Best Two choices ($m = 1$ and $m = \infty$) → choose depending on your situation.
→ in case one Tx & many Rx's : use ($m = 1$).
→ in case one Tx & one Rx : use ($m = \infty$). & so on.

Example

Sketch the AM modulated signal in *time domain* $\varphi_{AM}(t)$ and *frequency domain* $\Phi_{AM}(\omega)$, then calculate the modulated signal *bandwidth, average power, power efficiency*. Assume the case of tone modulation, and:

→ $m(t) = \alpha \cos(\omega_m t)$.

- $m = 0.5$ ← under modulation
- $m = 1$ ← Critical "
- $m = 2$ ← over "
- $m = \infty$ ← DSB-SC ≡ over "

$\phi_{AM}(t) = m(t)\cos\omega_c t + A\cos\omega_c t$ ⇒ $\text{Power} = \frac{1}{2}\overline{m^2(t)} + \frac{A^2}{2}$

Assume orthogonal:

Extra power ≡ Extra money.

* for the previous Example:

$m(t) = \alpha \cos(\omega_m t)$.

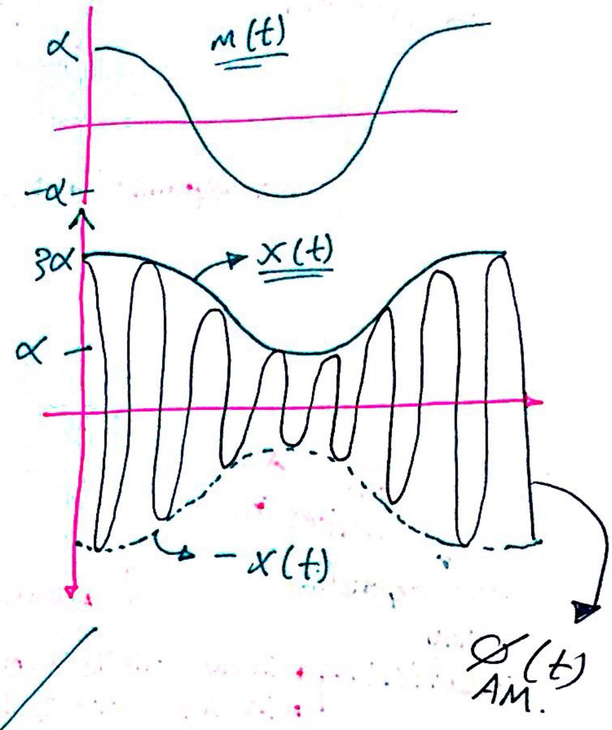
Take it for $m = 0.5$

- Time Domain:

$m = 0.5 = \frac{-m(t)_{min}}{A}$

$\frac{-(-\alpha)}{0.5} = A \Rightarrow A = 2\alpha$

$x(t) = 2\alpha + m(t)$.

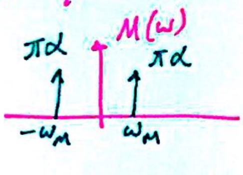


Homework:
Do the same for other cases $m = 1, 2, \infty$.

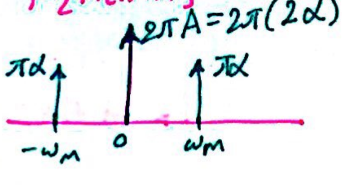
check:

$m = \frac{max - min}{max + min} = \frac{3\alpha - \alpha}{3\alpha + \alpha} = 0.5$ ✓.

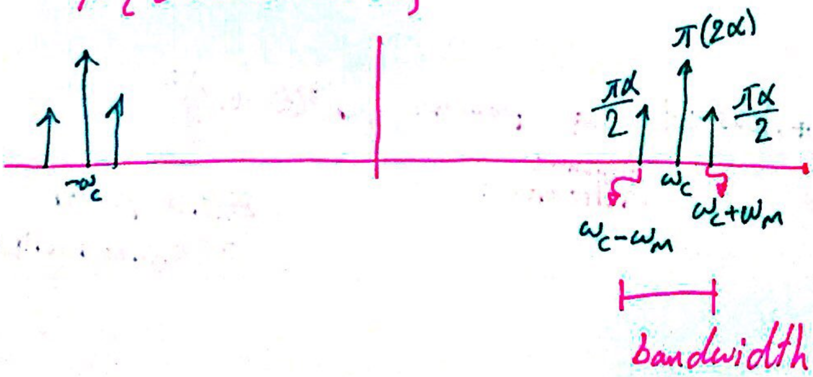
- Freq. Domain:



$\mathcal{F}[m(t) + A]$

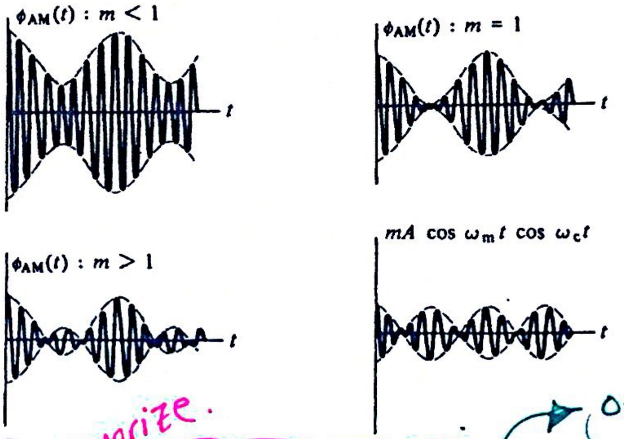


$\mathcal{F}\{[m(t)+A] \cdot \cos(\omega_c t)\}$



bandwidth = $2\omega_m$ rad/sec.

Scanned by CamScanner



memorize.

$$m = \frac{\textbf{max.}\,magnitude - \textbf{min.}\,magnitude}{\textbf{max.}\,magnitude + \textbf{min.}\,magnitude}$$

→ only for Tone Modulation.

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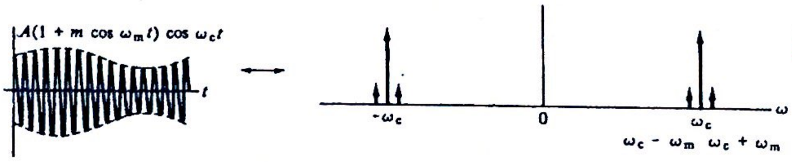
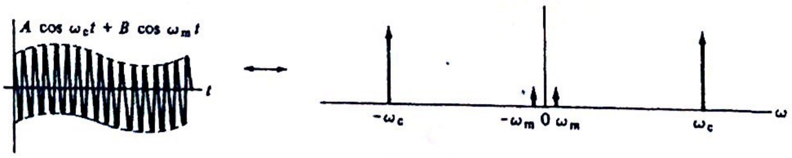
Notice the Difference!



⇒ this is Modulated.



⇒ this is Not modulated
⇓
it is Baseband + Modulated.

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for ①: $\overline{\cos^2(\omega_c t)} = \overline{\left[\frac{1}{2} + \frac{1}{2}\cos(2\omega_c t)\right]} = \frac{1}{2} + \frac{1}{2}\overline{\cos(2\omega_c t)} = \frac{1}{2} + 0 = \boxed{\frac{1}{2}}$

for ③: $\overline{m^2(t)\cos^2(\omega_c t)}$ (low freq. / high freq.); $m(t)\cos(\omega_c t)$ so $\simeq \overline{m^2(t)} \cdot \overline{\cos^2(\omega_c t)} = \boxed{\frac{1}{2}\overline{m^2(t)}}$

for ②: $\overline{m(t)\cos^2(\omega_c t)}\,(2A) \simeq 2A\,\overline{m(t)}\;\overline{\cos^2(\omega_c t)} = 2A\,\overline{m(t)} * \frac{1}{2} = \boxed{A\overline{m(t)}}$

AM Average Power

$$P_{\varphi_{AM}(t)} = \overline{\varphi_{AM}^2(t)} = \lim_{T\to\infty}\frac{1}{T}\int_T \varphi_{AM}^2(t)dt$$

$$\overline{\varphi_{AM}^2(t)} = \overline{[m(t)\cos(\omega_c t) + A\cos(\omega_c t)]^2}$$

$$\overline{\varphi_{AM}^2(t)} = \overline{m^2(t)\cos^2(\omega_c t) + A^2\cos^2(\omega_c t) + 2Am(t)\cos^2(\omega_c t)}$$

$$\overline{\varphi_{AM}^2(t)} = \underbrace{\overline{m^2(t)\cos^2(\omega_c t)}}_{③} + A^2\underbrace{\overline{\cos^2(\omega_c t)}}_{①} + 2A\underbrace{\overline{m(t)\cos^2(\omega_c t)}}_{②}$$

$$\overline{\varphi_{AM}^2(t)} = \frac{1}{2}\overline{m^2(t)} + \frac{A^2}{2} + A\overline{m(t)} = P_s + P_c + 0$$

memorize.

if $A\overline{m(t)}$ is zero then $m(t)\cos(\omega_c t)$ & $A\cos(\omega_c t)$ are ortho.

if there is DC:

$$\eta = \frac{P_s}{P_s + P_c + P_{extra}}$$

AM Power Efficiency

in case NO DC in m(t):

$$\eta = \frac{\text{Useful power}}{\text{Total power}} = \frac{P_s}{P_t} = \frac{P_s}{P_s + P_c}$$

$P_s = \frac{1}{2}\overline{m^2(t)}$

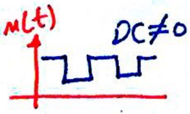
$P_c = \frac{A^2}{2}$

$$\eta = \frac{\frac{1}{2}\overline{m^2(t)}}{\frac{1}{2}\overline{m^2(t)} + \frac{A^2}{2}}$$ (general)

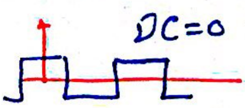
$P_{extra} = A\overline{m(t)}$ → it is useless power.

$$\eta = \frac{m^2}{m^2 + 2}$$ (tone modulation)

* In Practical systems, we make sure that $\overline{m(t)} = 0$ (m(t) has NO DC)



⇒ m(t) →|⊢→ capacitor in series
- AC → short cct.
- DC → open cct.



* for previous example: $m(t) = \alpha \cos(\omega_m t)$

$\Rightarrow \overline{m^2(t)} = \alpha^2/2$, $\overline{m(t)} = 0$. (No Need for a capacitor).

$$P_t = \overline{\phi^2_{AM}} = \frac{1}{2}\overline{m^2(t)} + \frac{A^2}{2} + 0$$

$$= \frac{1}{2} \cdot \frac{\alpha^2}{2} + \frac{(\alpha/m)^2}{2} = \boxed{\frac{\alpha^2}{4} + \frac{\alpha^2}{2m^2}}$$

we could find m if α & P_t are Known.

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

$$\eta = \frac{P_s}{P_t} = \frac{\frac{1}{2}\overline{m^2(t)}}{\frac{1}{2}\overline{m^2(t)} + \frac{A^2}{2}} = \frac{\alpha^2/4}{\frac{\alpha^2}{4} + \frac{\alpha^2}{2m^2}} \Rightarrow \eta = \frac{m^2}{m^2+2}$$

This is just for Tone modulation.

$\Rightarrow$ for the Efficiency:

m	$\eta = m^2/(m^2+2)$
0.5	11.11%
1	33.33%
2	66.67%
∞	100%

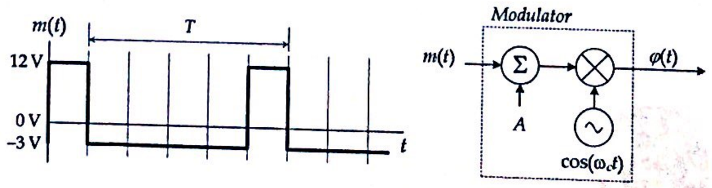
$P_c = \frac{A^2}{2} = \frac{V^2}{R=1\Omega}$ if $R = 50\Omega \Rightarrow P_c = \frac{A^2/2}{50}$

Homework #1

- A given AM (DSB-LC) broadcast station transmits an average carrier power, P_c, of 40 kW and uses a modulation index, m, of 0.707 for *tone* modulation. *Assuming* the antenna is represented by a 50 Ω resistive load, calculate:
  - The transmission efficiency (η). $= \frac{m^2}{m^2+2} = \frac{\frac{1}{2} m^2(t)}{\frac{1}{2} m^2(t) + \frac{A^2}{2}}$
  - The total average power output (P_t).
  - The *extra carrier* amplitude (A).
  - The peak amplitude of the output signal.
  - *Answers*: 20%; 50 kW; 2000 V; 3414 V.

Homework #2

- The baseband signal *m*(*t*) shown is passed through the following modulator. Assume the power efficiency is 90%, *T* = 60 μs and f_c = 40 MHz. Determine: ≡ 2B Hz.



Homework #2

- Type of the modulated signal $\varphi(t)$?
- Bandwidth of the modulated signal?
- Average power in the sidebands P_s?
- Average power in the extra carrier P_c?
- Modulation index of the modulated signal?
- Magnitude spectrum density of the modulated signal $|\Phi(\omega)|$ at $\omega=\omega_c-2\pi/T$?
- *Answers*: AM; 166.67 kHz; 18 W; 2 W; 1.5; $2\pi\times1.403\ \delta(\omega-\omega_c+2\pi/T)$;

$\rightarrow m = 1.5$

$m = \frac{-m_{min}(t)}{A}$

$A = \sqrt{2P_c} = 2$

$m = \frac{3}{2} = 1.5$

AM vs. DSB-SC

- Both require the same transmission bandwidth (equal to $2B$).
- DSB-SC allows for a more efficient *transmitter* (power savings).
- AM allows for a cheaper *receiver* (asynchronous demodulator), while DSB-SC only works with synchronous detection.

AM vs. QAM

- **Advantages of QAM:**
  - QAM is more bandwidth efficient than AM, allowing us to send two signals on the same channel (of bandwidth 2*B*).
  - QAM allows for more power efficiency at the transmitter.
- **Disadvantages of QAM:**
  - AM can be demodulated using cheap asynchronous demodulators, but QAM only works with synchronous detection (because of orthogonality).
  - There is *NO* such thing as QAM-LC.

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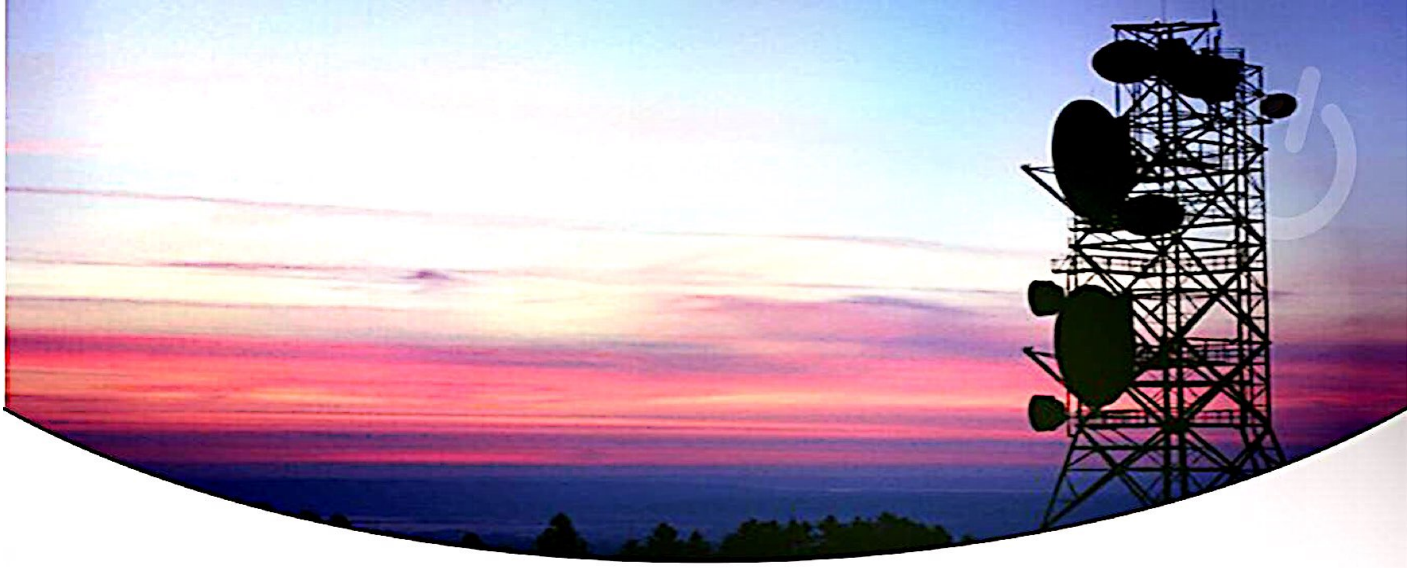
memorize: $\eta_{QAM} = 100\%$; No Useless power.



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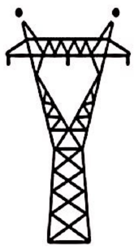

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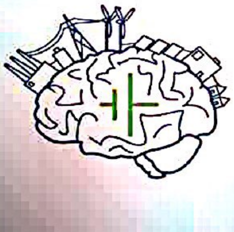
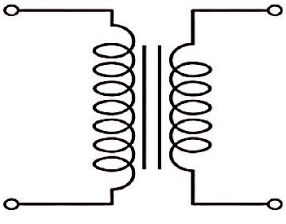
By: Mhmd Abuhashya





Lecture 11: AM Hardware

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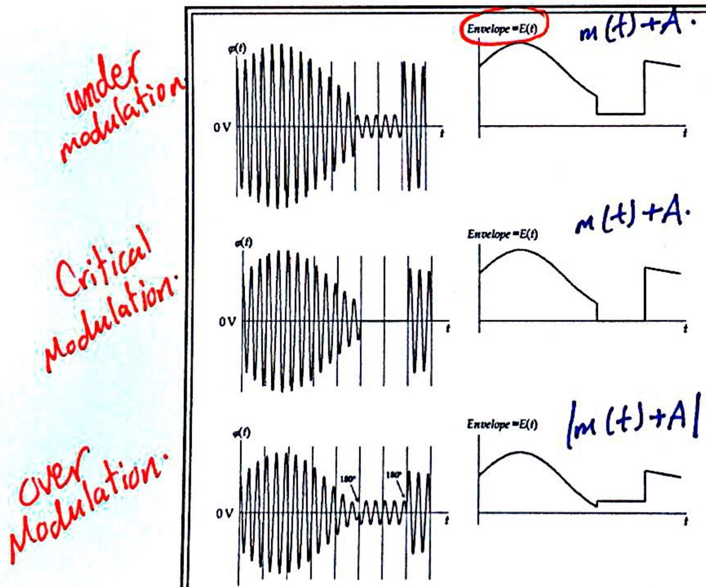
University of Jordan

EE421: Communications I. For more information read Chapter 4 in your textbook or visit http://wikipedia.org/.

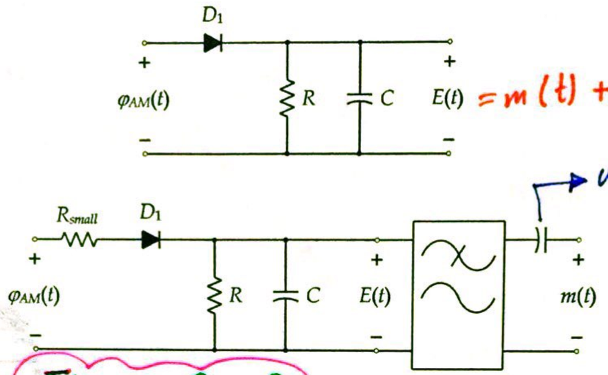


AM Demodulation

$m \leq 1$ (choice between: Synch. & Asynch.)

$m \geq 1$ (one choice: Synch.)

Design #A: Envelope Detector



Try for:

- ✓ Case1: under Mod.
- ✓ Case2: critical.
- ✗ Case3: over Mod.
  - $E(t) \neq m(t)+A$
  - $E(t) = |m(t)+A|$

$E(t) = m(t) + A$

Capacitor → used to Block the DC.

$\tau_{charge} = R_{small}C$

$\tau_{discharge} = RC$

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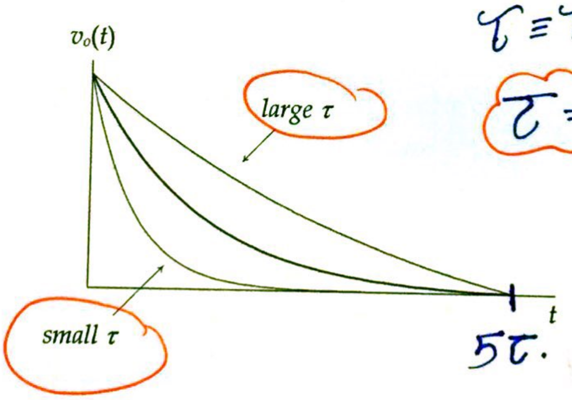
First-order RC circuit dischage



$\tau \equiv$ Time Constant.

$\tau = RC$

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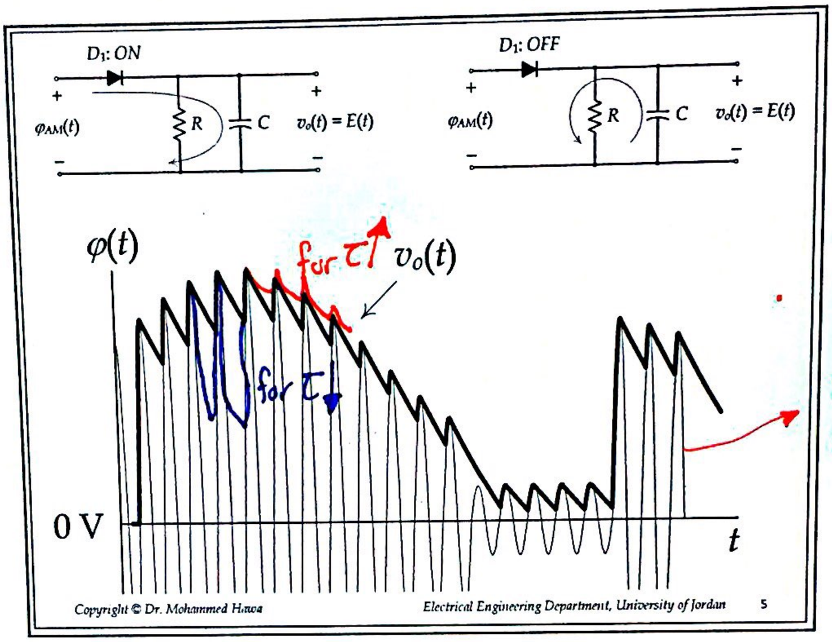
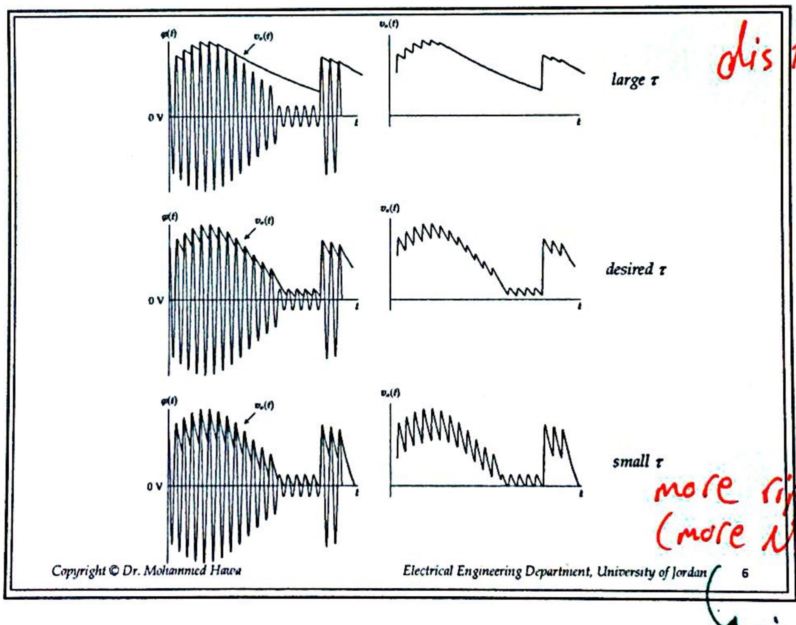


-ve → discharge
+ve → charge

This is AM under modulation.



distortion.

Need τ to be in between.

more ripple. (more Noise).

similar to extra noise.

$\tau_{small} \ll \tau \ll \tau_{big}$

"Extra Ripple" "Distortion"

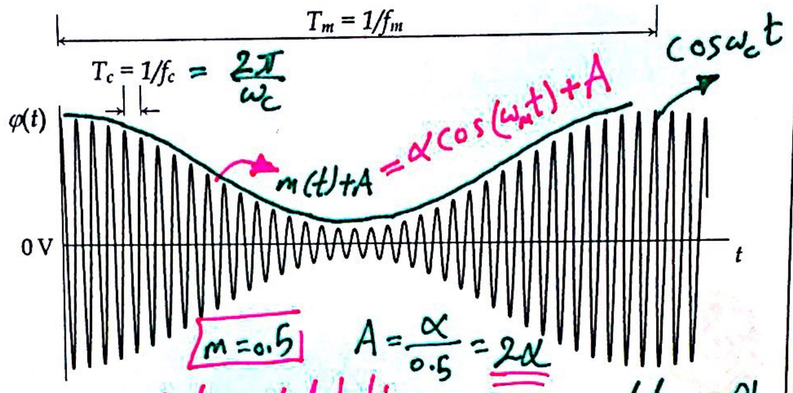
⇓

$T_c \ll \tau \ll T_m$

$\frac{1}{f_c} \ll \tau \ll \frac{1}{f_m}$ ⇐ for Tone Modulation.

⇒ $\frac{1}{f_c} \ll \tau \ll \frac{1}{B}$ for any general signal.

Choosing Time Constant τ



Under Modulation ⇒ No sudden Phase shift.

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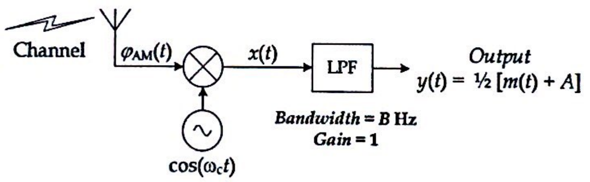
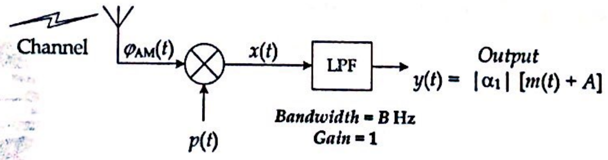
Design #B: Synchronous Detector (aka Product Detector)

HW:
Try synch. demodulator for:
a) under Mod.
b) Critical Mod.
c) over Mod.





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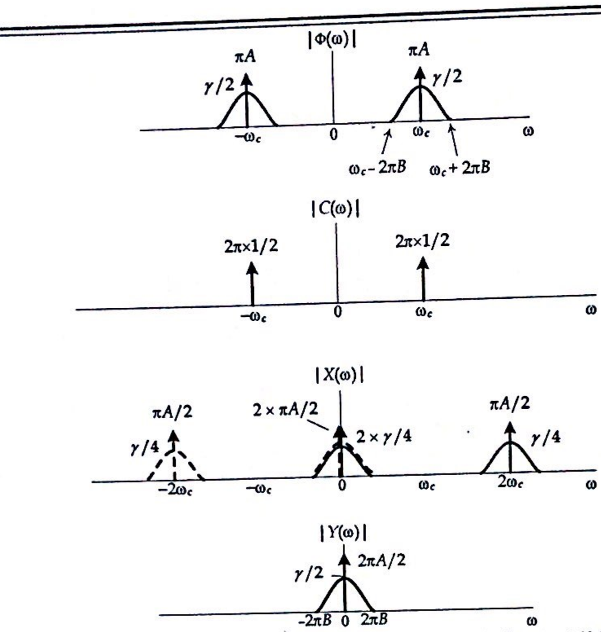

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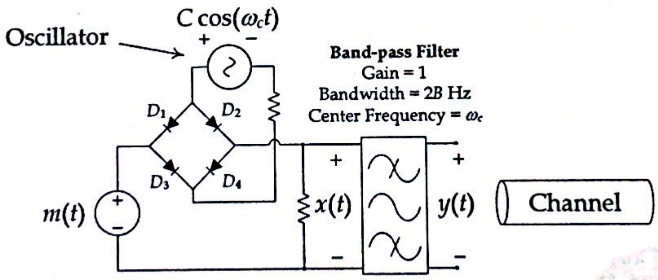
Remember:
series-bridge diode modulator



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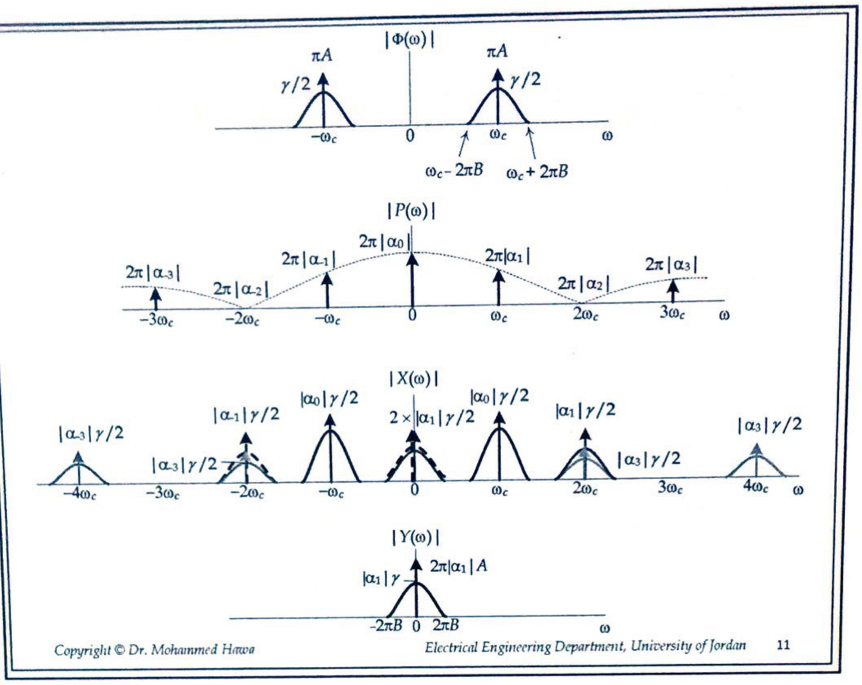
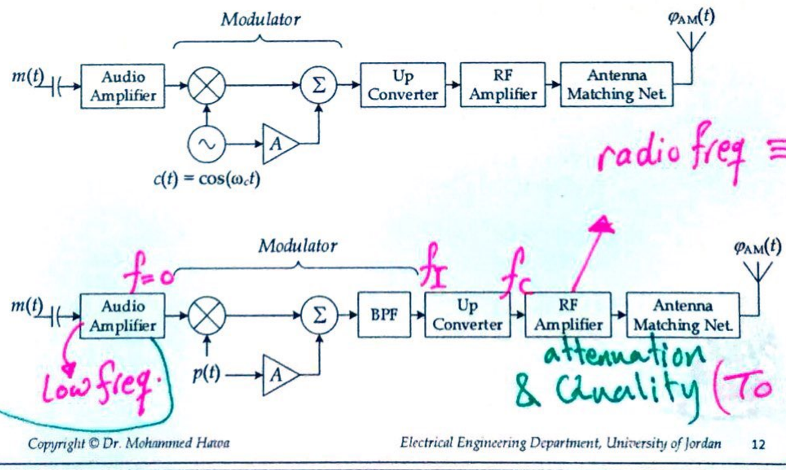
$\phi_{AM}(t) = m(t)\cos(\omega_c t) + A\cos(\omega_c t) = [m(t)+A]\cdot\cos(\omega_c t)$ x&+.

for Design A
$m(t)\cdot p(t) + Ap(t)$.

for Design B



AM Transmitters: Design #A



radio freq ≡ Means high freq.

f=0, f_I, f_c

Low freq.

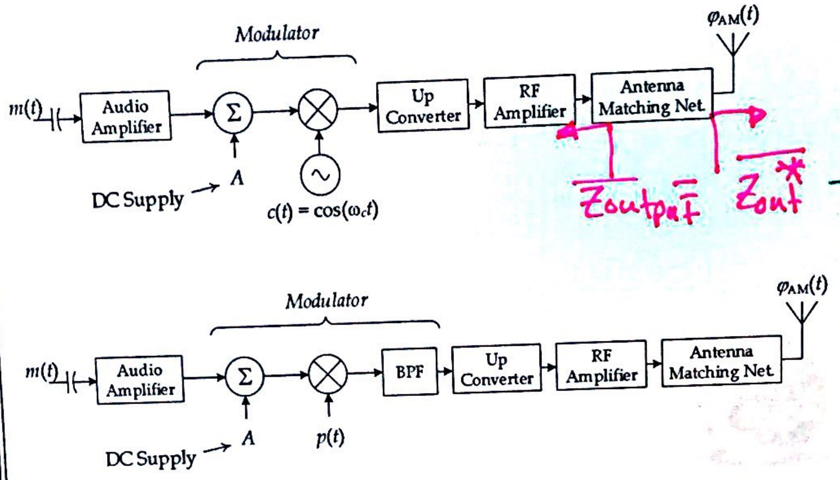
SNR, attenuation & drive electronics.

attenuation & Quality (To overcome Noise).

Amplifiers Classes:

- class A, class B } small gain (linear Behaviour).
- class C
- class D, class E } very high gain (Non-linear) Behaviour.

AM Transmitters: Design #B

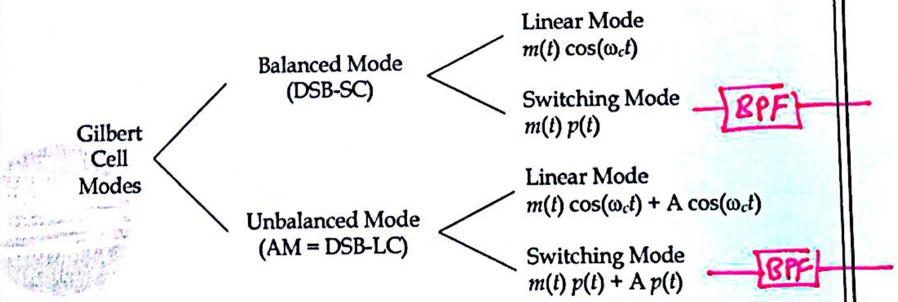


50Ω, 75Ω, 300Ω

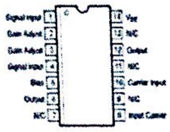
→ for Max. power transfer.

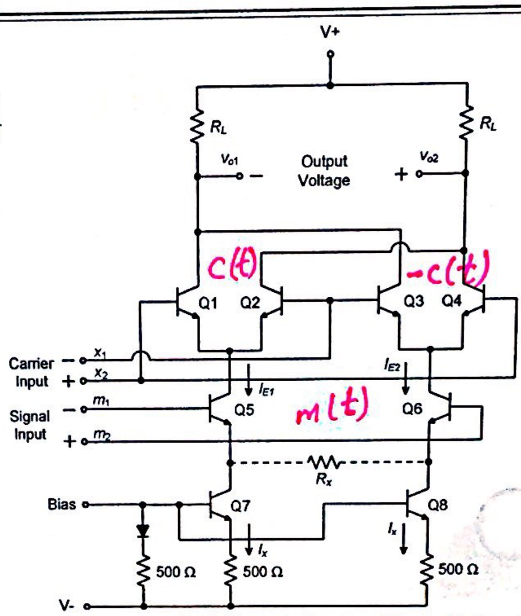
AM Transmitters: Design #C

- Use the Gilbert Cell (MC1496) in the unbalanced mode, in which the gain of the top two differential amplifiers is unbalanced, which adds a residual carrier in the output signal.



Gilbert Cell (MC1496) Schematic





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AM Signal-to-Noise Ratio

- An AM (DSB-LC) signal is sent though a channel with no attenuation. The channel is affected by AWGN noise. At the receiver side:
- Show the block diagram of the receiver. Use a product detector with capacitor in series. → synch & asynch gives the same results. (synch easier).
- Determine $SNR_{channel}$. $= -\infty$ dB.
- Determine SNR_{in}.
- Determine SNR_{out}.
- Determine NF for the demodulator.

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Solution

AM(DSB-LC)

$$SNR_{out} = \eta \frac{S_{in}}{N_0 B}$$

$\eta = 100\% = 1$ in DSB-SC

$$S_{in} = \frac{1}{2}\overline{m^2(t)} + \frac{A^2}{2}$$

$$NF = -10\log(2\eta)$$

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(DSB-SC)

$$SNR_{out} = \frac{S_{in}}{N_0 B}$$

$NF = -10\log 2 = -3dB.$