Lecture 1: Communication Blocks for Amplitude Modulation

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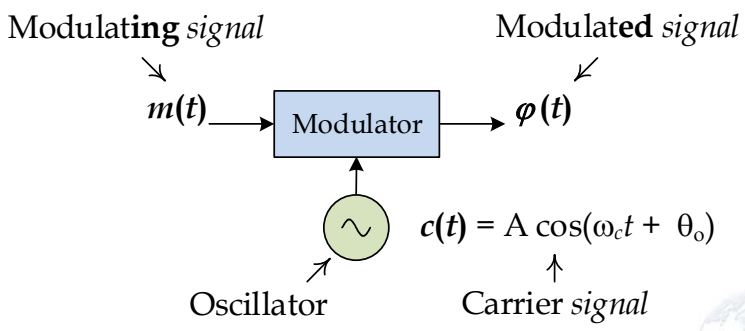
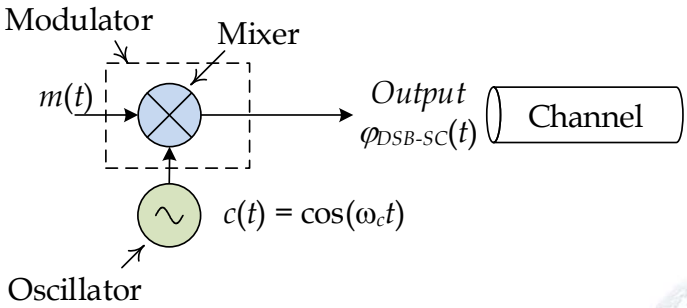
Notation

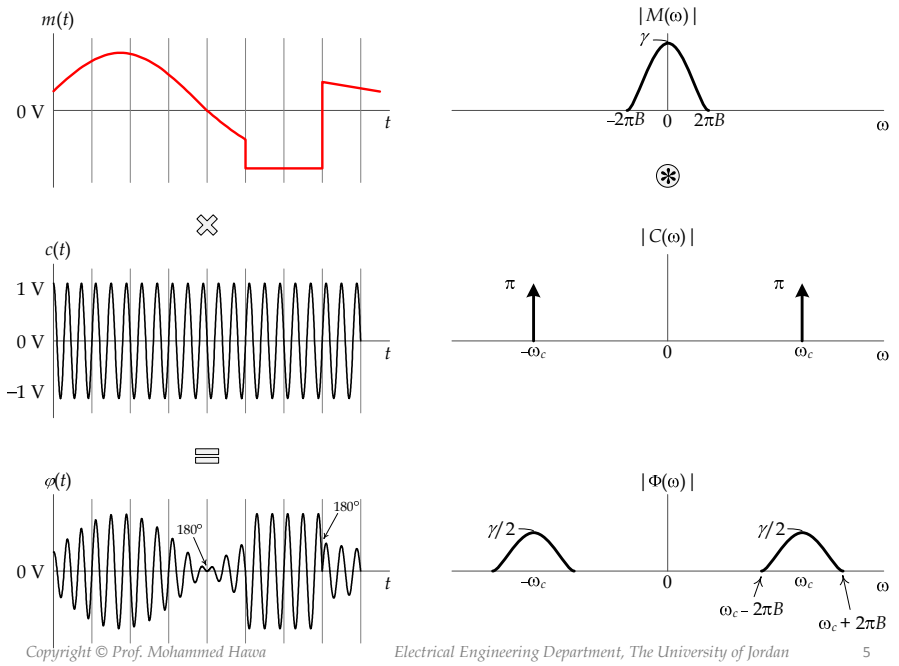


Three Modulation Types

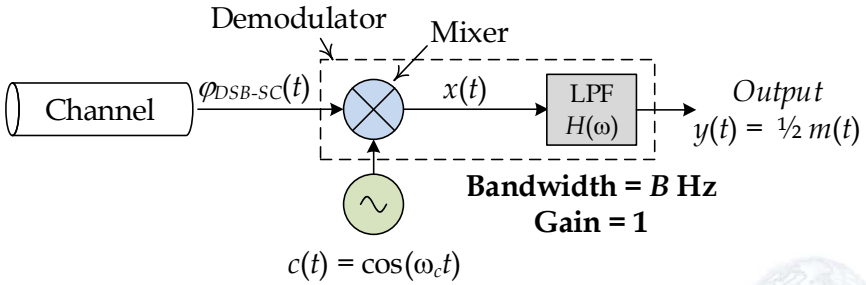
- $A \propto m(t)$; ω_c = *constant*; θ_o = *constant*
  - Amplitude Modulation (AM)
  - Amplitude Shift Keying (ASK)
- A = *constant*; $\omega_c \propto m(t)$; θ_o = *constant*
  - Frequency Modulation (FM)
  - Frequency Shift Keying (FSK)
- A = *constant*; ω_c = *constant*; $\theta_o \propto m(t)$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

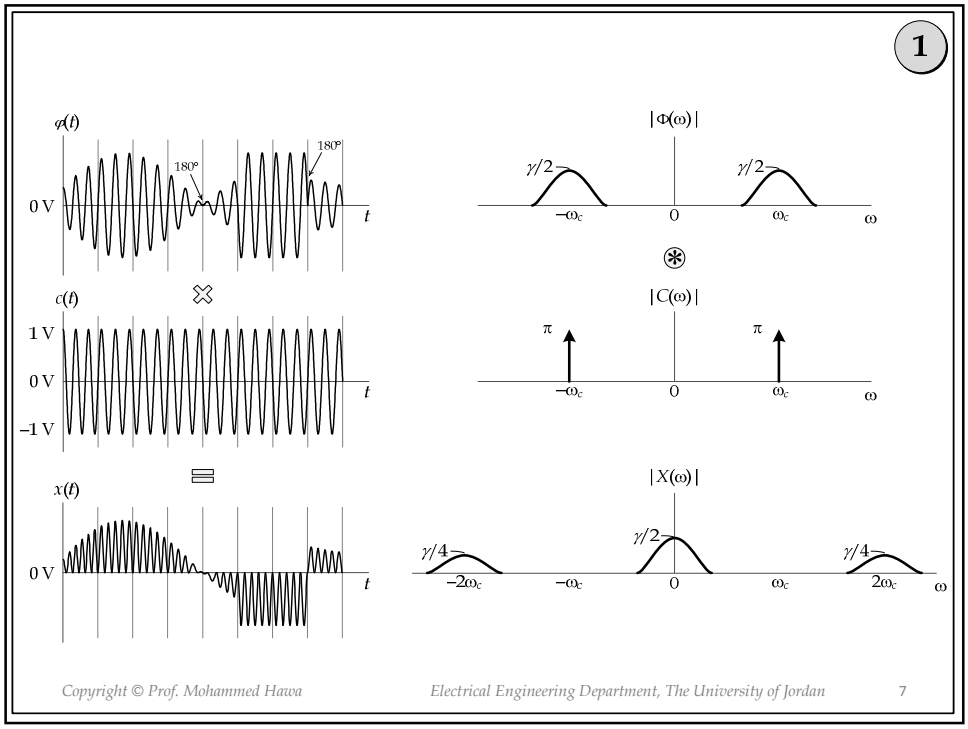
Double Sideband Suppressed Carrier (DSB-SC) Modulator





DSB-SC Demodulator




1
φ(t)
180°
180°
0 V
t
|Φ(ω)|
γ/2
γ/2
−ωc
0
ωc
ω
c(t)
1 V
0 V
−1 V
t
|C(ω)|
π
π
−ωc
0
ωc
ω
x(t)
0 V
t
|X(ω)|
γ/4
γ/2
γ/4
−2ωc
−ωc
0
ωc
2ωc
ω
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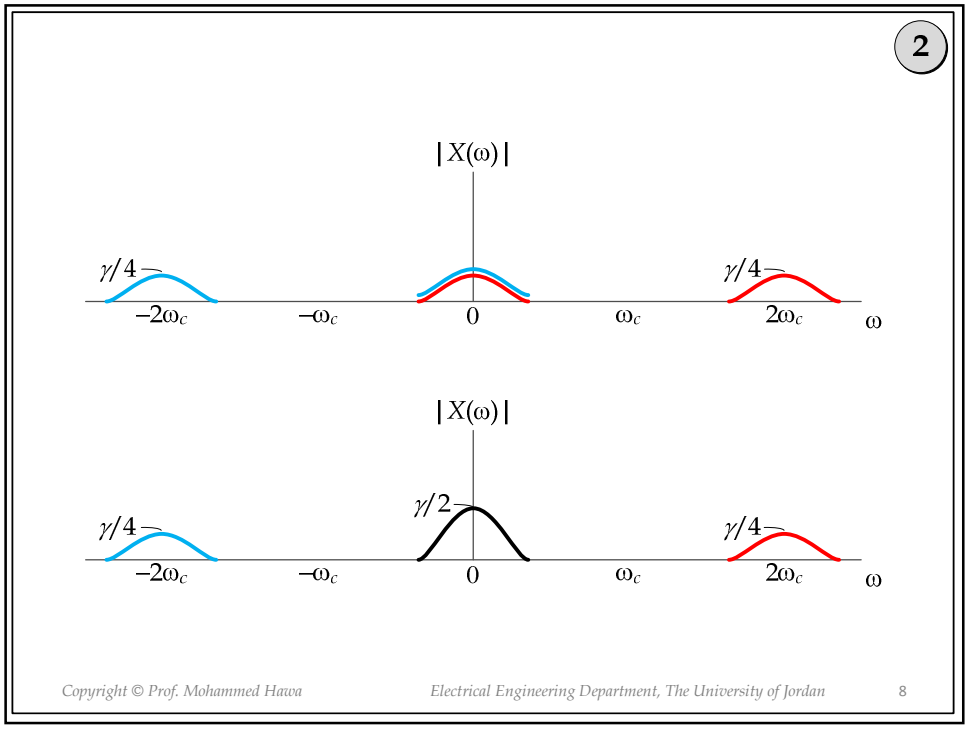
7


2
|X(ω)|
γ/4
γ/4
−2ωc
−ωc
0
ωc
2ωc
ω
|X(ω)|
γ/4
γ/2
γ/4
−2ωc
−ωc
0
ωc
2ωc
ω
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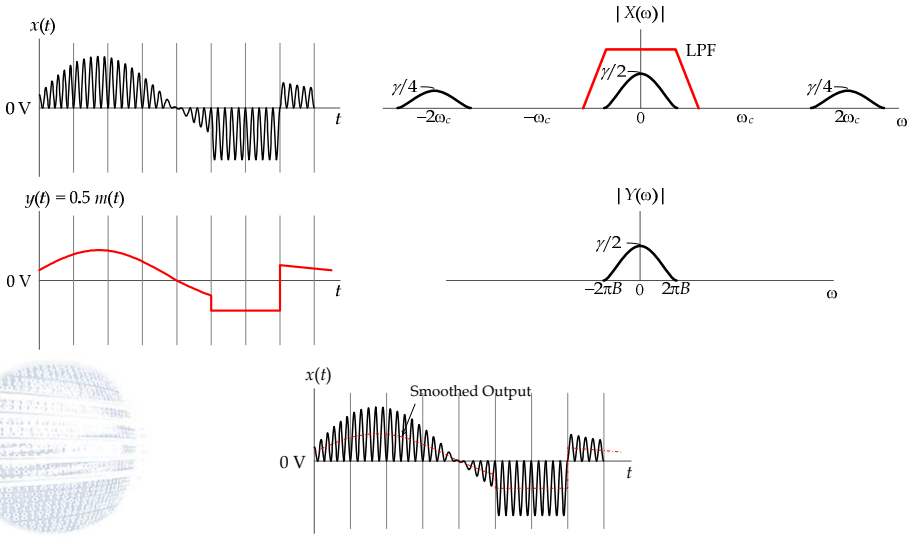
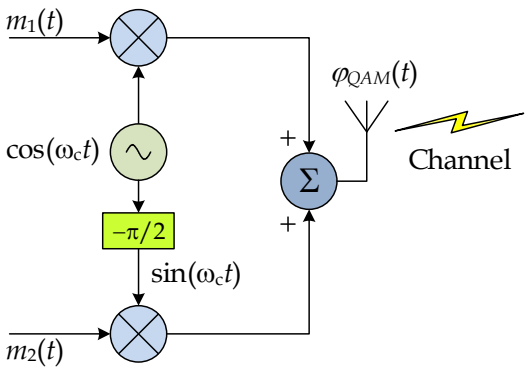
Final step: LPF

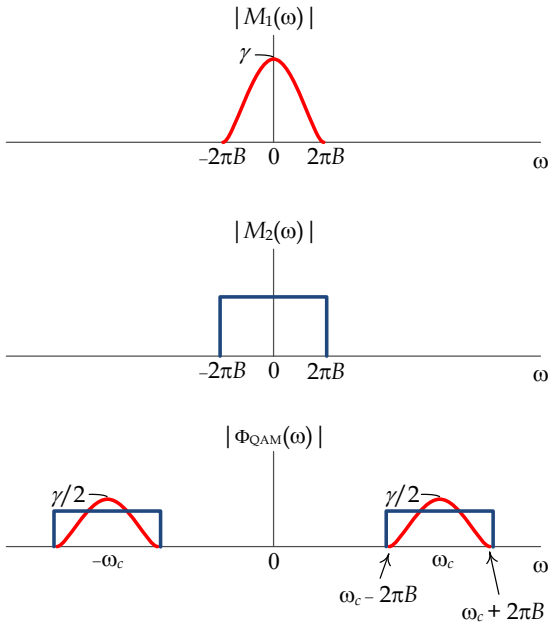
3



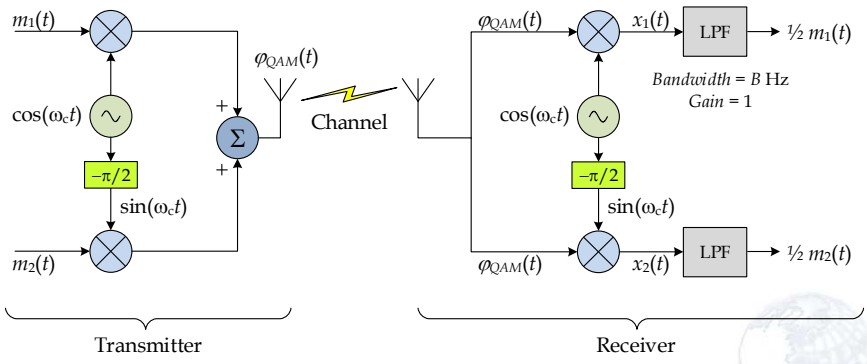
QAM (*Quadrature Amplitude Modulation*)



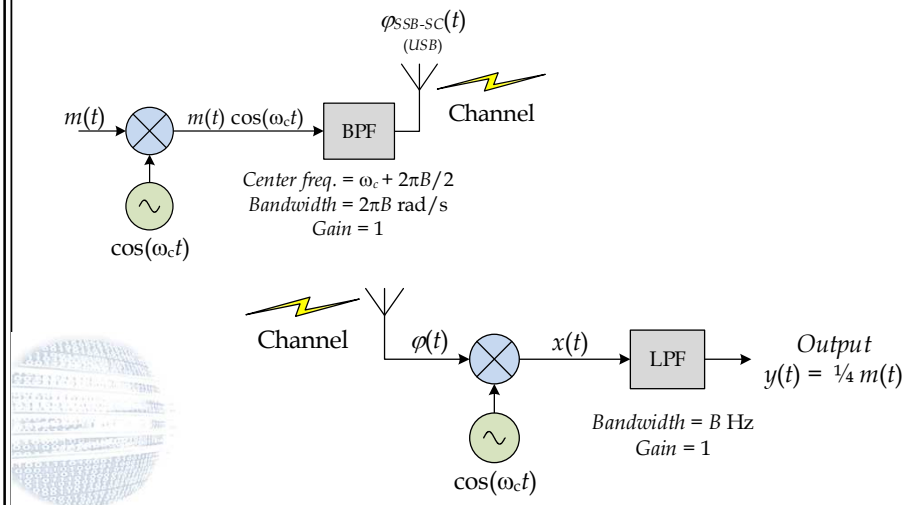
$$\phi_{QAM}(t) = m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)$$

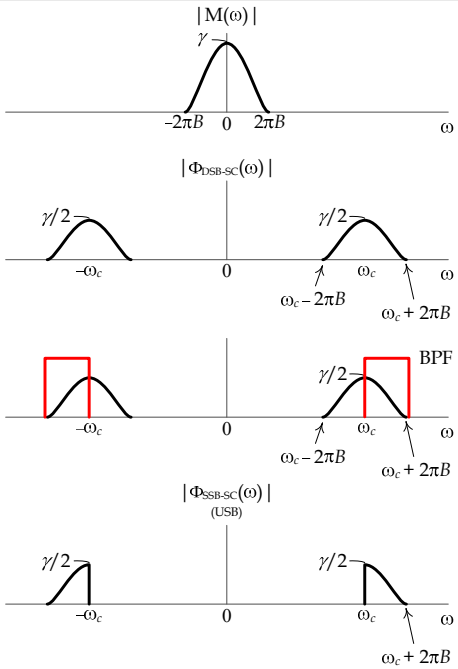


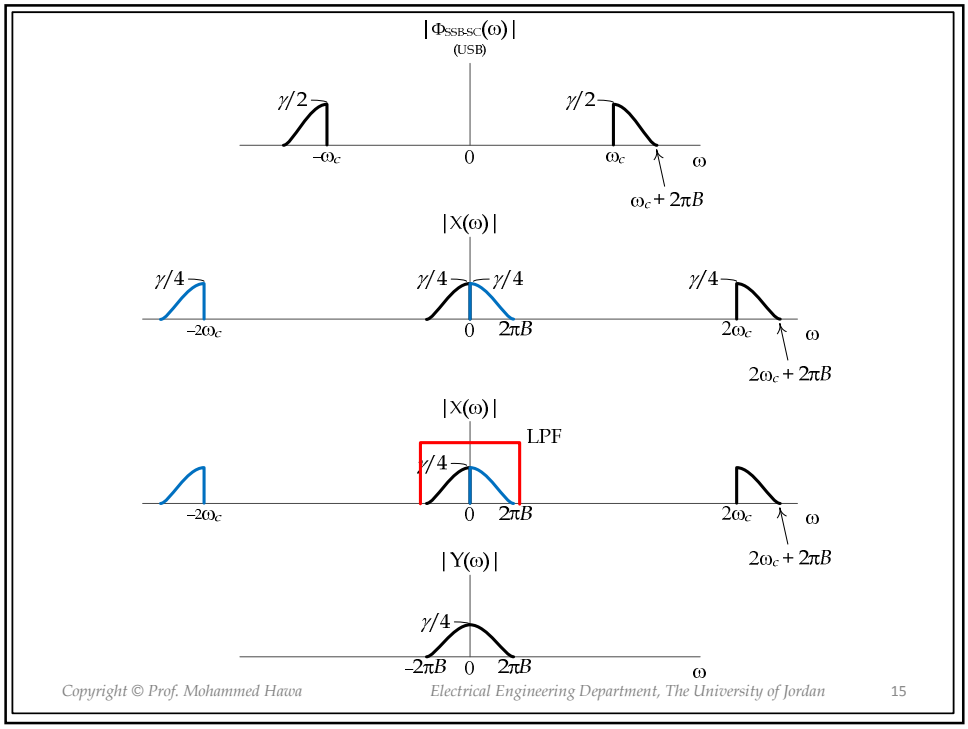
QAM Transmitter and Receiver



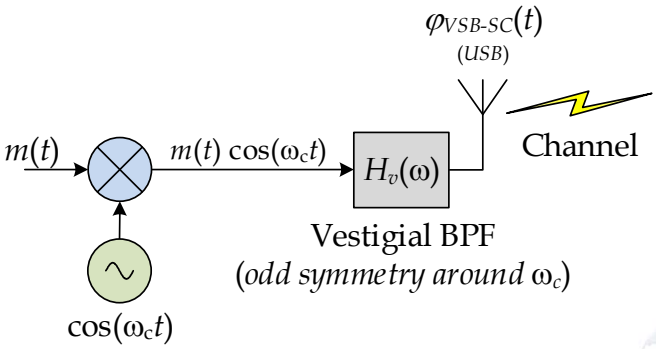
SSB-SC (USB) Modulation

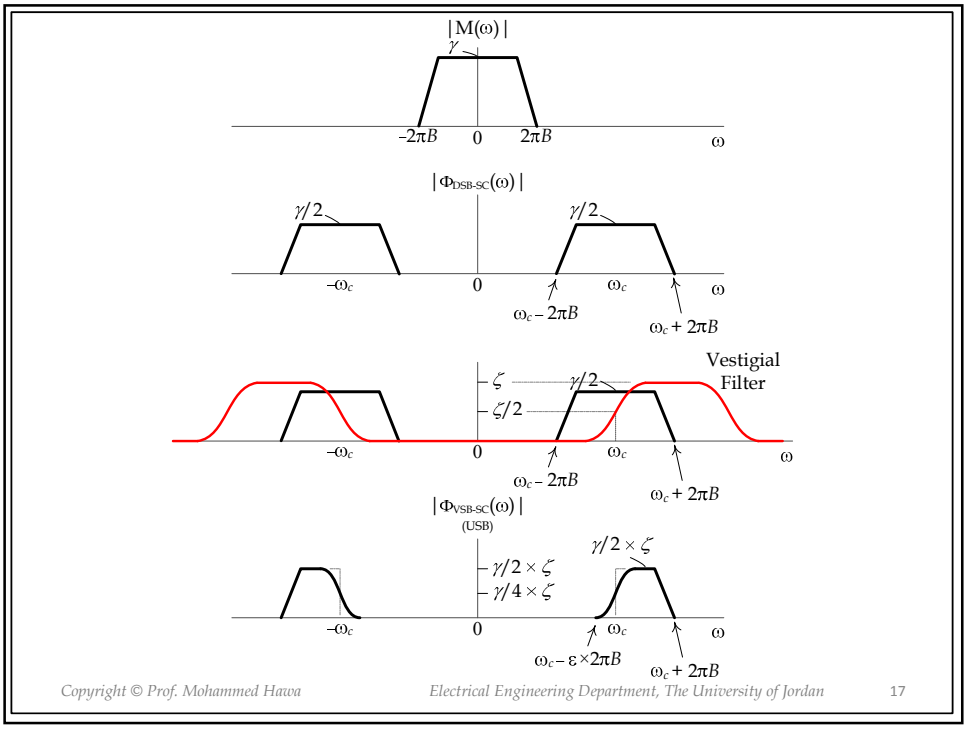




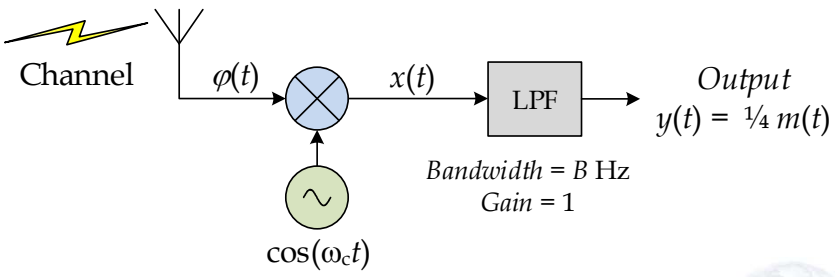


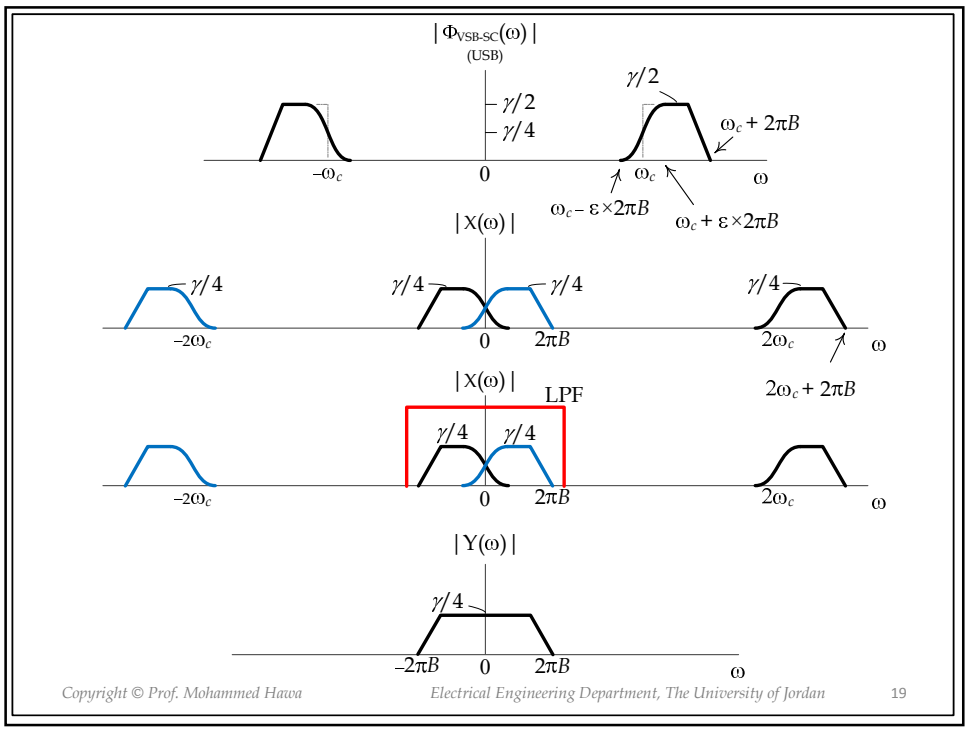
VSB-SC (USB) Transmitter



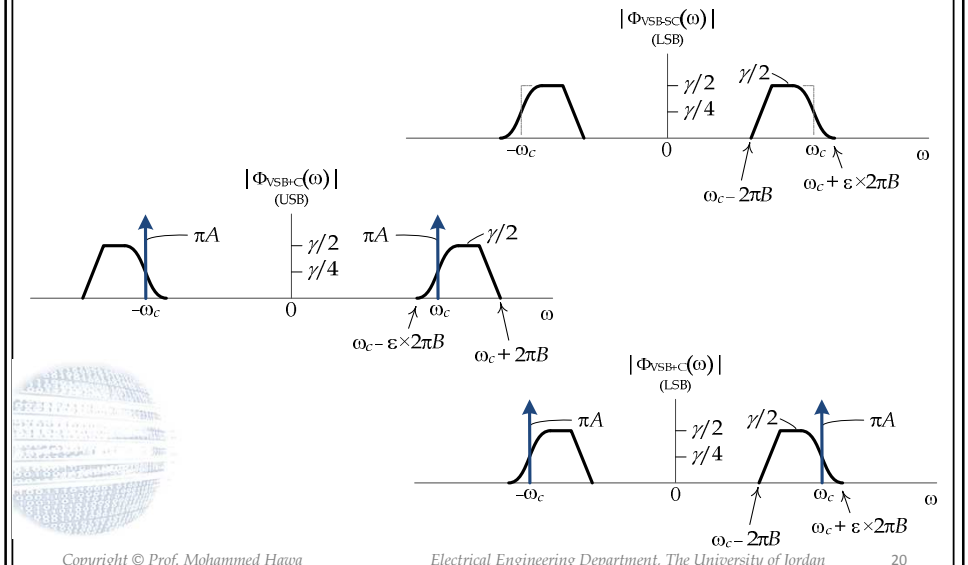


VSB-SC (USB) Receiver

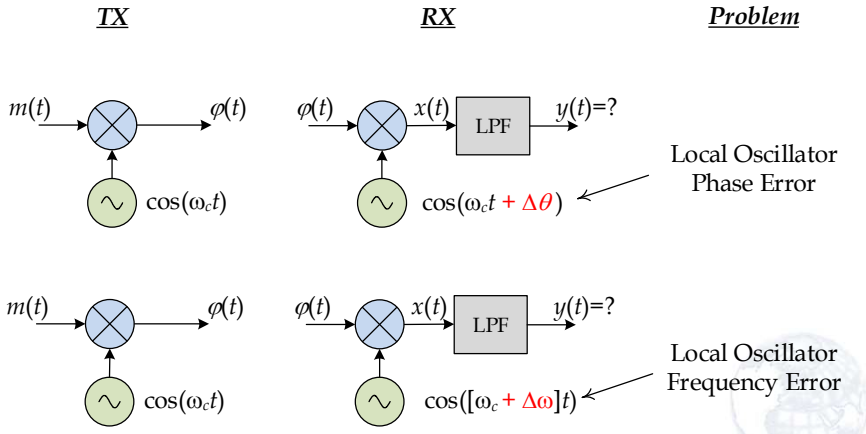




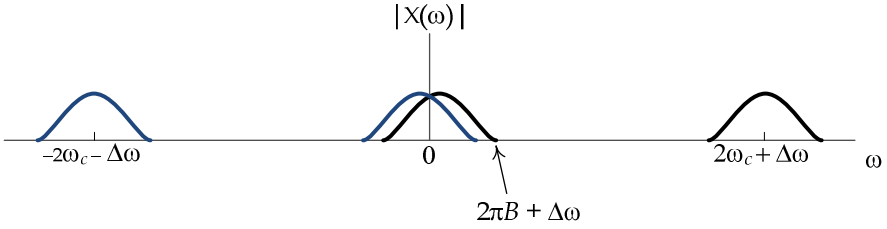
VSB-SC (LSB), VSB+C (USB), VSB+C (LSB)



Synchronizing Oscillator at the RX



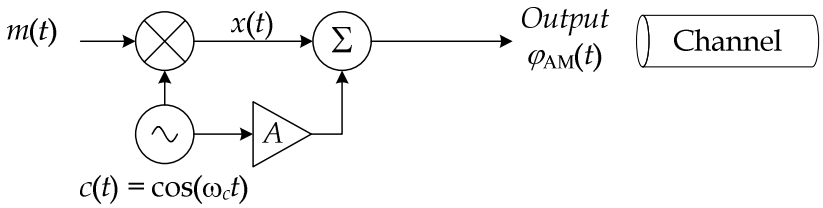
Frequency Error at the Receiver



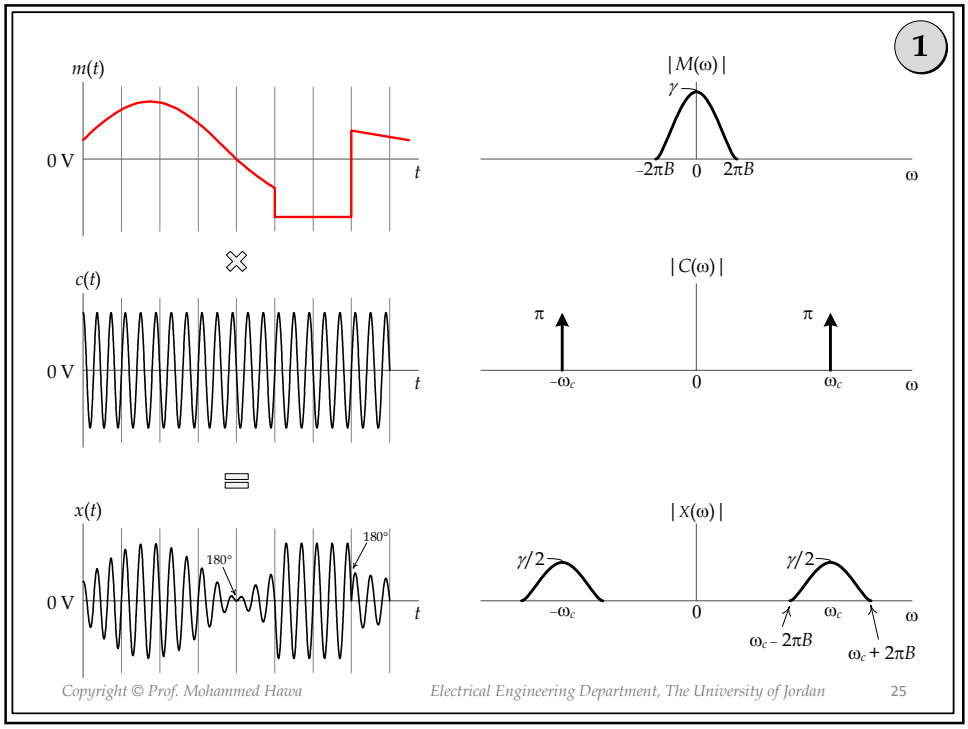
To avoid problems due to phase and frequency errors

- Solution **#1**: Use a PLL (Phase-Locked Loop) at the RX. A PLL can, by observing $\varphi(t)$, recover the exact frequency and phase of the carrier at the TX, and hence use these values at the RX. The PLL is called a **carrier-recovery circuit** (*complex* and *expensive*). The receiver in this case is known as a **synchronous** or **coherent** receiver.
- Solution **#2**: Do not generate a carrier at the RX. Rather, let the TX send an extra copy of the carrier (e.g., DSB-LC) to help the RX demodulate $\varphi(t)$. The RX is known as **asynchronous** or **incoherent** receiver (*cheaper*), but the TX is *power inefficient*.

Amplitude Modulation (Double Sideband Large Carrier, DSB-LC or AM)



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


1
m(t)
0 V
t
|M(ω)|
γ
−2πB
0
2πB
ω
c(t)
0 V
t
|C(ω)|
π
π
−ωc
0
ωc
ω
x(t)
0 V
180°
180°
t
|X(ω)|
γ/2
γ/2
−ωc
0
ωc
ω
ωc − 2πB
ωc + 2πB
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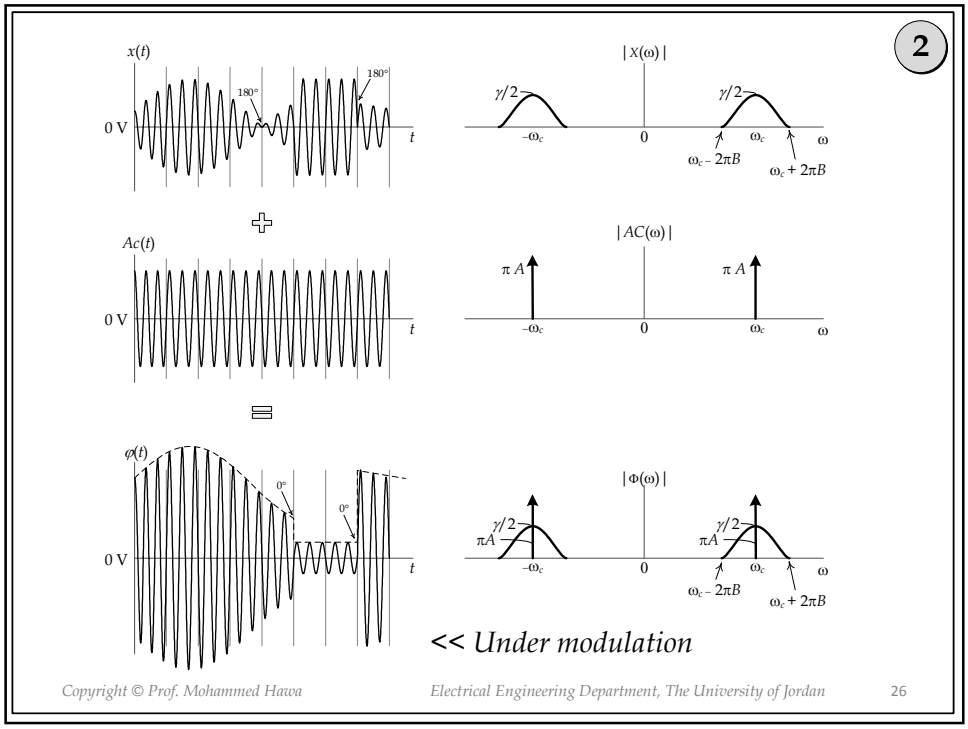
2
x(t)
0 V
180°
180°
t
|X(ω)|
γ/2
γ/2
−ωc
0
ωc
ω
ωc − 2πB
ωc + 2πB
Ac(t)
0 V
t
|AC(ω)|
π A
π A
−ωc
0
ωc
ω
φ(t)
0 V
0°
0°
t
|Φ(ω)|
γ/2
πA
γ/2
πA
−ωc
0
ωc
ω
ωc − 2πB
ωc + 2πB
<< Under modulation
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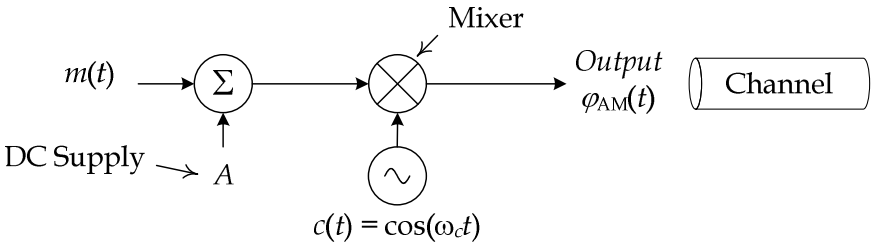
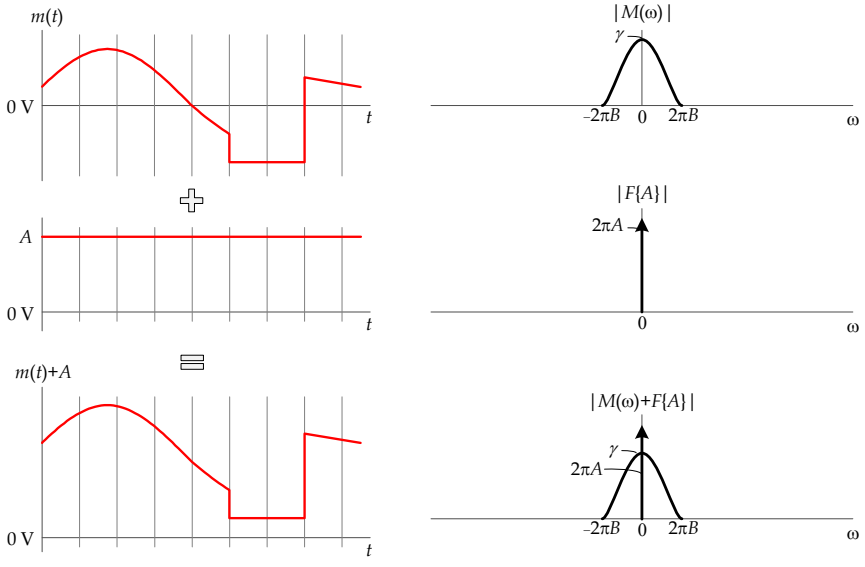
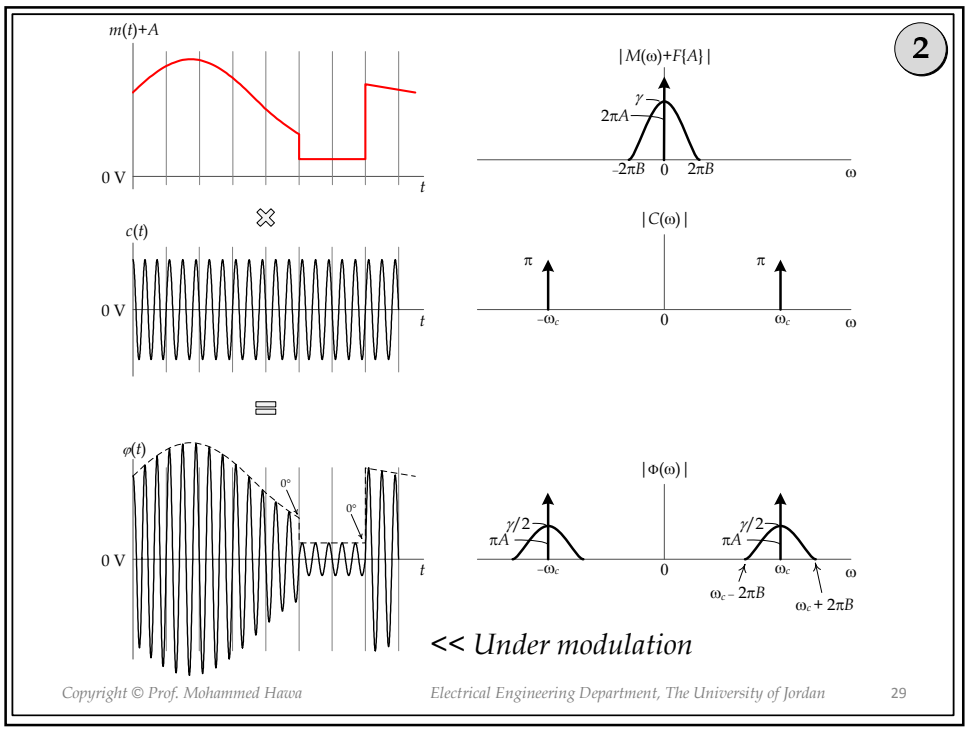
AM Modulator (*Method #2*)



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

1




2
m(t)+A
0 V
t
|M(ω)+F{A}|
γ
2πA
-2πB
0
2πB
ω
c(t)
|C(ω)|
π
π
-ωc
0
ωc
φ(t)
0°
0°
|Φ(ω)|
γ/2
πA
γ/2
πA
<< Under modulation
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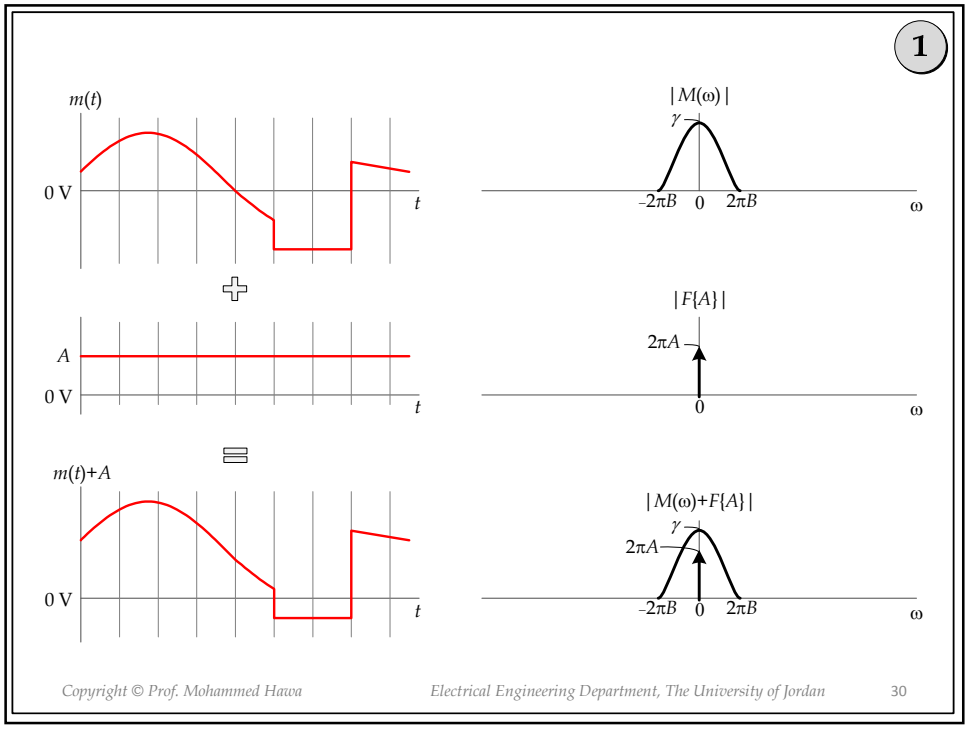
1
m(t)
0 V
t
|M(ω)|
γ
-2πB
0
2πB
ω
|F{A}|
A
2πA
m(t)+A
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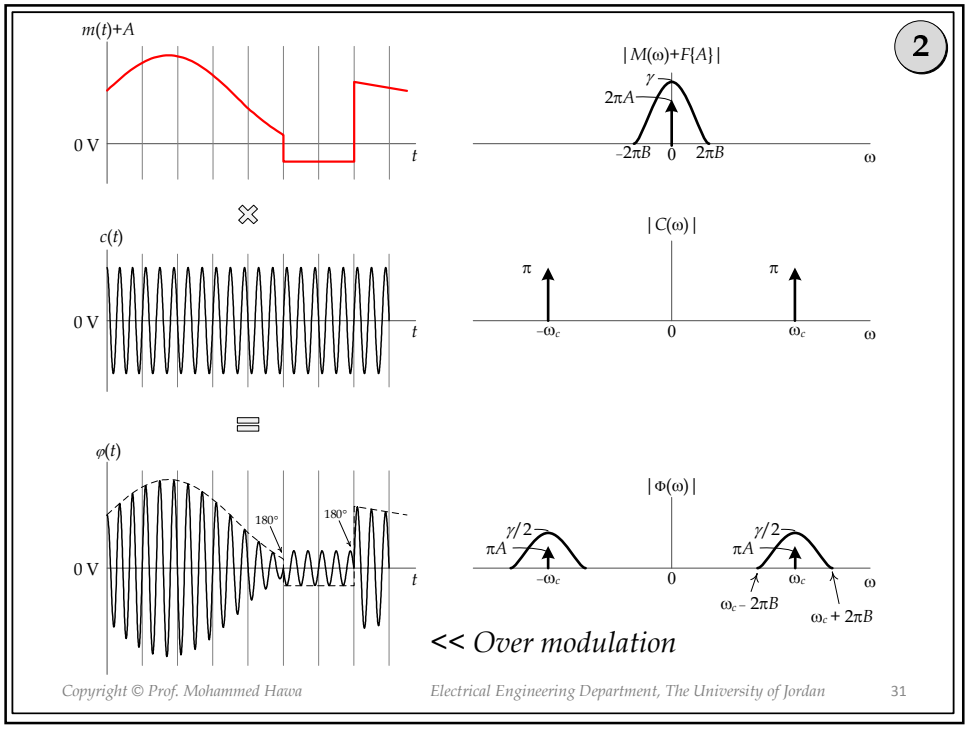
2
m(t)+A
0 V
t
|M(ω)+F{A}|
γ
2πA
–2πB
0
2πB
ω
c(t)
|C(ω)|
π
π
–ωc
0
ωc
φ(t)
180°
180°
|Φ(ω)|
γ/2
πA
γ/2
πA
ωc – 2πB
ωc + 2πB
<< Over modulation
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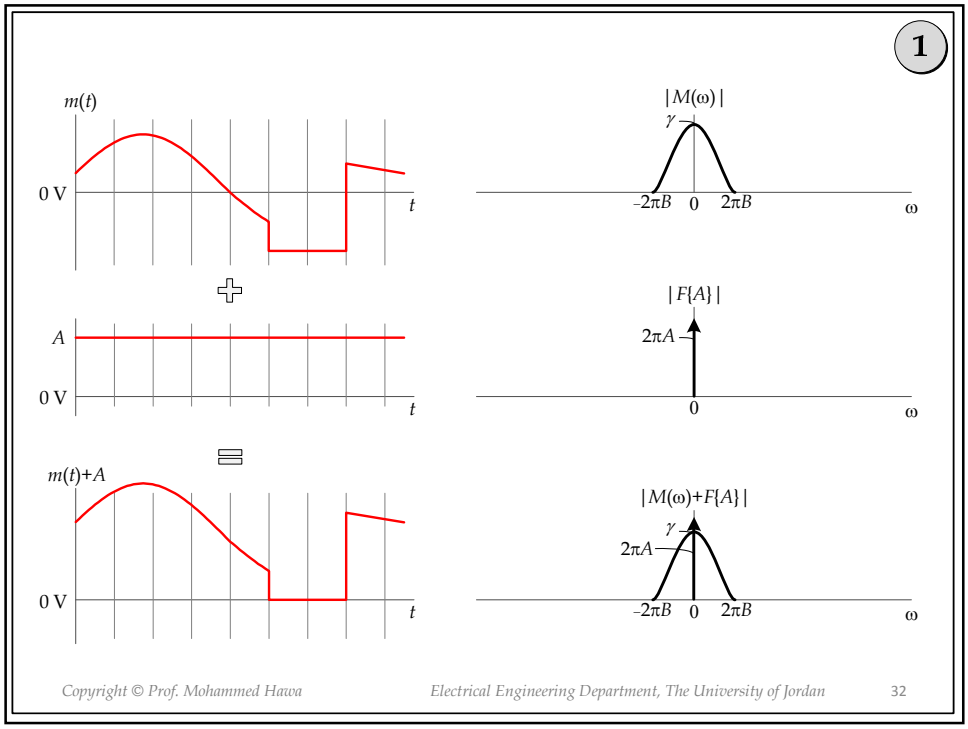
1
m(t)
0 V
t
|M(ω)|
γ
–2πB
0
2πB
ω
A
0 V
|F{A}|
2πA
m(t)+A
|M(ω)+F{A}|
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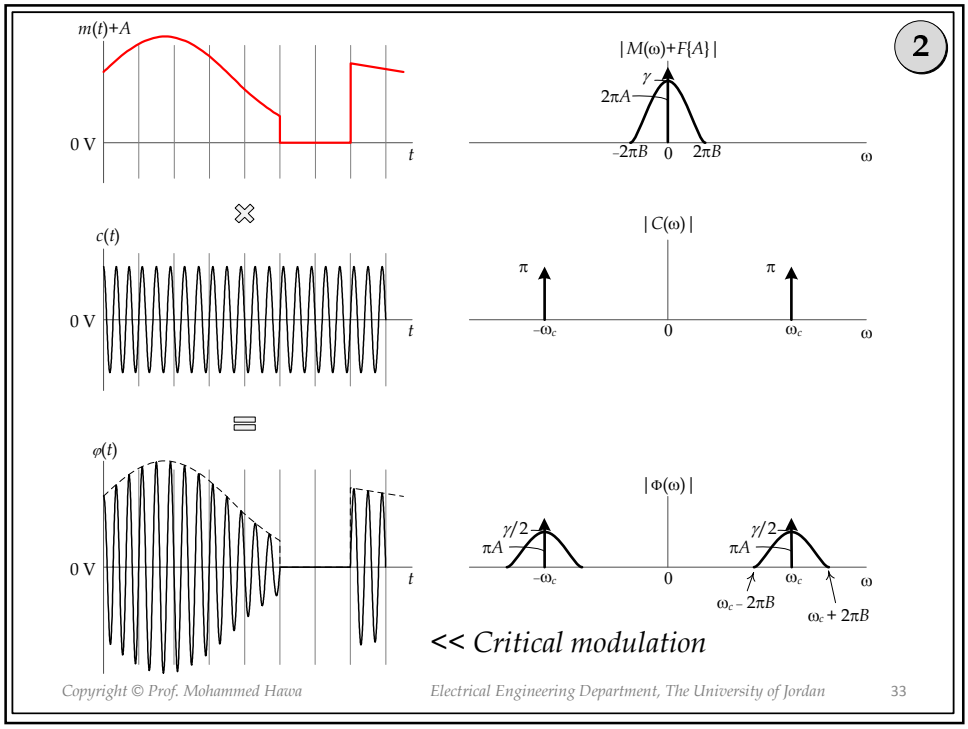


AM Modulation Index, m

More power needed from transmitter (Larger A)

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

$m < 1$

$m = 1$

Asynchronous (*incoherent*) receivers can demodulate (Very *simple* and very *inexpensive*)

$m > 1$

$m = \infty$

Only *synchronous* (*coherent*) receivers can demodulate. Such RX requires using a PLL (*Expensive*)

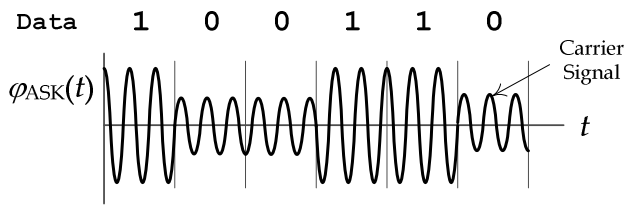
Digital Modulation

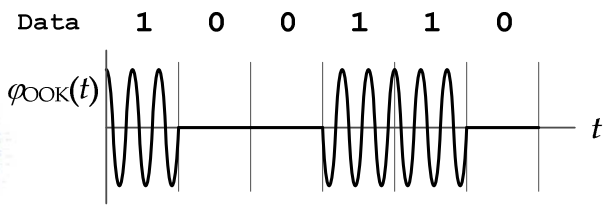
- *Four* main modulation techniques:
  - Amplitude-Shift Keying (**ASK**).
  - Frequency-Shift Keying (**FSK**).
  - Phase-Shift Keying (**PSK**).
  - Quadrature Amplitude Modulation (**QAM**).
- PSK and QAM are the most popular nowadays because of their *smaller* bandwidths.
- PSK and QAM require synchronous detection, which is easier nowadays (PLLs).

Analog vs. *Digital* Modulation

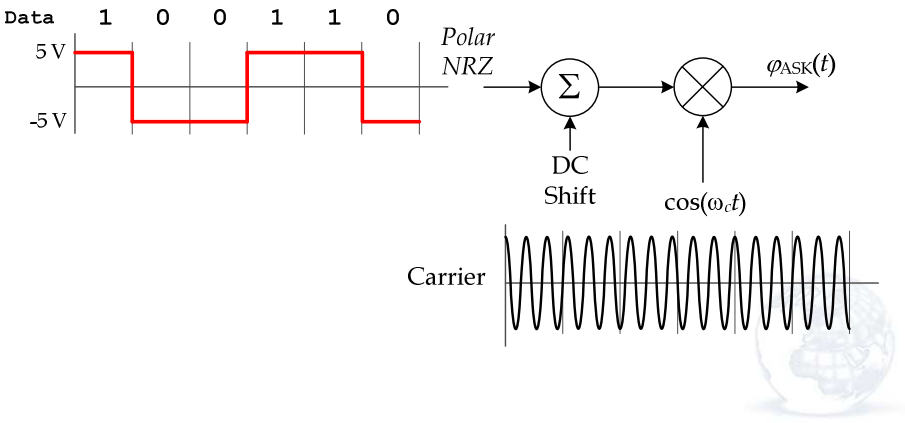
- $m(t)$ *is* Polar NRZ + AM = **ASK**
- $m(t)$ *is* Polar NRZ + FM = **FSK**
- $m(t)$ *is* Polar NRZ + PM = **BPSK**
- $m(t)$ *is* Q-ary NRZ + PM = **QPSK**
- $m(t)$ *is* M-ary NRZ + PM = **M-PSK**
- $m(t)$ *is* M-ary NRZ + QAM = **QAM**
- $m(t)$ *is* M-ary NRZ + AM = **M-ASK**

ASK and OOK

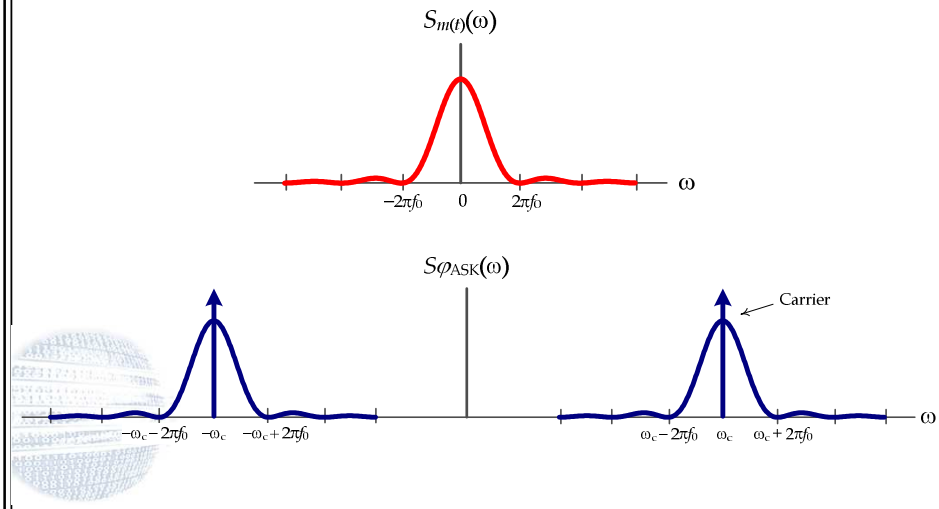




ASK *is* AM

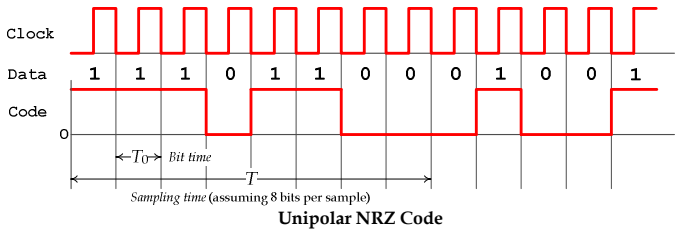


PSD of an ASK Signal

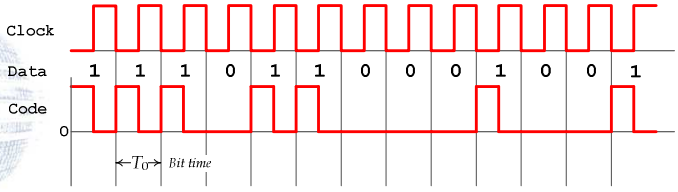


Unipolar NRZ and Unipolar RZ

Uses a positive rectangular pulse p(t) to represent binary 1, and the absence of a pulse (i.e., zero voltage) to represent a binary 0.

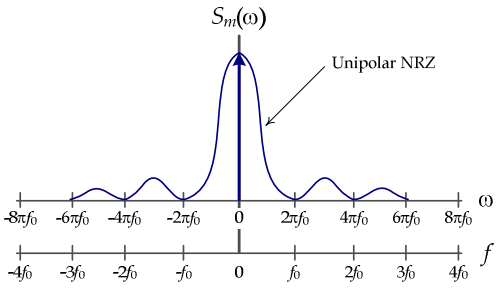


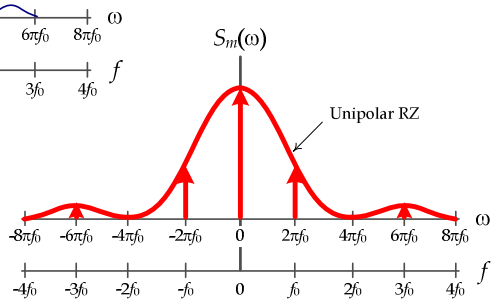
Unipolar NRZ Code



Unipolar RZ Code

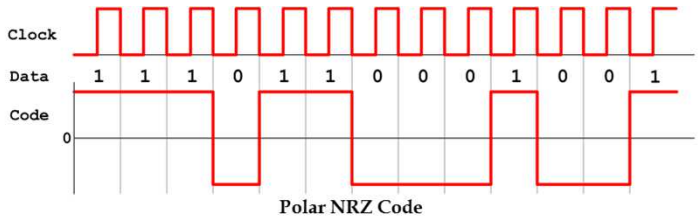
Unipolar PSD



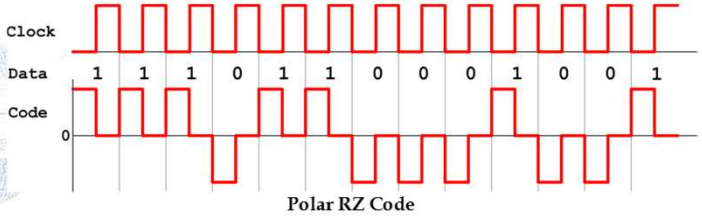


Polar NRZ and Polar RZ

Binary 1's are represented by a pulse p(t) and binary 0's are represented by the negative of this pulse -p(t).

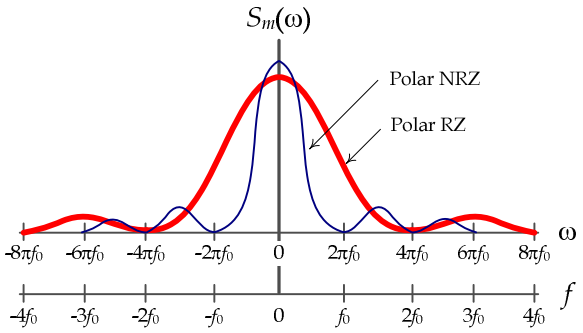


Polar NRZ Code

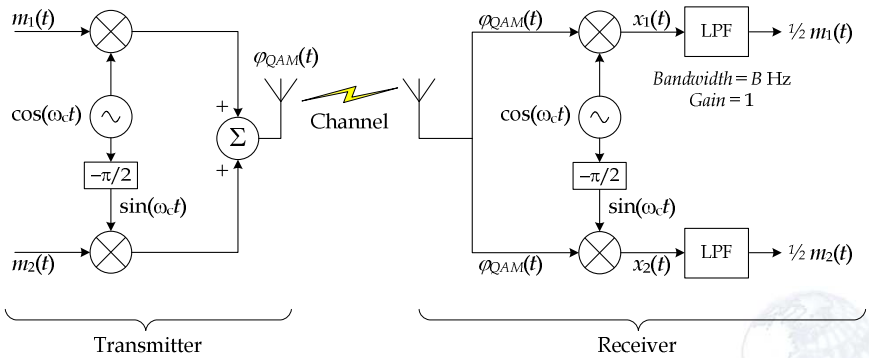


Polar RZ Code

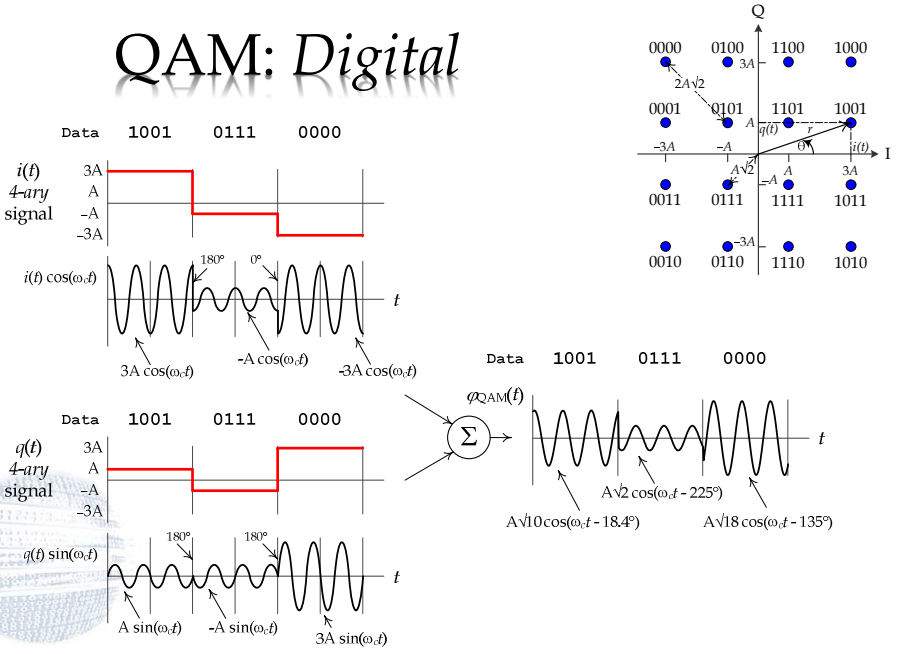
Polar PSD



QAM: *Analog*



QAM: *Digital*



Many QAM Constellations