Signals and Systems (Lab)

Project 2: OFDM Technology

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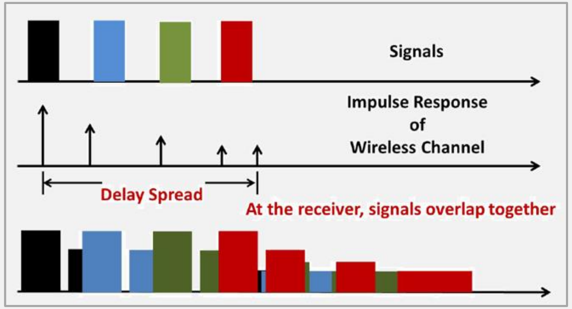
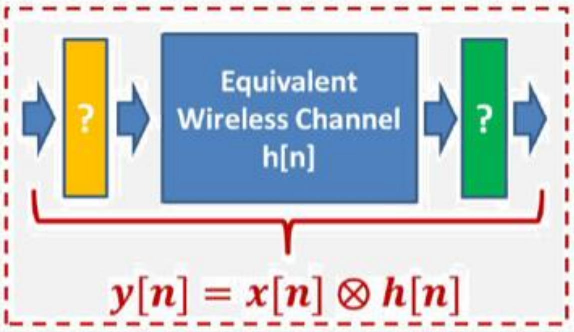
Overview

- **Wireless channel model:**
  - Multipath propagation
  - Equivalent Channel model



- **OFDM Introduction:**
  - The basic principle of OFDM
  - How to design the OFDM receiver ?



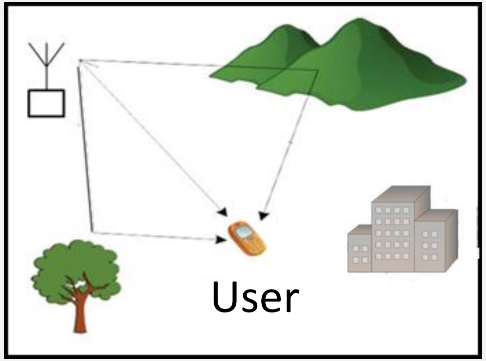
- **Project Tasks:**
  - OFDM receiver design

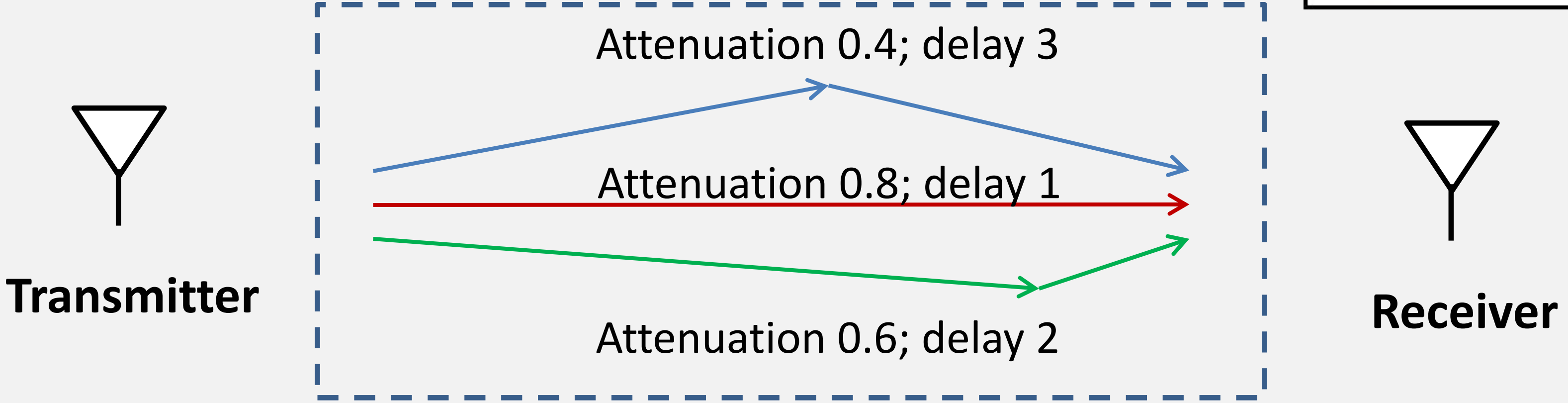
Part I: Wireless channel model

Multi-path propagation

Wireless Channel Model:

$$y[n] = 0.8\, x[n-1] + 0.6\, x[n-2] + 0.4\, x[n-3]$$



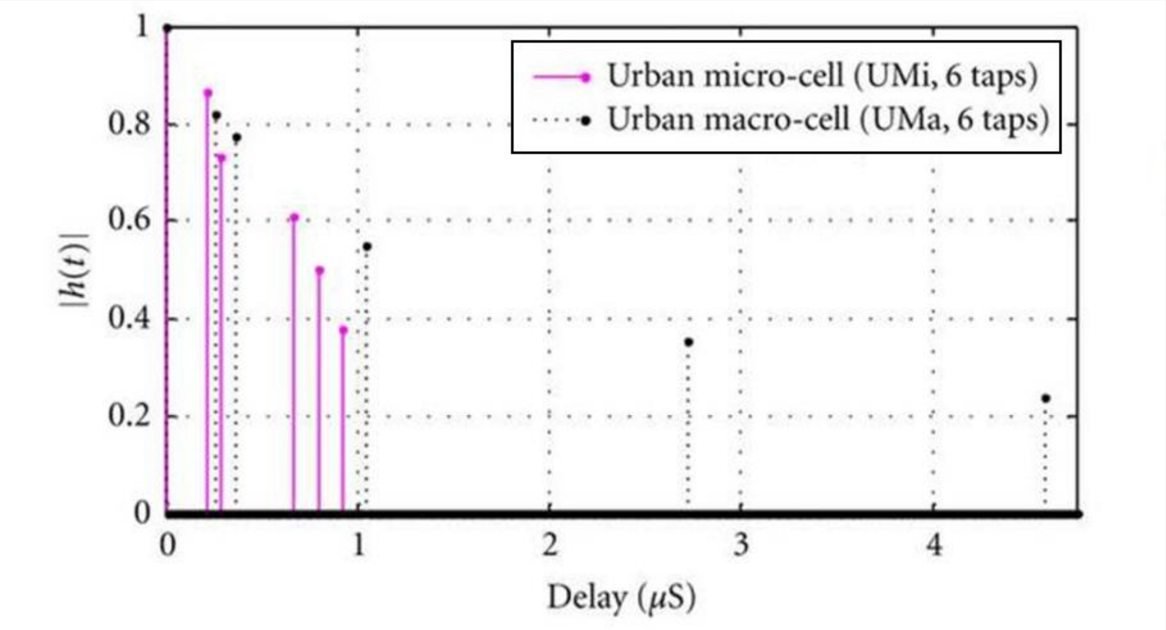


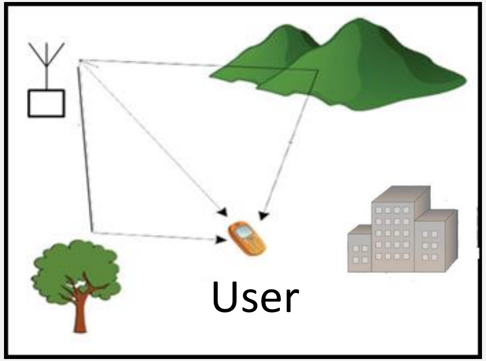
x[n]

x[n]*h1[n]=y[n]

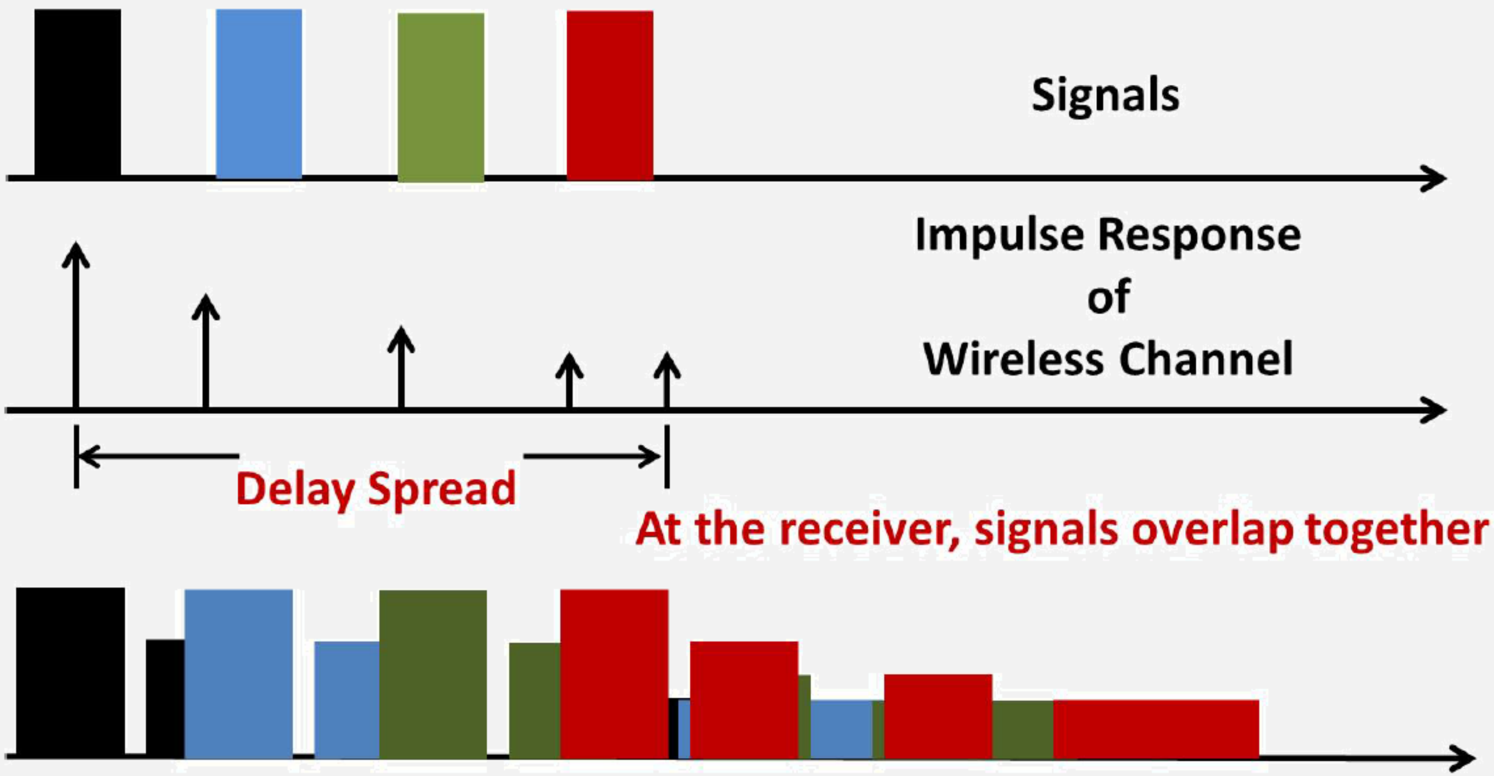
y[n]

Multipath delay spread

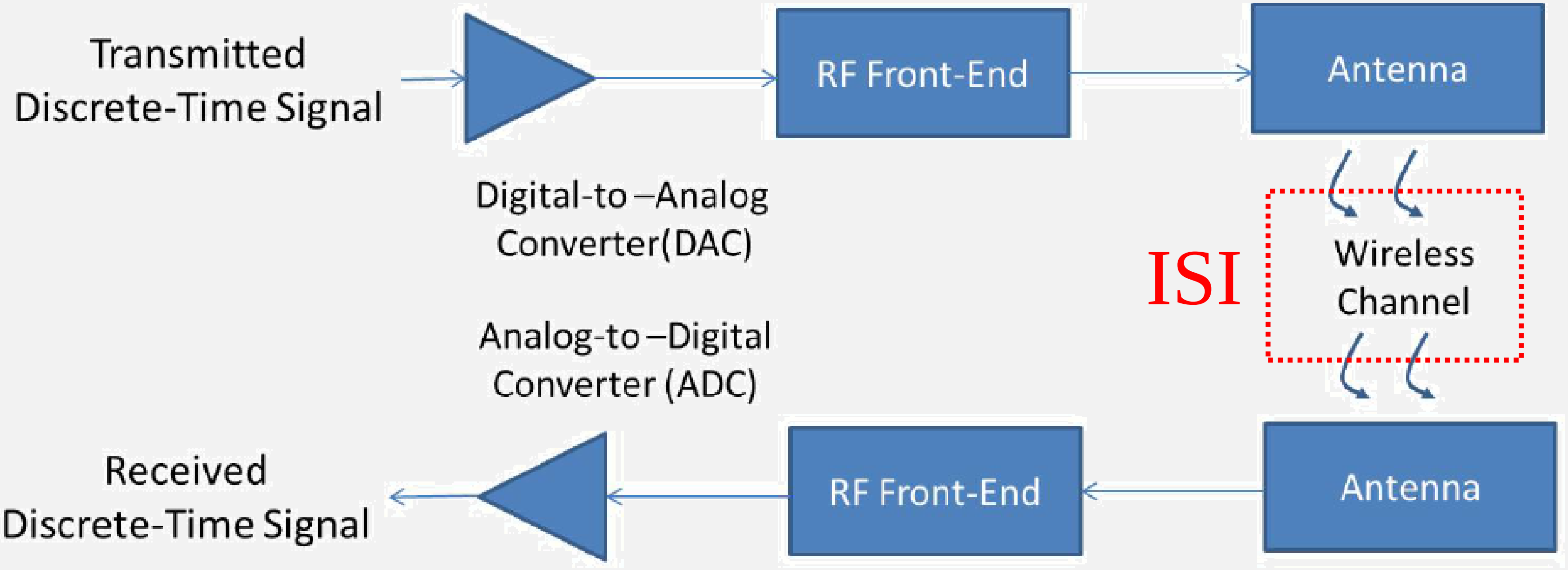




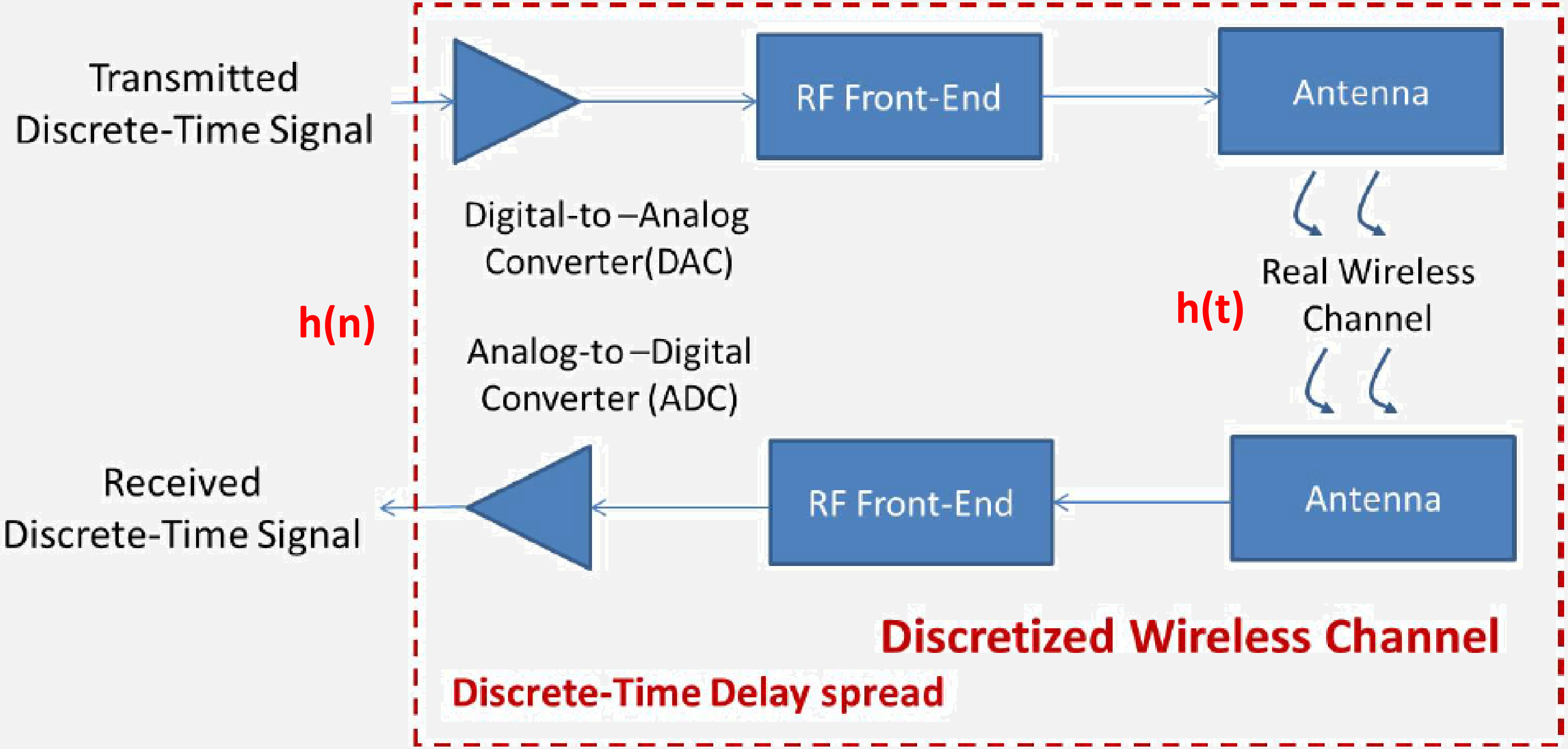
Inter-Symbol Interference: ISI



Let's begin with a wireless system



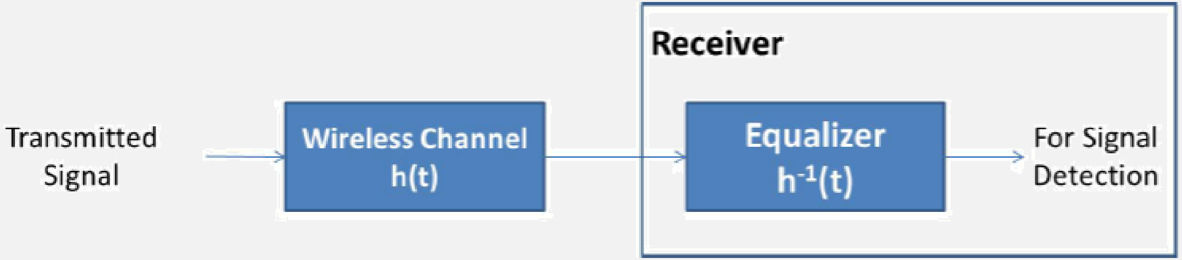
Equivalent Channel model



Part II: OFDM Introduction

How to deliver signals without ISI ?

- How to deliver signals without inter-symbol interference?
  - Suppose the duration of delay spread is ΔH seconds
- Approach 1: Send data on every ΔH seconds
- Approach 2: Channel equalizer

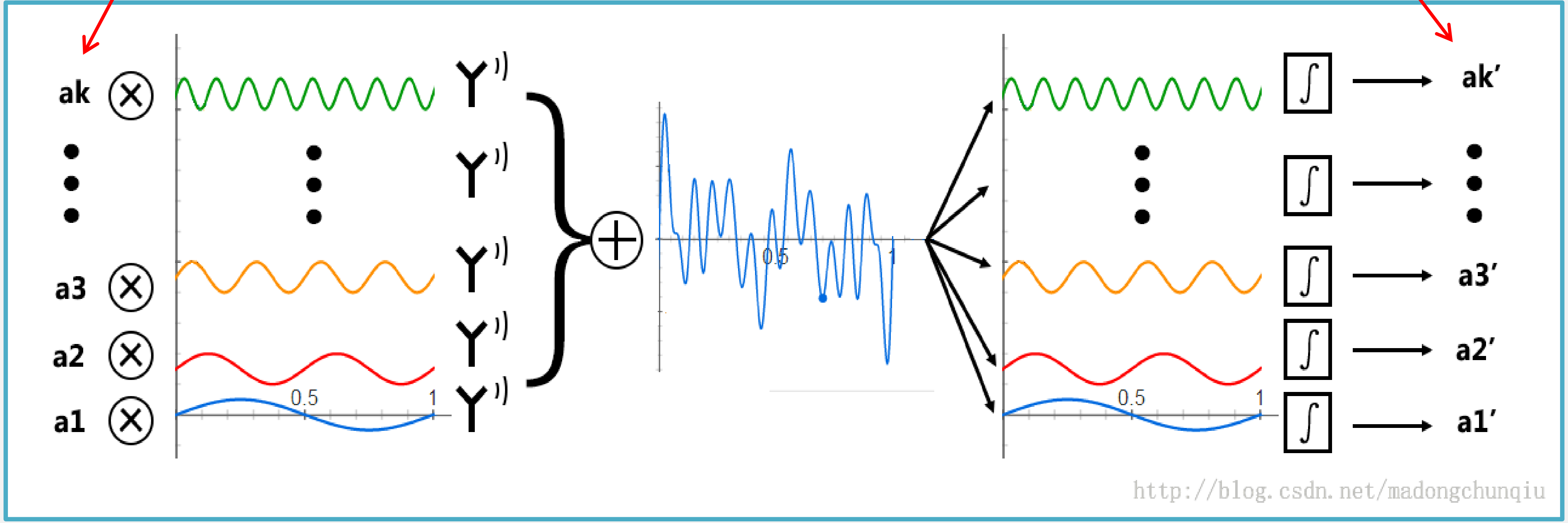


- Approach 3: Orthogonal Frequency Division Multiplexing
  - Pre-processing at the transmitter + post-processing at the receiver

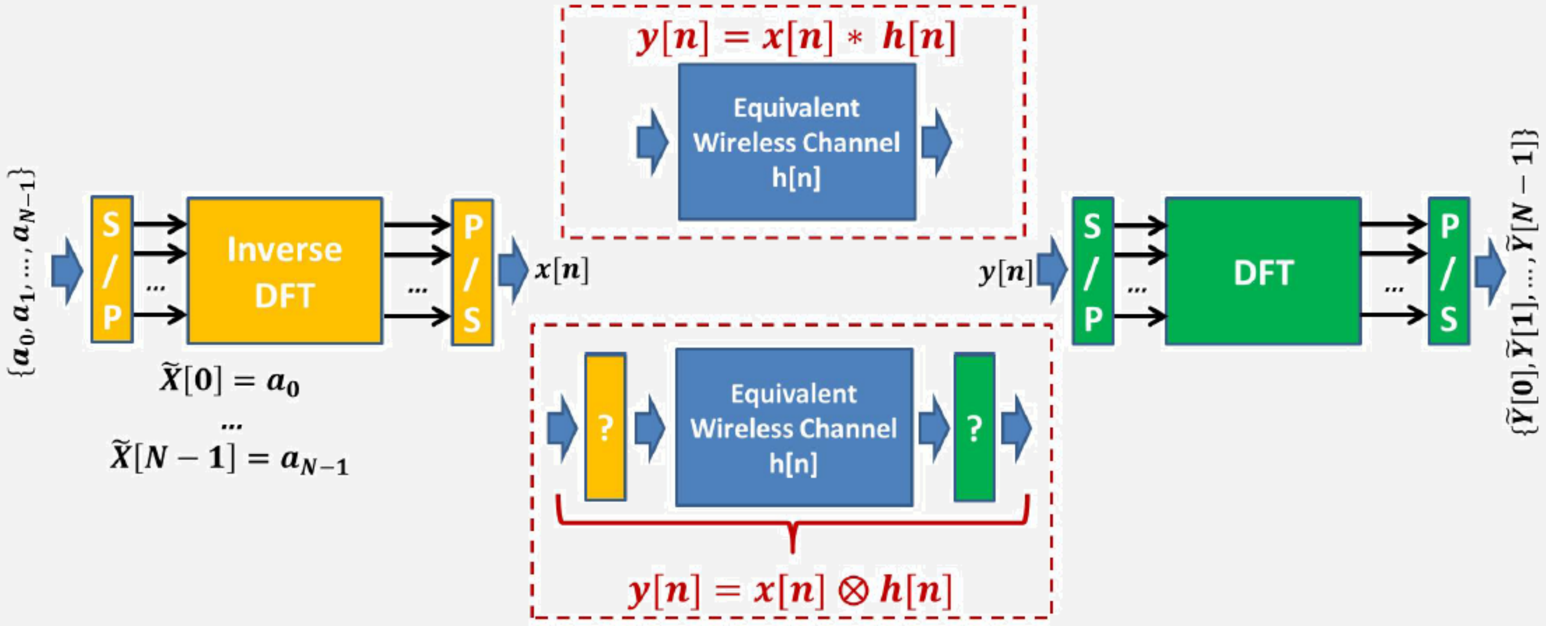
The basic principle of OFDM

Transmitted signal

Received signal

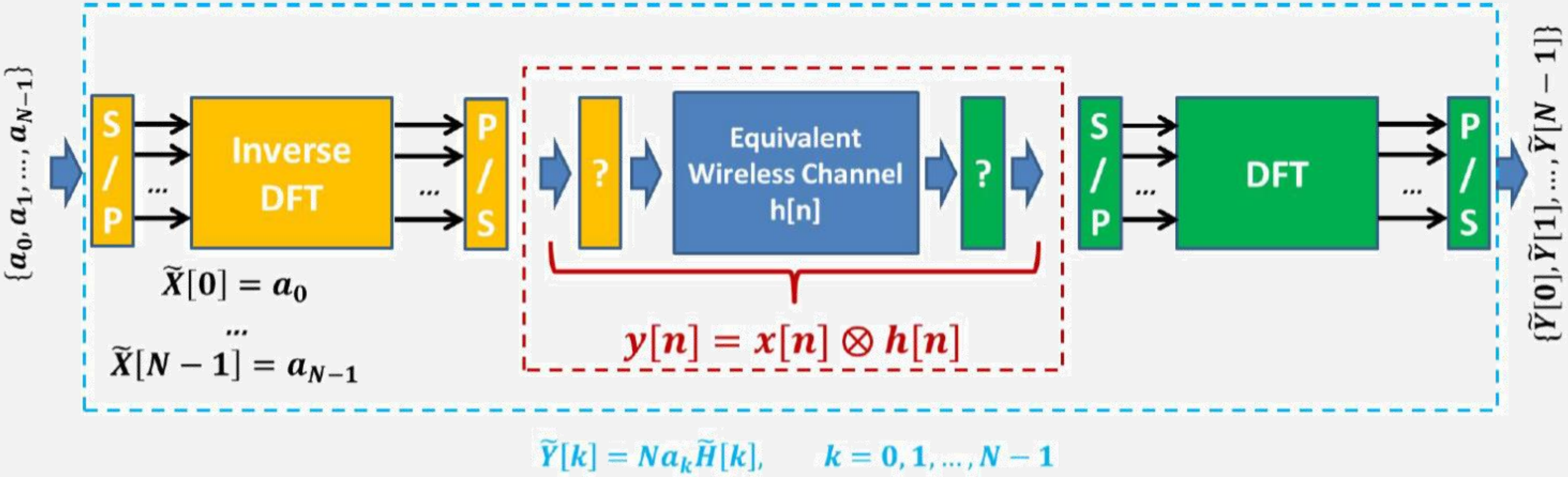


OFDM at first glance



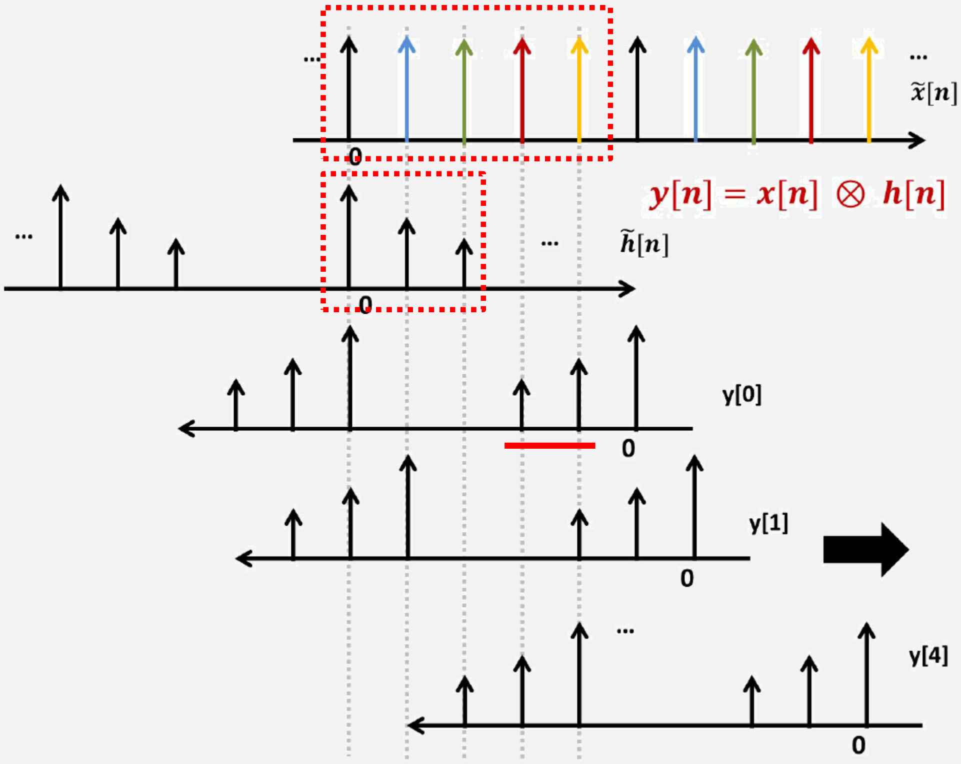
- Signals are loaded in frequency domain
- Some mechanism is necessary to generate the effect of periodic convolution

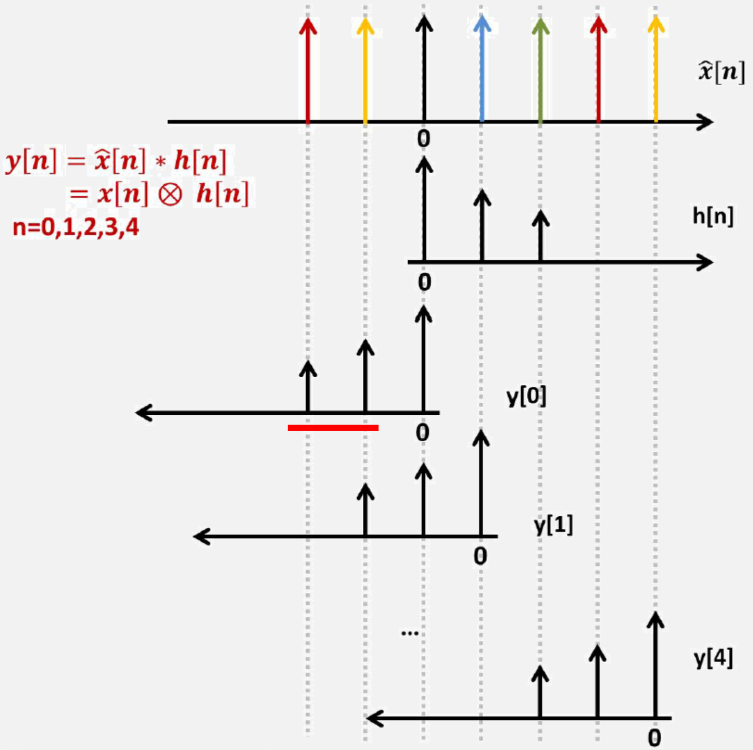
How to design the block "?" ?



- How to detect $\{a_k | \forall k\}$ from $\{\tilde{Y}[k] | \forall k\}$?
- How to design the blocks "?" ?

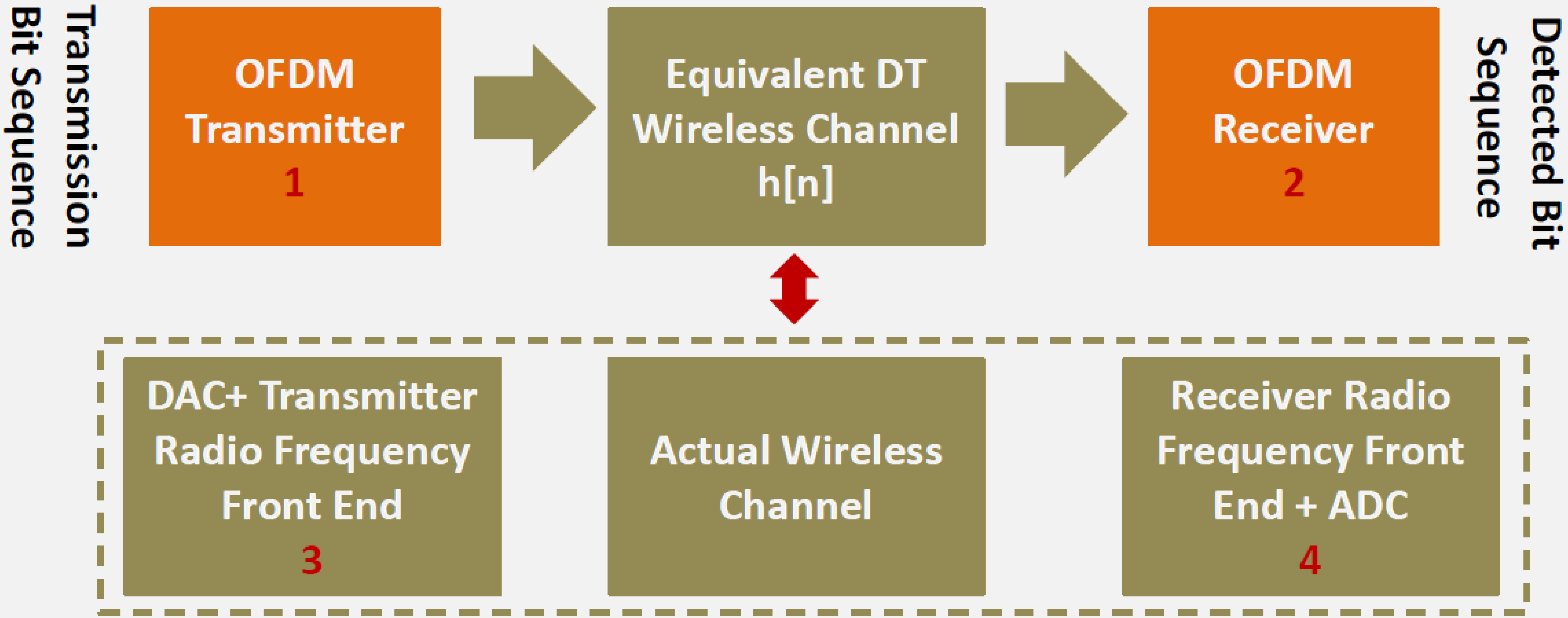
Convolution=Periodic convolution?





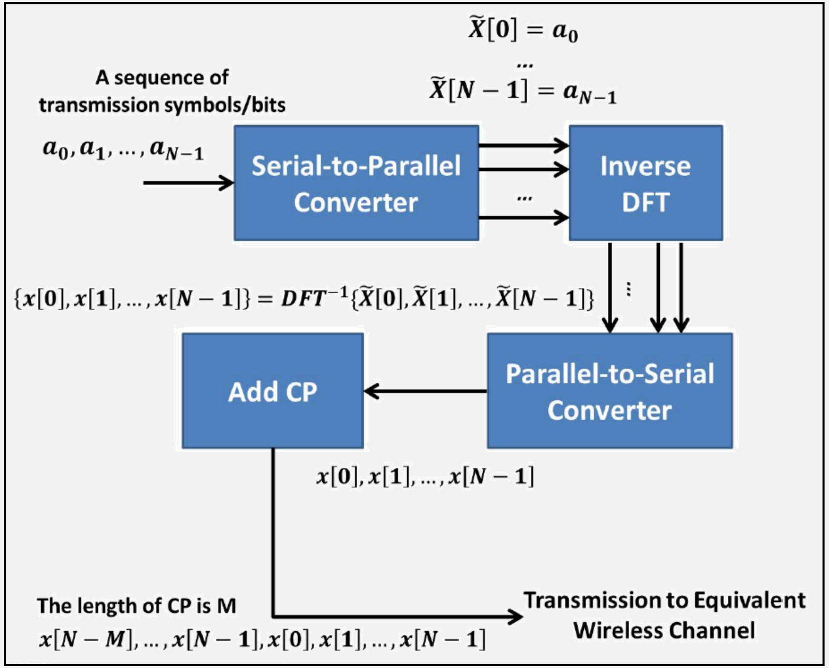
Part III: Project Tasks

OFDM transceiver model

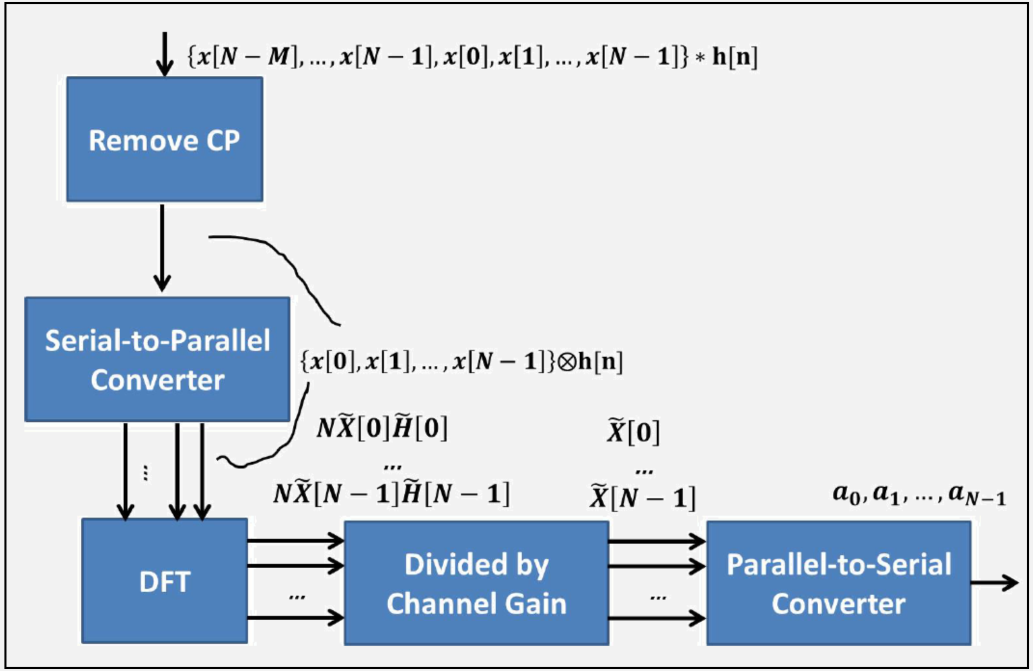


Block 1 and Block 2

Block 1

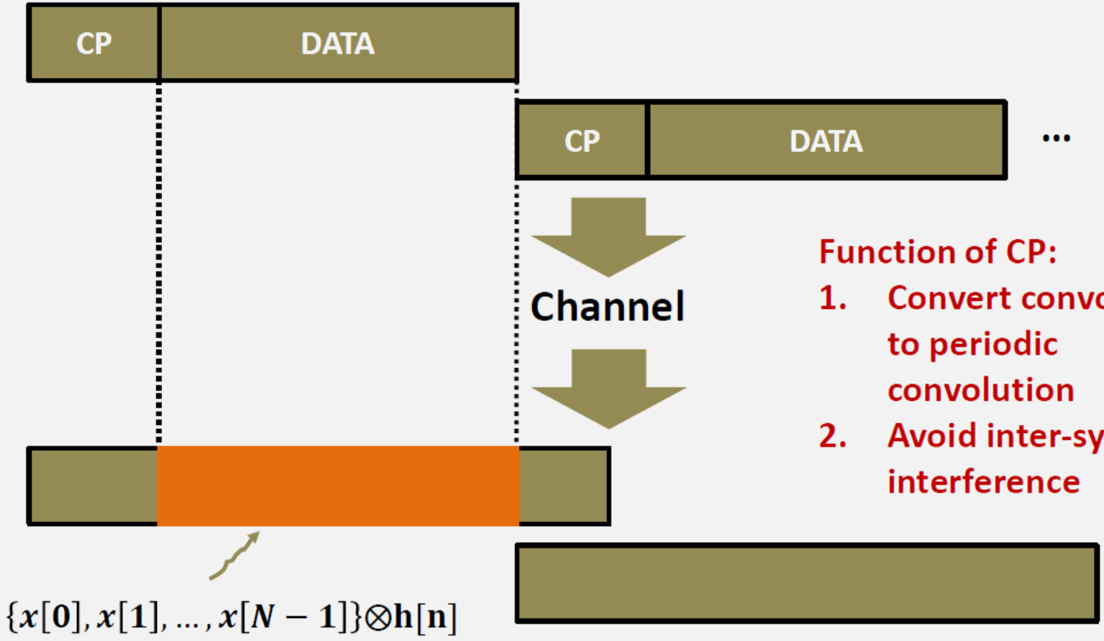


Block 2



Tips: Function of CP

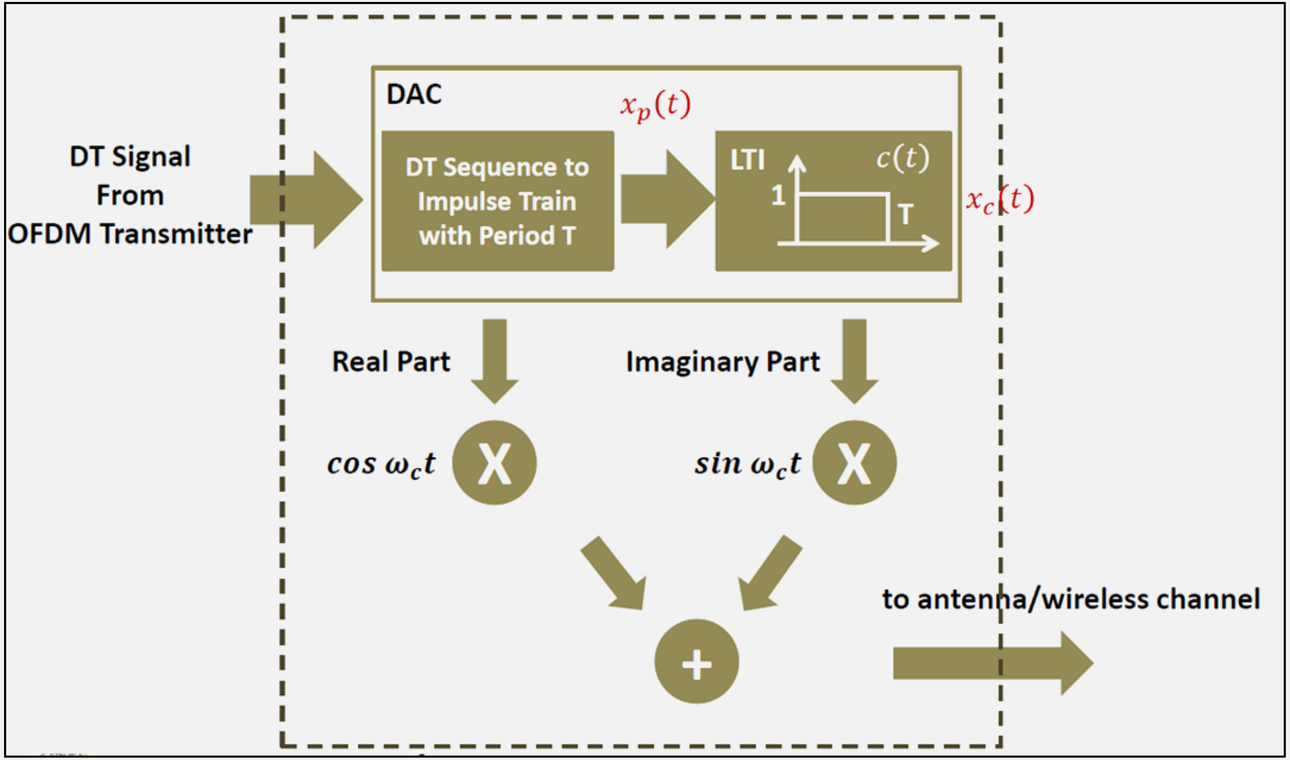
OFDM Symbol: $\{x[N-M], \ldots, x[N-1], x[0], x[1], \ldots, x[N-1]\}$



Function of CP:

1. Convert convolution to periodic convolution
2. Avoid inter-symbol interference

Block 3: DAC Transmitter + RF-front end



Analysis for the Block 3

- Suppose the input signal to the RF front end is $x[n]$
- Convert to impulse train: $x_p(t) = \sum_n x[n]\delta(t - nT)$
- After DAC: $x_c(t) = \sum_n x[n]c(t - nT)$
  - c(t) is a rectangular wave
- Real part: $x_r(t) = real[x_c(t)]$
- imaginary part: $x_i(t) = imag[x_c(t)]$
- After modulation
  - $x_{cos}(t) = x_r(t)cos\omega_c t$
  - $x_{sin}(t) = x_i(t)sin\omega_c t$
- After summation: $\mathrm{x}_{tx}(t) = x_r(t)cos\omega_c t + x_i(t)sin\omega_c t$

Actual wireless channel

- In this project, the wireless channel is approximated as a continuous-time LTI systems

- The impulse response is a causal finite-length continuous-time function

- Assume the channel impulse response is
  - $h(t) = 0.5\delta(t) + 0.4\delta(t - 1.5T) + 0.35\delta(t - 2.5T) + 0.3\delta(t - 3T)$
  - T is the sampling period

Your tasks

a. Design the receiver's RF front-end + ADC (Block 4), explain why your design can lead to correct signal detection

b. Derive h[n] and discuss the relation between h(t) and h[n] (see Page 3), determine the length of CP

c. Randomly generate two discrete time signals {xp[0],xp[1],...,xp[31]} (pilot) and {x[0],x[1],...,x[31]} (data), transmit these two signals by two OFDM symbols, and at least show the following items (in the simulation, T=1us and carrier frequence $\boldsymbol{\omega_c = 100MHz}$)

- Plot the highlighted signals in the block 1, block 2 and block 3.
- Plot and discuss the Fourier transform of signal highlighted in the block 3.
- Plot how the signal changes in the block 4 step-by-step.
- Compare the final detected signal with the original transmitted signal.

d. Elaborate on the applications of OFDM technology
   – Any practical communication system using OFDM? Why?

Report

- Abstract
  - What you have done in this report
- Introduction
  - Elaborate on the baseband of OFDM (Block 1&2)
  - Elaborate on the DAC + RF front-end of the transmitter (Block 3)
- Receiver Design and Analysis
  - Task a: Elaborate on your design of receiver RF front-end + ADC (Block 4)
  - Task b: Elaborate on the relation between h(t) and h[n]
- Simulations
  - Task c: show how the signal transforms step-by-step with figures
- Discussions
  - Task d: elaborate on the advantages of OFDM systems (>300 words)
- Please attach the matlab code in your report

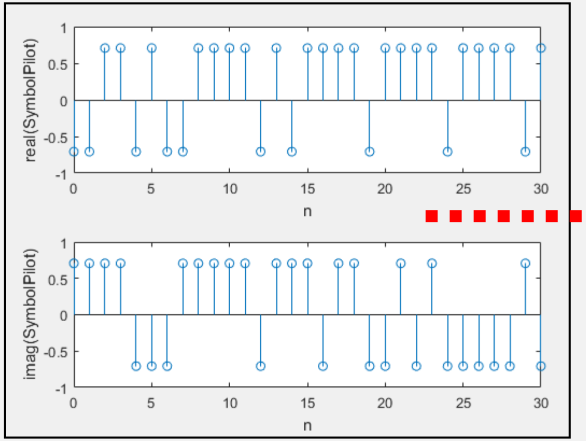
Reference

- Reference:
  - www.gaussianwaves.com/2011/05/introduction-to-ofdm-orthogonal-frequency-division-multiplexing-2/
  - www.wirelesscommunication.nl/reference/chaptr05/ofdm/ofdmmath.htm
  - home.deib.polimi.it/spalvier/sistemi_di_comunicazione/integrazione_lezioni/ofdm_tutorial.htm

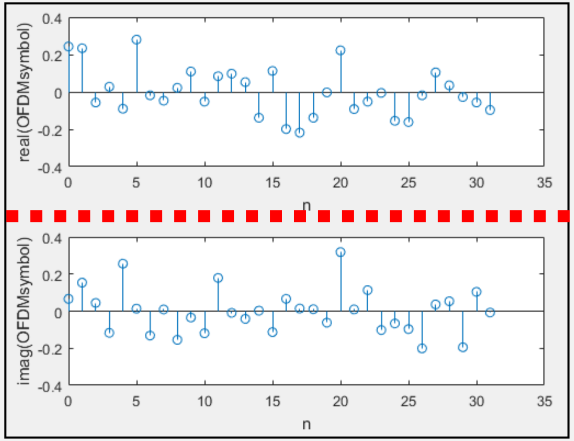
Tips on receiver design

- In order to demodulate the signal, receiver should
  - Multiple the received signal with carrier: $cos\omega_c t \ and \ sin\omega_c t$
  - Use an ideal lowpass filter

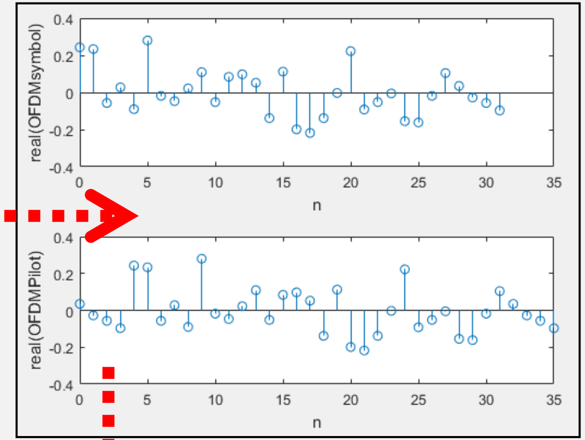
- After demodulation, the receiver should
  - Use integrator to accumulate the received power: $y_{int}(t) = \int_{t-T}^{t} y_{dem}(\tau) \ d\tau$
  - Use ADC to generate DT signal for further processing: $y_{int}(nT)$ keeps all the necessary information



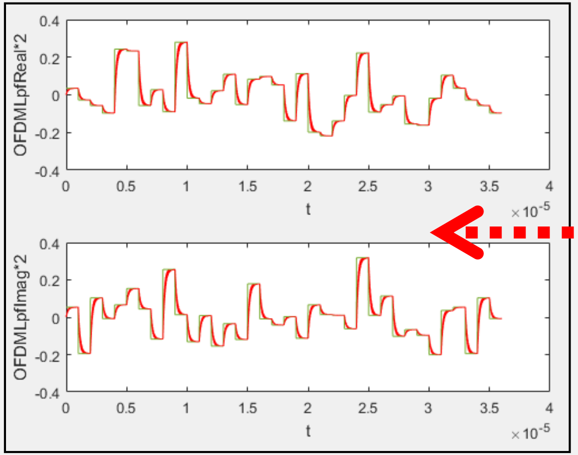
需要传输的数据（31）



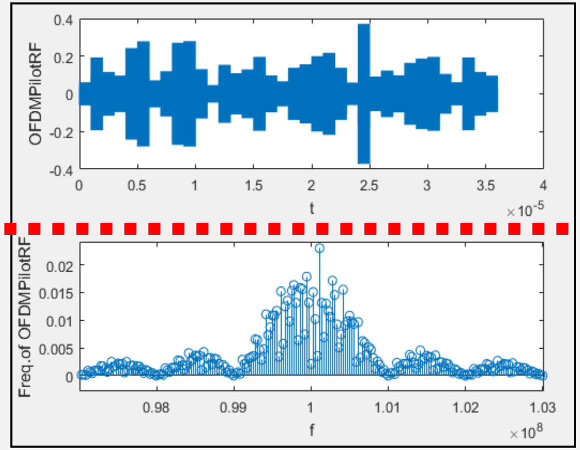
OFDM符号（32）



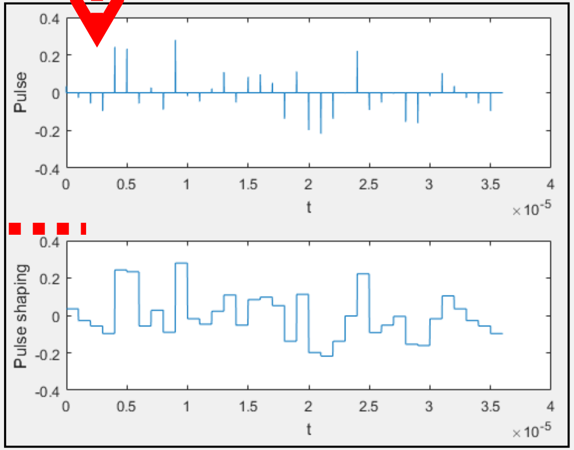
增加循环前缀（36）



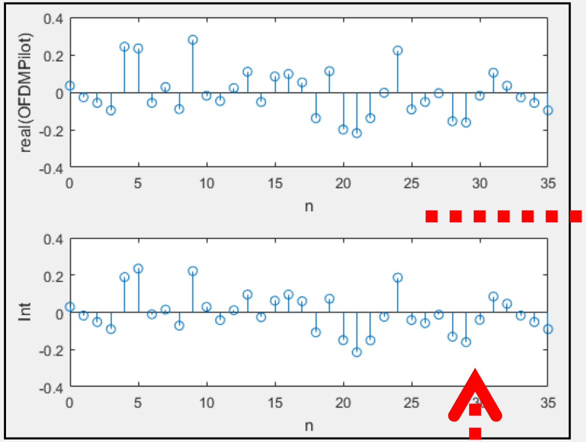
低通滤波器后的复信号



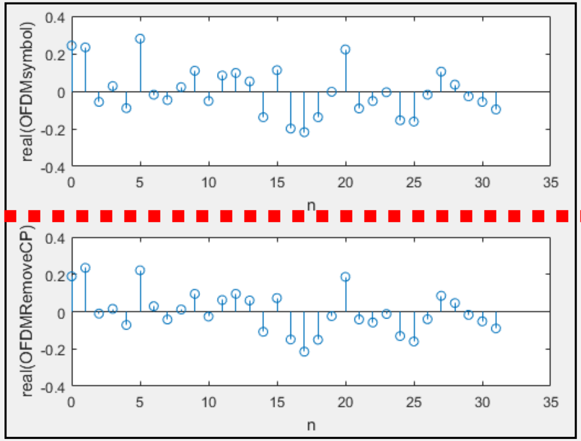
OFDM射频信号及其频谱



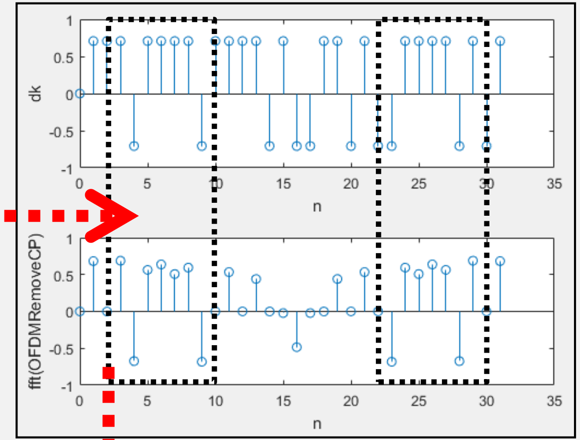
实部连续脉冲和脉冲成形



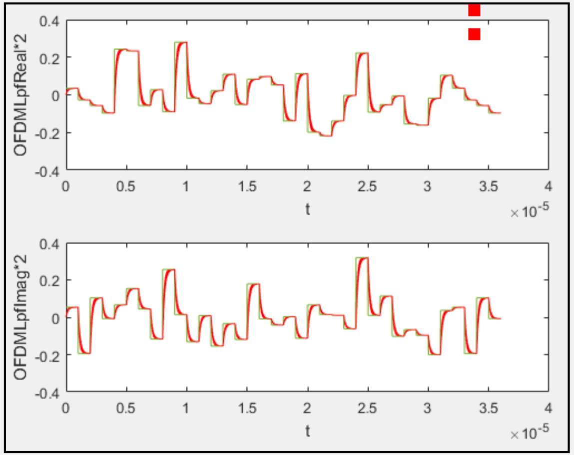
积分采样后的信号



移除循环前缀后的信号

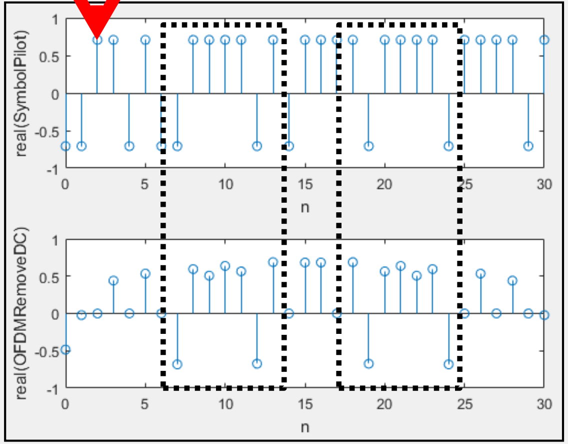


FFT恢复信号（3-9子载波）



低通滤波器后的复信号

dt = 1ns
Length of CP=4us
Length of OFDM=32us
Filter type = ‘butter’
Num. of subcarrier = 31



有效数据恢复

Questions