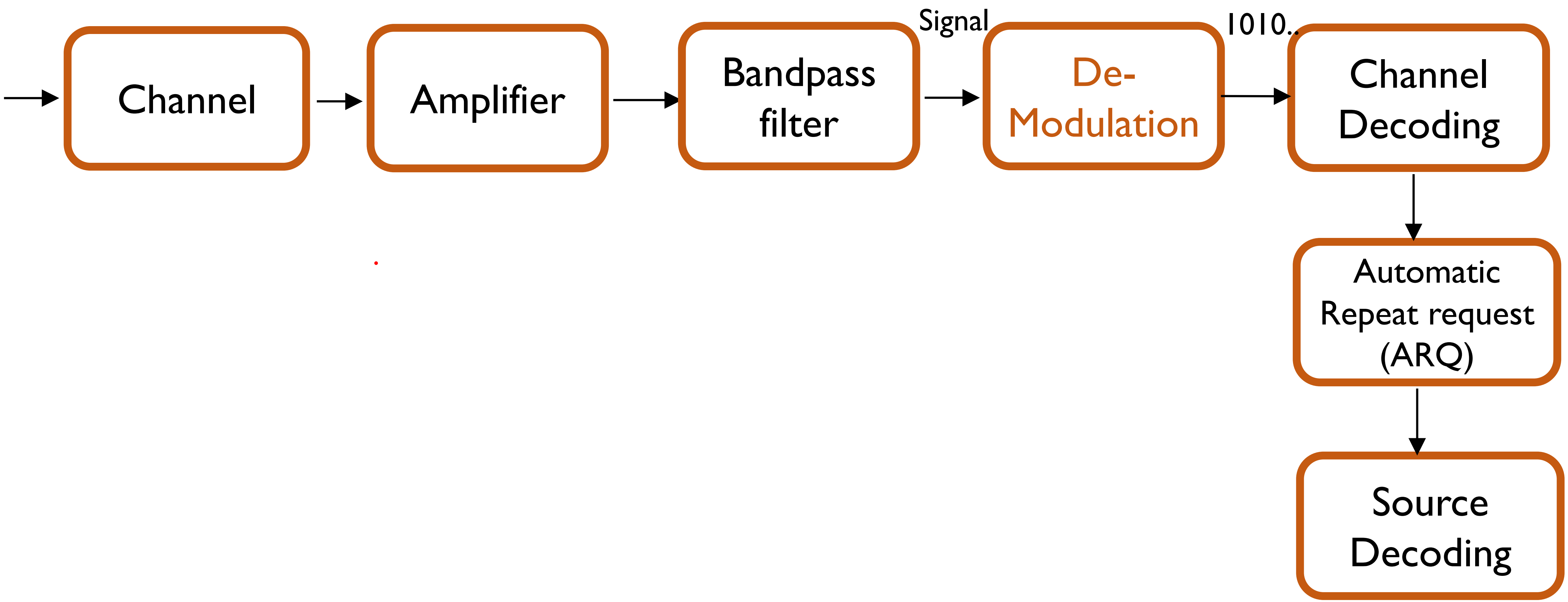
Lecture 03-10: Physical Layer
QAM

CS 356R

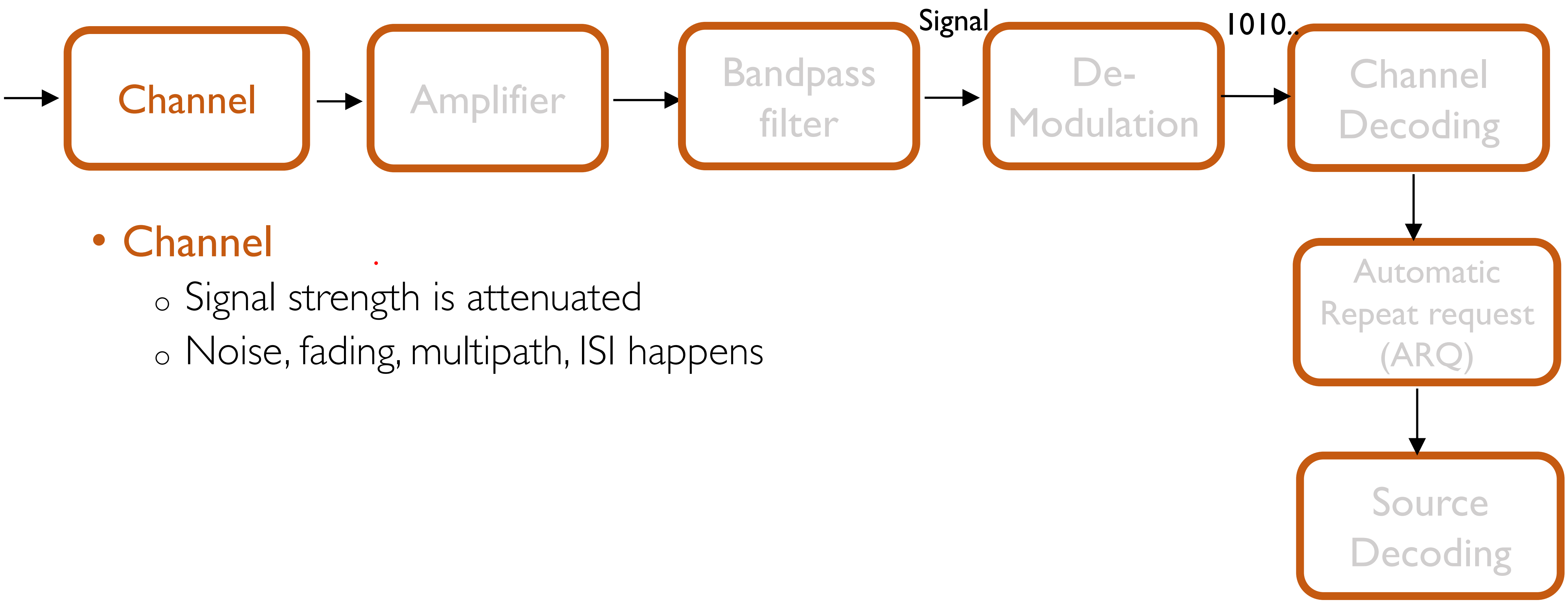
Intro to Wireless Networks

Mikyung Han

Receiver side story

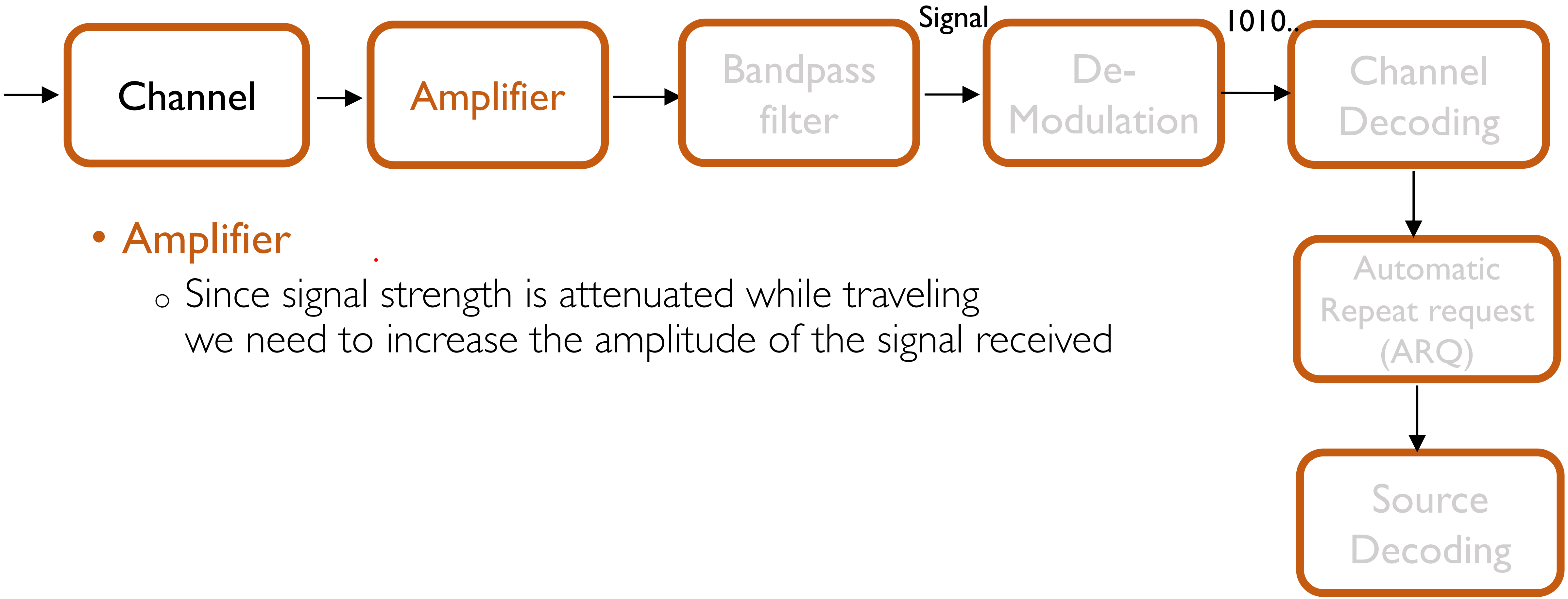


Receiver side story



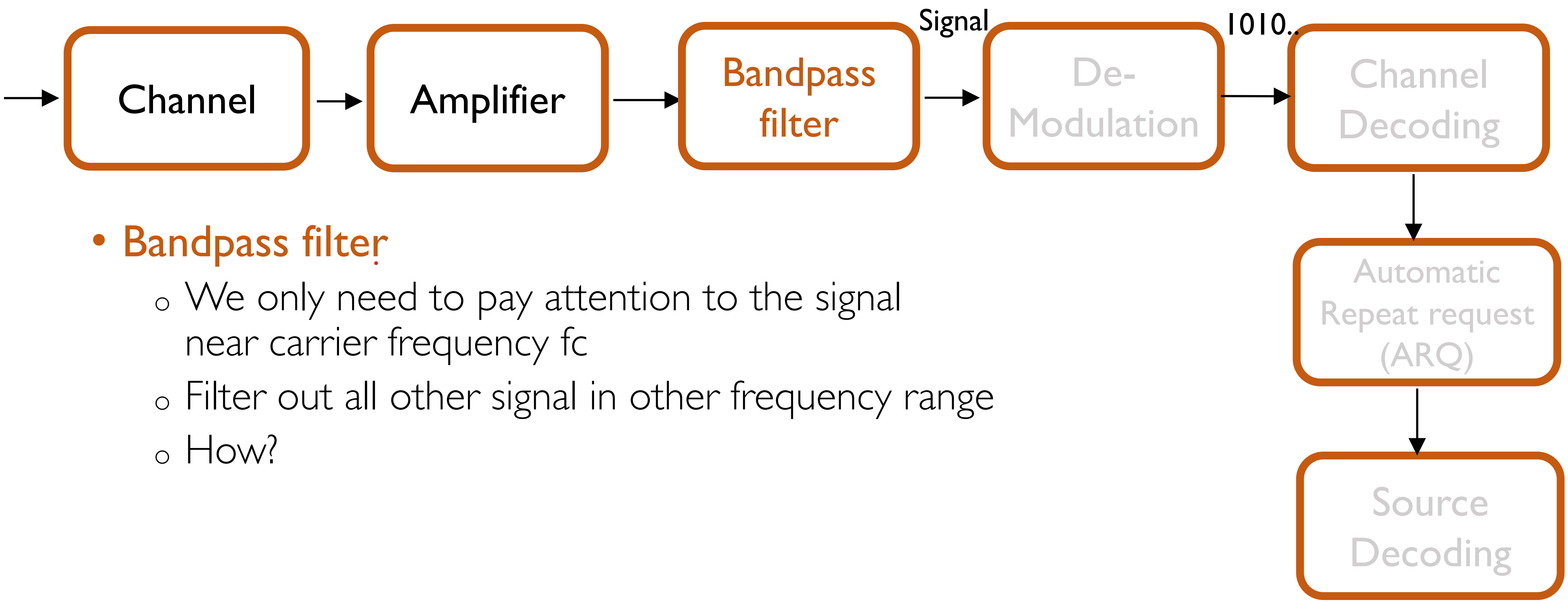
- Channel
  - Signal strength is attenuated
  - Noise, fading, multipath, ISI happens

Receiver side story



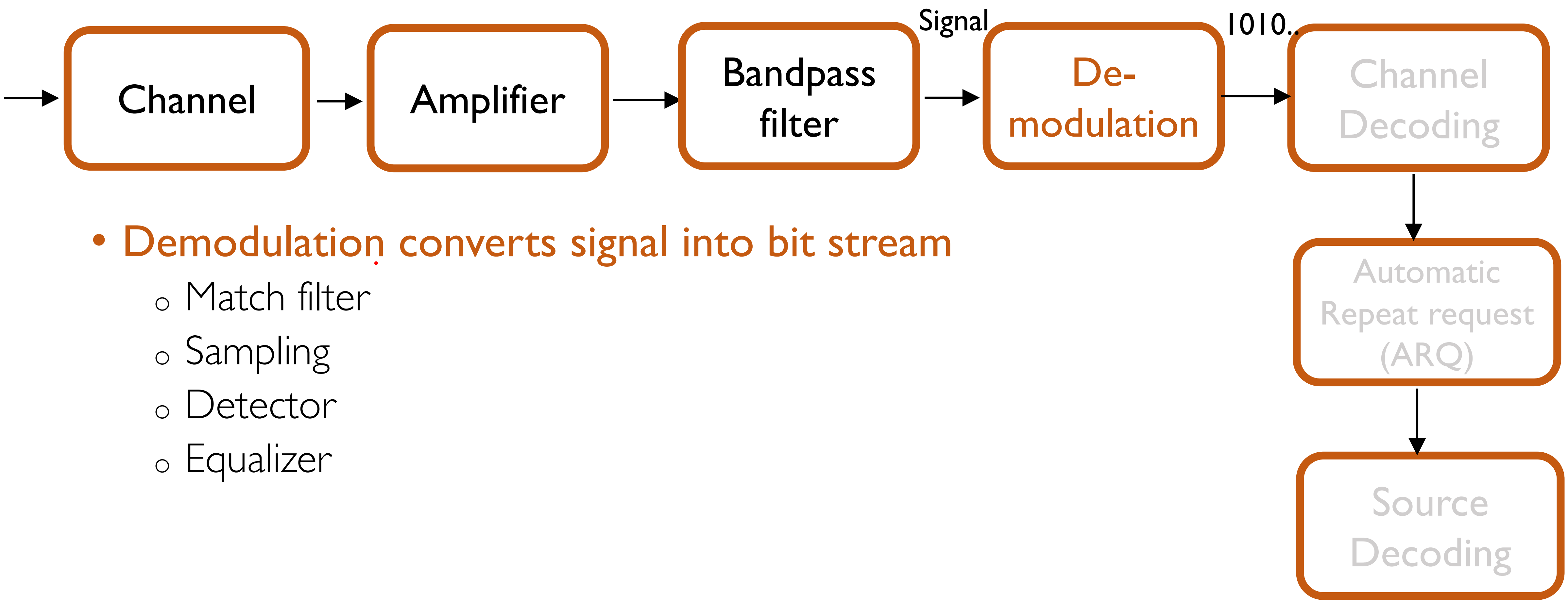
- Amplifier
  - Since signal strength is attenuated while traveling we need to increase the amplitude of the signal received

Receiver side story



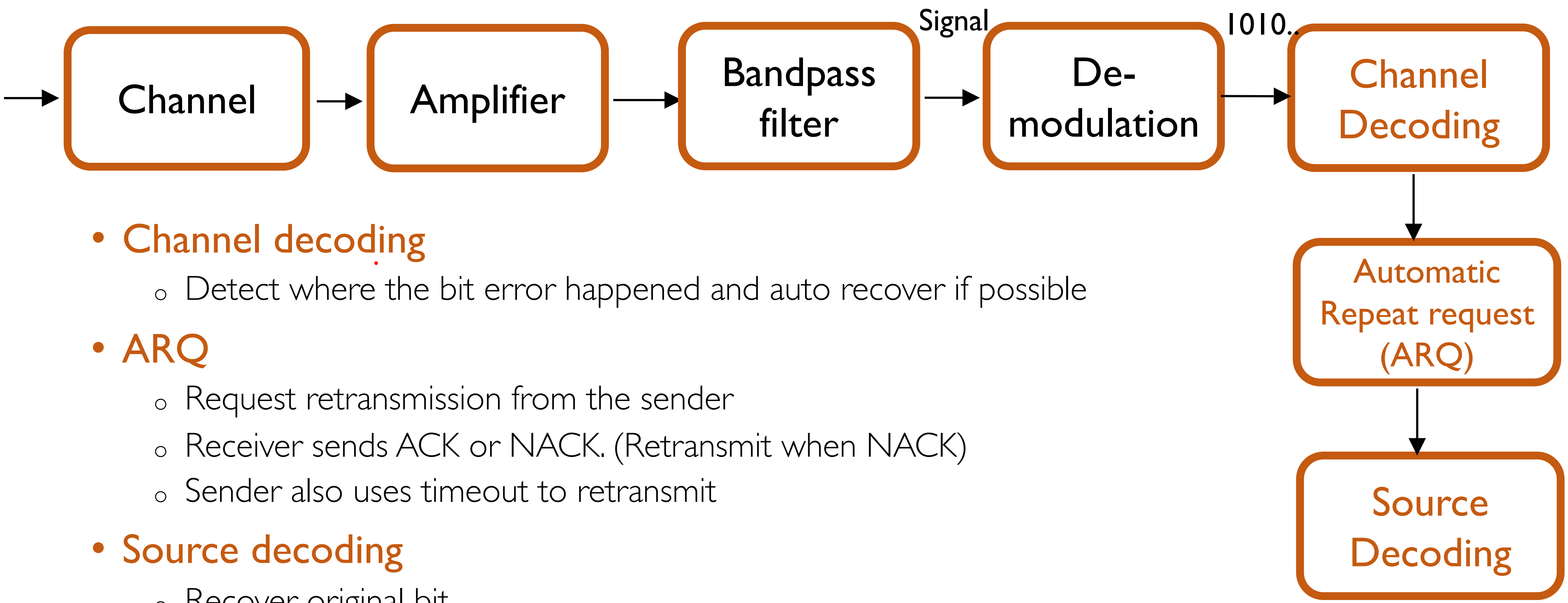
- Bandpass filter
  - We only need to pay attention to the signal near carrier frequency fc
  - Filter out all other signal in other frequency range
  - How?

Receiver side story



- Demodulation converts signal into bit stream
  - Match filter
  - Sampling
  - Detector
  - Equalizer

Receiver side story



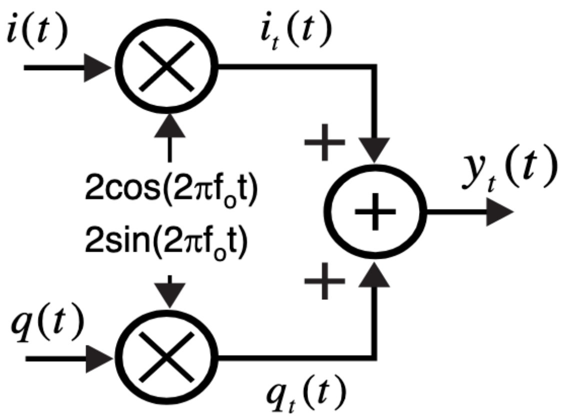
- Channel decoding
  - Detect where the bit error happened and auto recover if possible
- ARQ
  - Request retransmission from the sender
  - Receiver sends ACK or NACK. (Retransmit when NACK)
  - Sender also uses timeout to retransmit
- Source decoding
  - Recover original bit
  - Ex) 0 1101 → 0000000000000 (recover 13 0's)

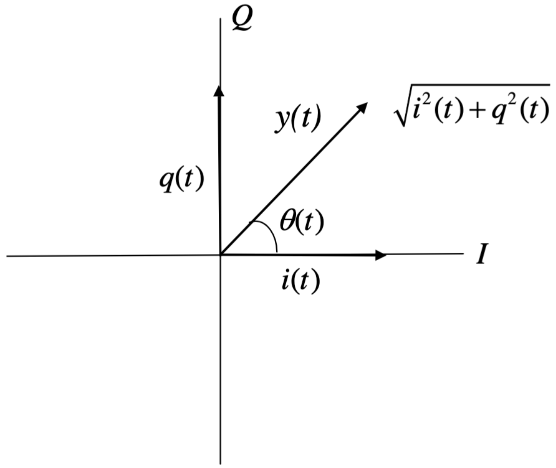
Outline

1. Receiver side story
2. Quadrature Amplitude Modulation (QAM)

Quadrature Amplitude Modulation

- Change in both amplitude and phase
- Implemented by I/Q modulation
  - I signal = $I(t)\ \cos(2\pi f_c t)$
    + Q signal = $Q(t)\ \cos(2\pi f_c t + \pi/2)$
  - Y signal = $\text{sqrt}(I^2(t) + Q^2(t)) \times \cos(2\pi f_c t + \theta)$ where $\theta = \tan^{-1}\frac{Q(t)}{I(t)}$





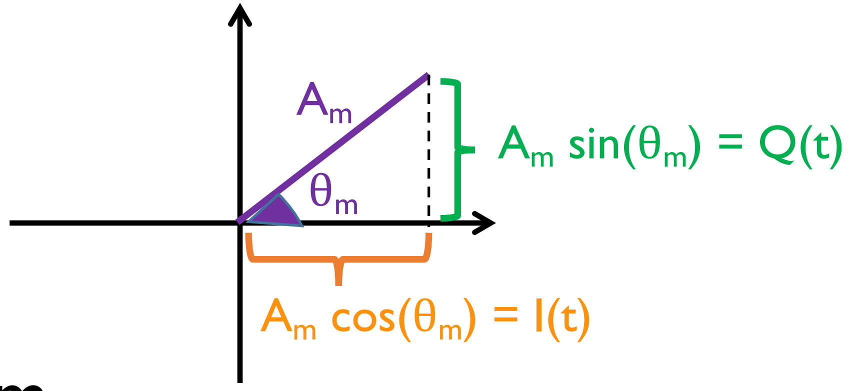
- Used by 802.11b, 802.11n, DVB (Digital Video Broadcast), WiMax, etc

How to get Y signal as single cosine function?

I signal

Q signal

- $Y(t) = I(t)\cos(2\pi f_c t) + Q(t)\cos(2\pi f_c t + \pi/2) = \text{sqrt}(I^2(t)+Q^2(t))\cos(2\pi f_c t + \theta_m)$
- By definition
  - $I(t) = A_m \cos(\theta_m)$
  - $Q(t) = A_m \sin(\theta_m)$



- From phasor diagram it is obvious to see $A_m = \text{sqrt}(Q^2(t) + I^2(t))$ by Pythagoras theorem
- Rewriting Y(t) in terms of A_m and θ_m
  - $Y(t) = \{A_m \cos(\theta_m)\} \times \cos(2\pi f_c t) - \{A_m \sin(\theta_m)\} \times \sin(2\pi f_c t)$

    $= A_m \{\cos(\theta_m) \times \cos(2\pi f_c t)\} - A_m \{\sin(\theta_m) \times \sin(2\pi f_c t)\}$

    $= A_m [\{\cos(\theta_m) \times \cos(2\pi f_c t)\} - \{\sin(\theta_m) \times \sin(2\pi f_c t)\}]$

    $= A_m \cos(2\pi f_c t + \theta_m)$

Because $\cos(2\pi f_c t + \pi/2) == -\sin(2\pi f_c t)$

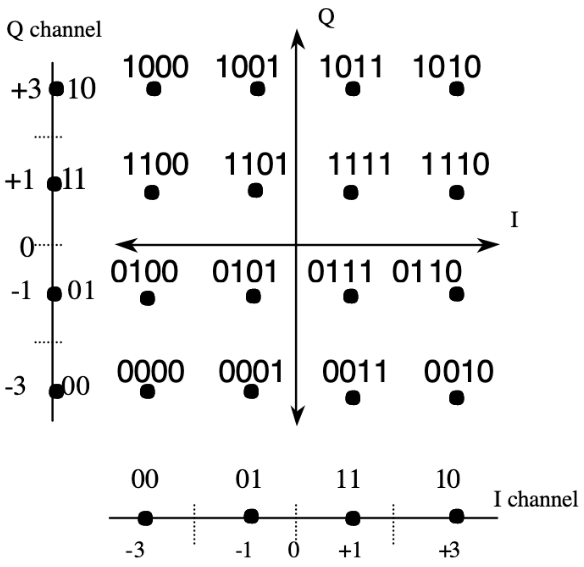
Simply rearrange

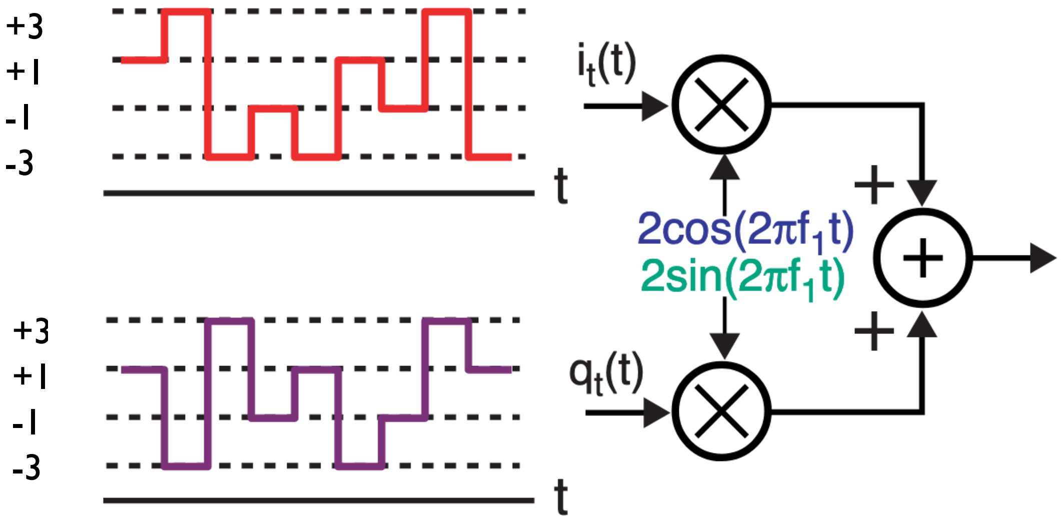
Factor out A_m

From $\cos(X+Y) = \cos X \cos Y - \sin X \sin Y$

16-QAM

- I/Qs are discrete values corresponding to digital data
  - For 16 QAM 4 levels each for I/Q
    ex) I: +3, +1, -1, -3
    Q: +3, +1, -1, -3
  - Each level is 2-bit data
  - Gray coding is used





1 symbol is the combination of 2-bit I value + 2 bit Q value
thus 1 symbol represents 4 bit in 16 QAM

True/False

- 5 QAM is possible
- 10 QAM is possible
- 32 QAM is possible
- 64 QAM is possible
- 128 QAM is possible
- 256 QAM is possible

True/False

- ~~5 QAM is possible~~
- ~~10 QAM is possible~~
- ~~32 QAM is possible~~
- 64 QAM is possible (6 bits per symbol)
- ~~128 QAM is possible~~
- 256 QAM is possible (8 bits per symbol)

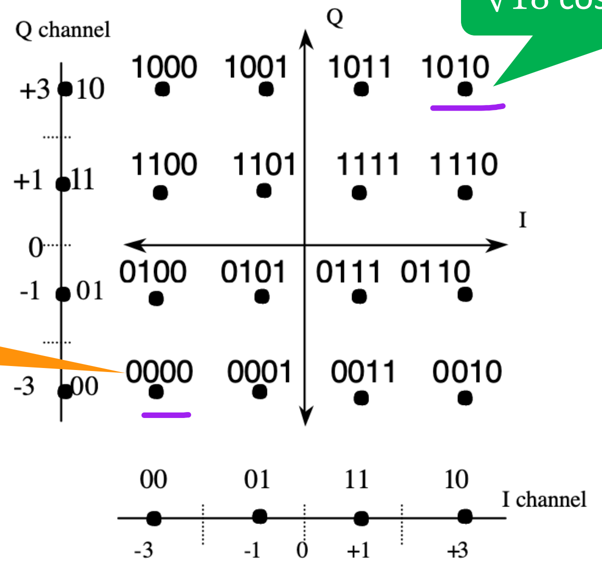
2^n levels for each I and Q
Thus, only $2^n \times 2^n = 2^{2n}$ order is possible

16 QAM with Gray Coding

- I/Q modulation
  - $\quad$ I signal = $I(t)\cos(2\pi f_c t)$
    + Q signal = $Q(t)\cos(2\pi f_c t + \pi/2)$
  - Y signal = $\text{sqrt}(I^2(t) + Q^2(t)) \times \cos(2\pi f_c t + \theta)$ where $\theta = \tan^{-1}\frac{Q(t)}{I(t)}$

Gray Coded			
Q	Q channel out put	I	I channel out put
00	$-3\sin(2\pi f_c t)$	00	$-3\cos(2\pi f_c t)$
01	$-1\sin(2\pi f_c t)$	10	$-1\cos(2\pi f_c t)$
11	$+1\sin(2\pi f_c t)$	11	$+1\cos(2\pi f_c t)$
10	$+3\sin(2\pi f_c t)$	10	$+3\cos(2\pi f_c t)$

$\sqrt{18}\cos(2\pi f_c t + 135°)$



$\sqrt{18}\cos(2\pi f_c t + 45°)$

There are 4 phases with 2 amplitude each

Outline

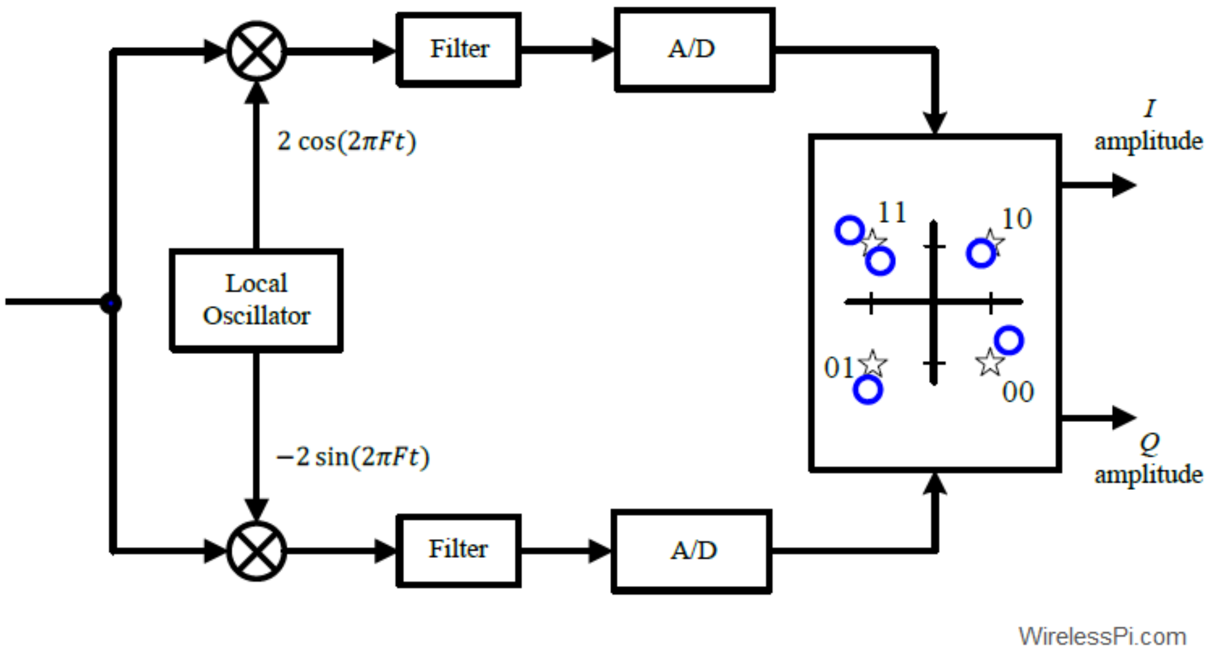
1. Receiver side story
2. Quadrature Amplitude Modulation (QAM)
3. Demodulation in QAM

QAM Demodulation

Trigonometric cheat sheet

$$\cos(x)\cos(y) = \tfrac{1}{2}\left[\cos(x-y) + \cos(x+y)\right]$$

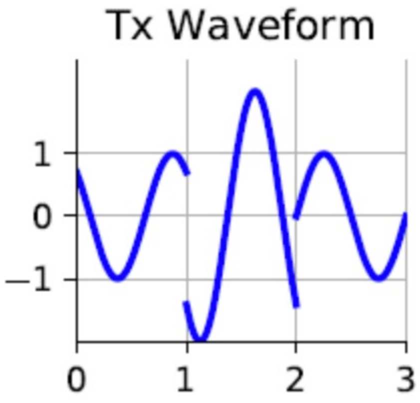
$$\cos(x)\sin(y) = \tfrac{1}{2}\left[\sin(x+y) - \sin(x-y)\right]$$

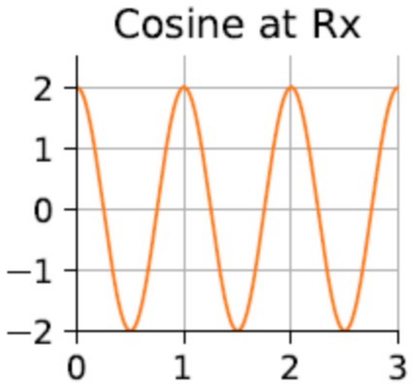


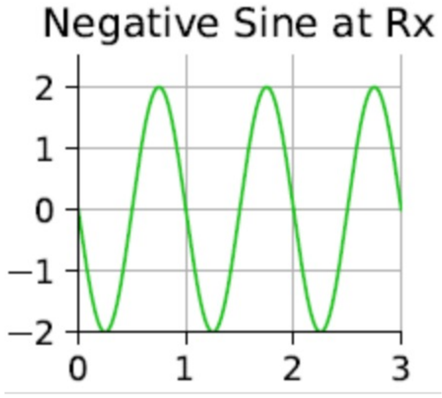
- Let s(t) be received signal
  - $s(t) = A_m \cos(2\pi f c t + \theta_m)$
- I arm:
  - $s(t) \times 2\cos(2\pi f_c t) = A_m \cos(2\pi f_c t + \theta_m) \times 2\cos(2\pi f_c t)$
    $= A_m \{\cos(\theta_m) + \underbrace{\cos(2\pi\, 2f_c\, t + \theta_m)}_{\text{Filtered out}}\} \approx A_m \cos(\theta_m)$
- Q arm:
  - $s(t) \times -2\sin(2\pi f_c t) = A_m \cos(2\pi f_c t + \theta_m) \times -2\sin(2\pi f_c t)$
    $= A_m \{\sin(\theta_m) + \underbrace{\sin(2\pi\, 2f_c\, t + \theta_m)}_{\text{Filtered out}}\} \approx A_m \sin(\theta_m)$

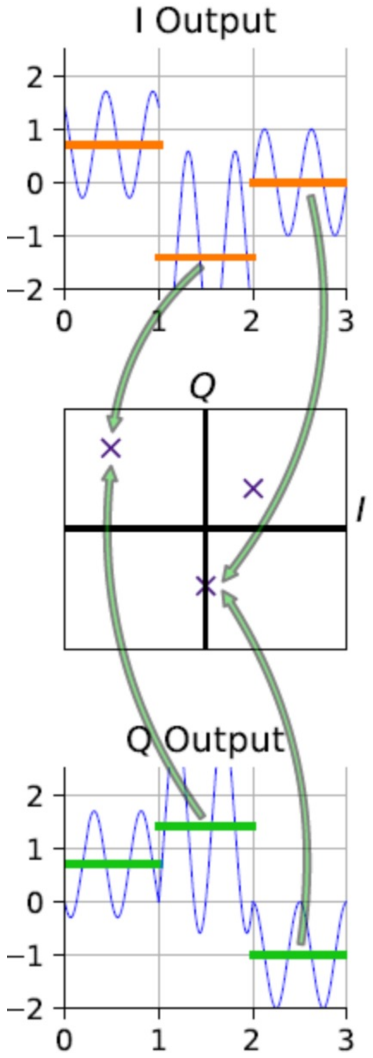
Example QAM Demodulation

- Let's have 3 symbols that are modulated via given $A_m = \{1, 2, 1\}$ and $\theta_m = \{45, 135, 270\}$









What are these coordinates?

Compare with BPSK demodulation

- Matlab bpsk_manual_example.m

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