Lecture 03-13: Physical Layer OFDM 3

CS 356R

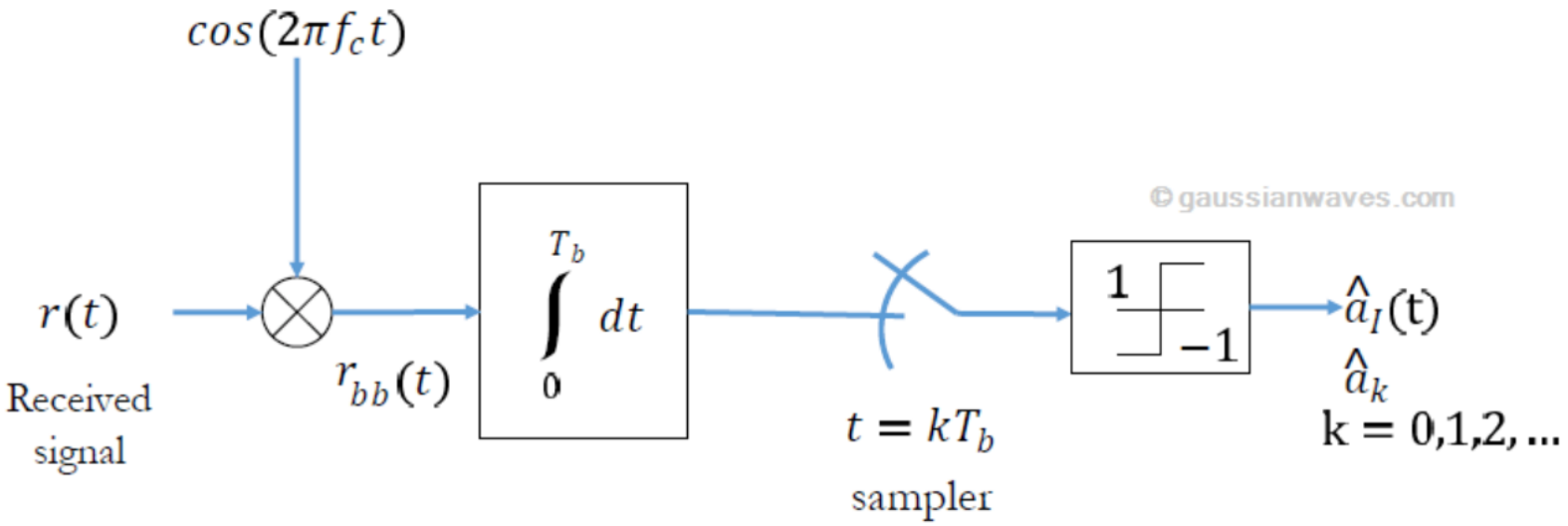
Intro to Wireless Networks

Mikyung Han

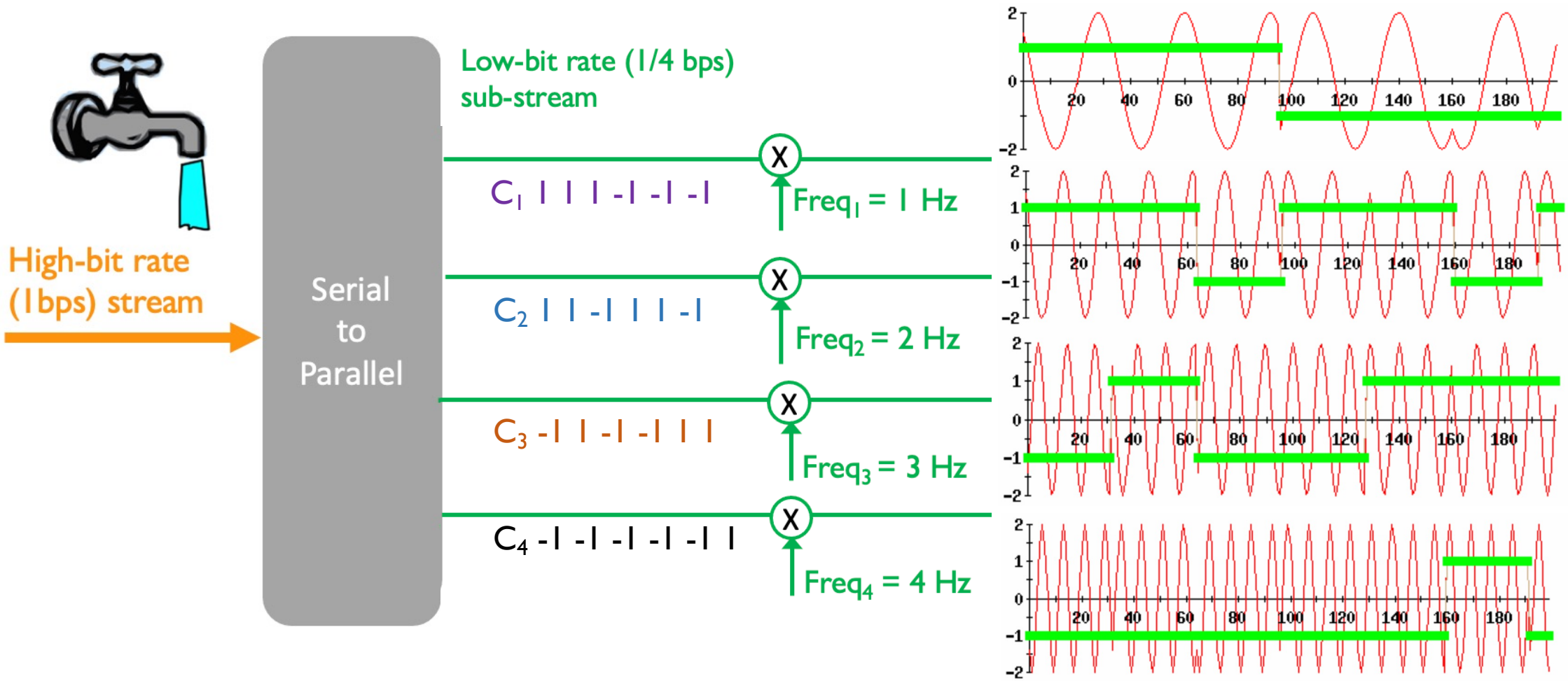
Outline

1. BPSK recap

BPSK demodulation

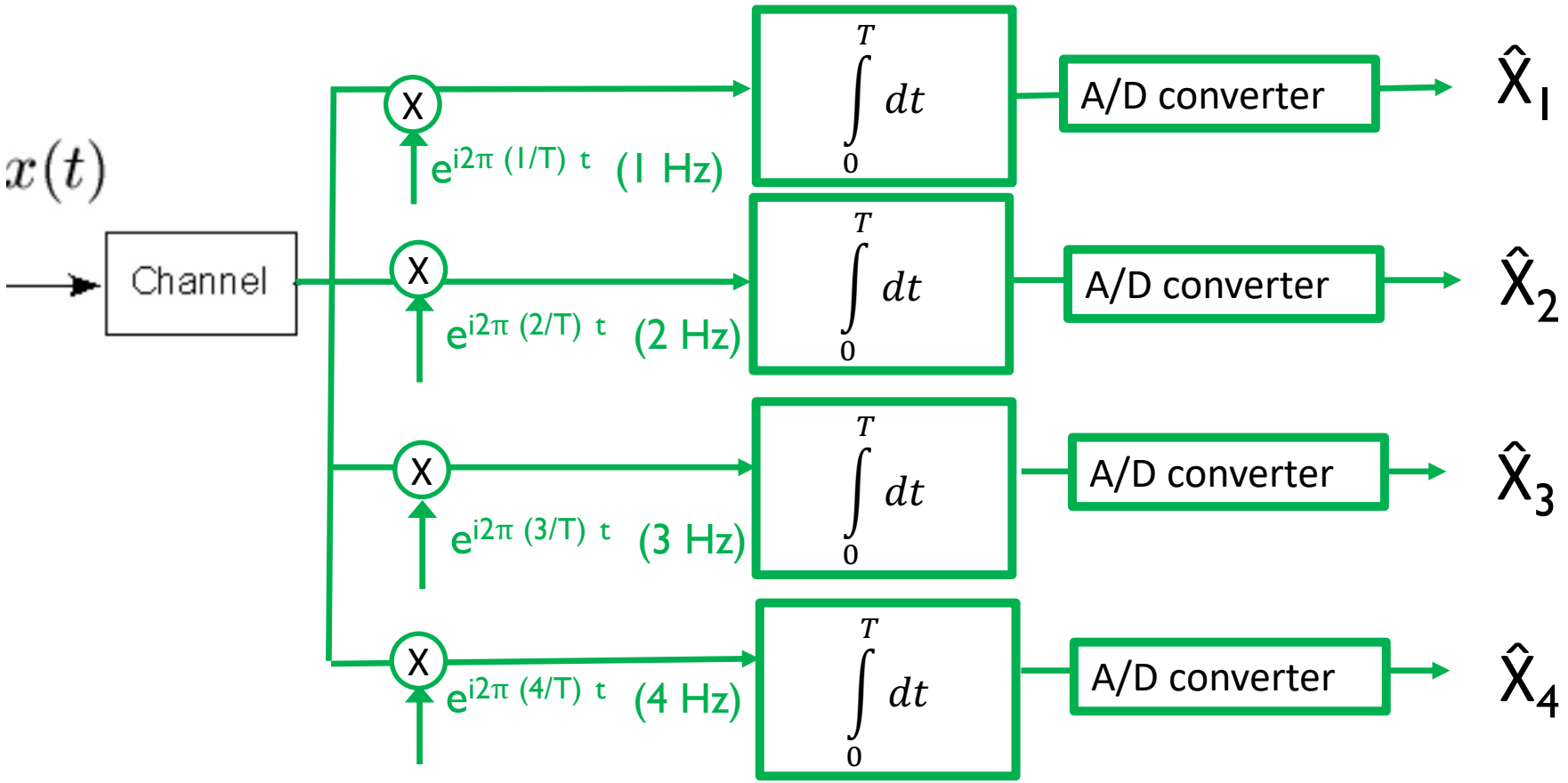


Simple OFDM example

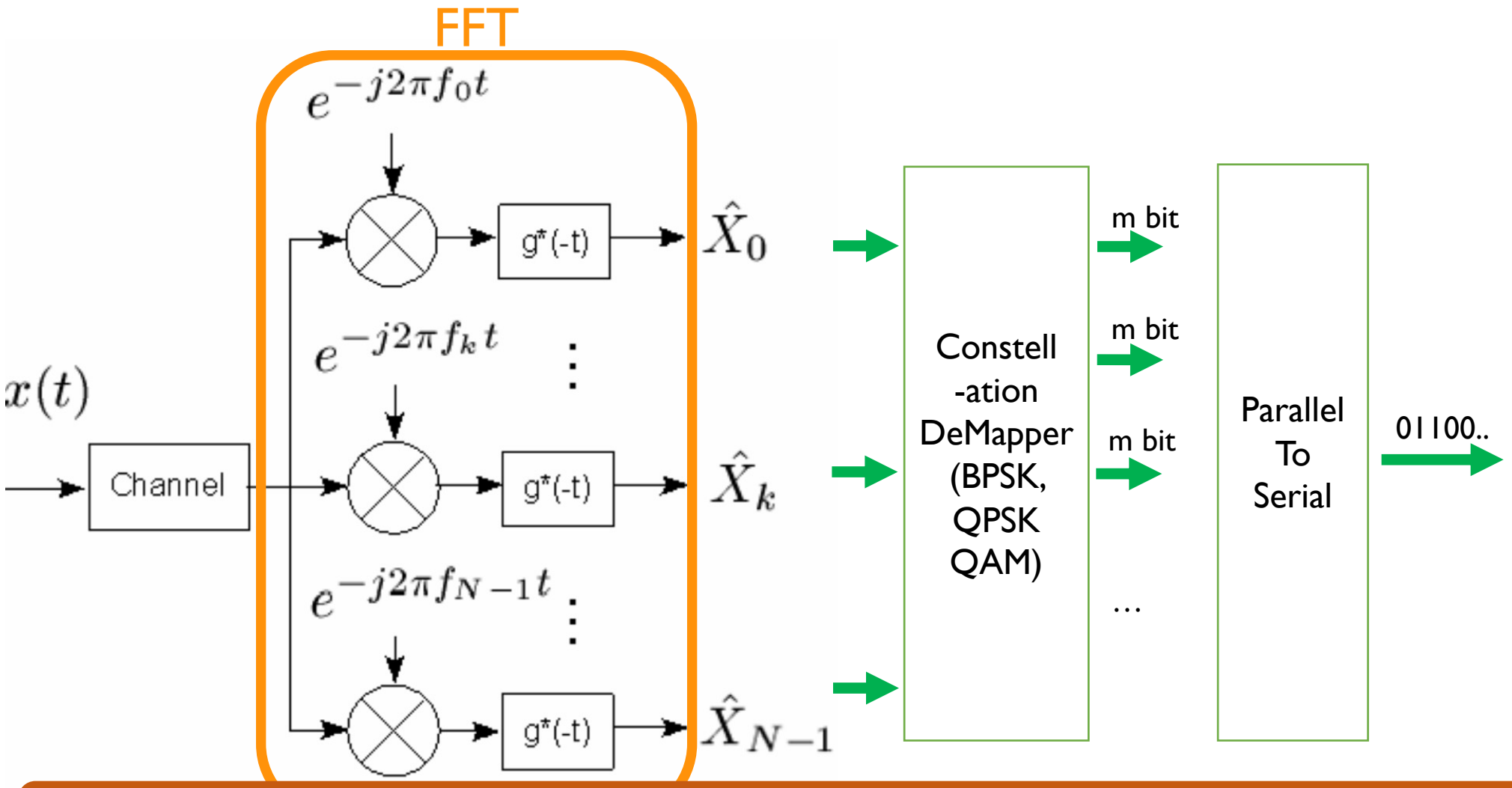


OFDM with BPSK: "manual" implementation

- If we did NOT have FFT then… this is what we need in receiver side
  - BPSK example used



Receiver-side OFDM demodulation is implemented via FFT

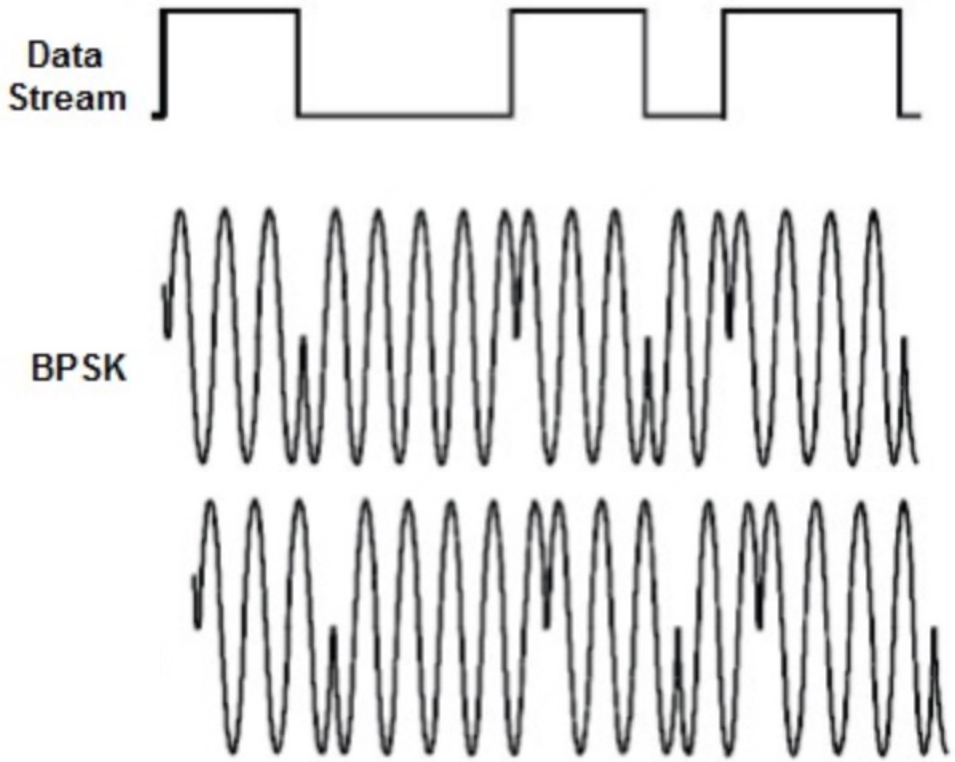


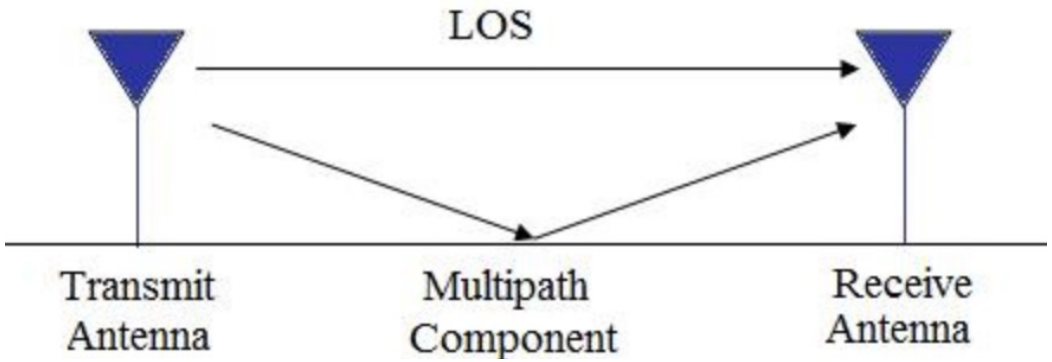
FFT's are much faster than implementing the whole circuit

Outline

1. BPSK recap
2. Multipath and Cyclic Prefix

Multipath illustration using BPSK



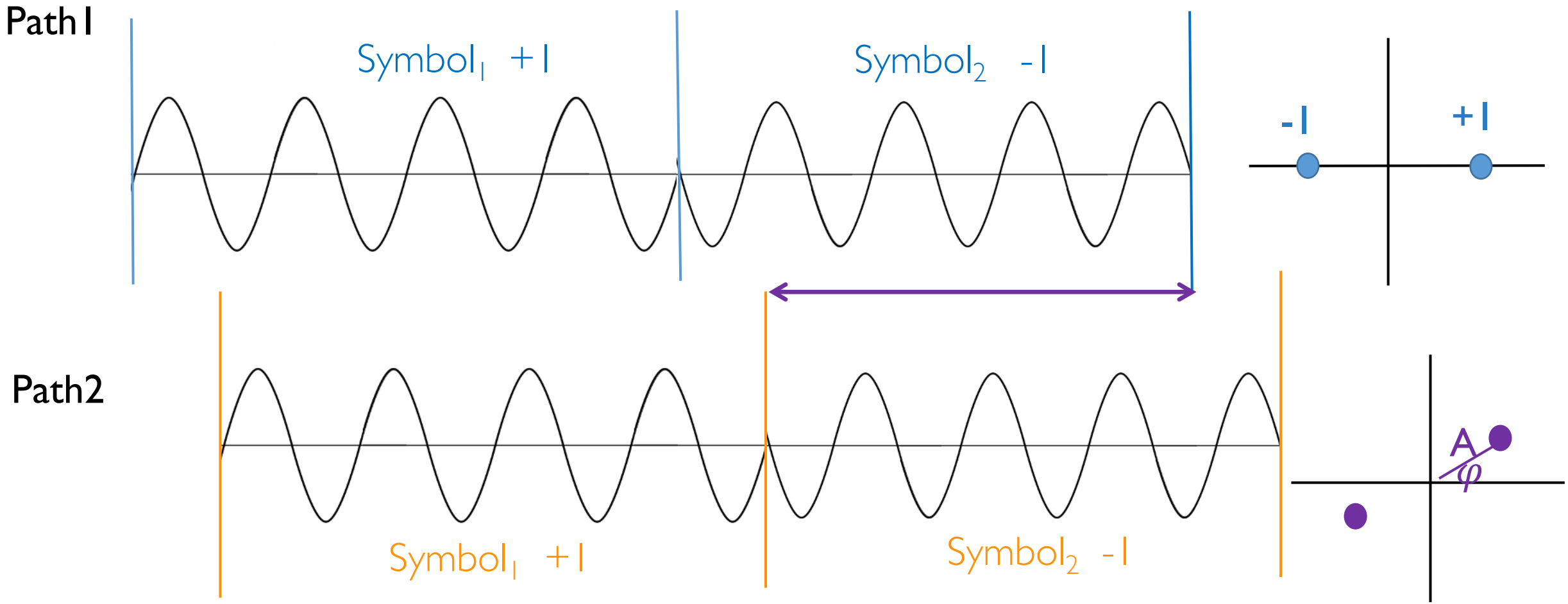


Path1: LOS direct path

Path2: bounced off of a wall
(additional phase shift of θ)

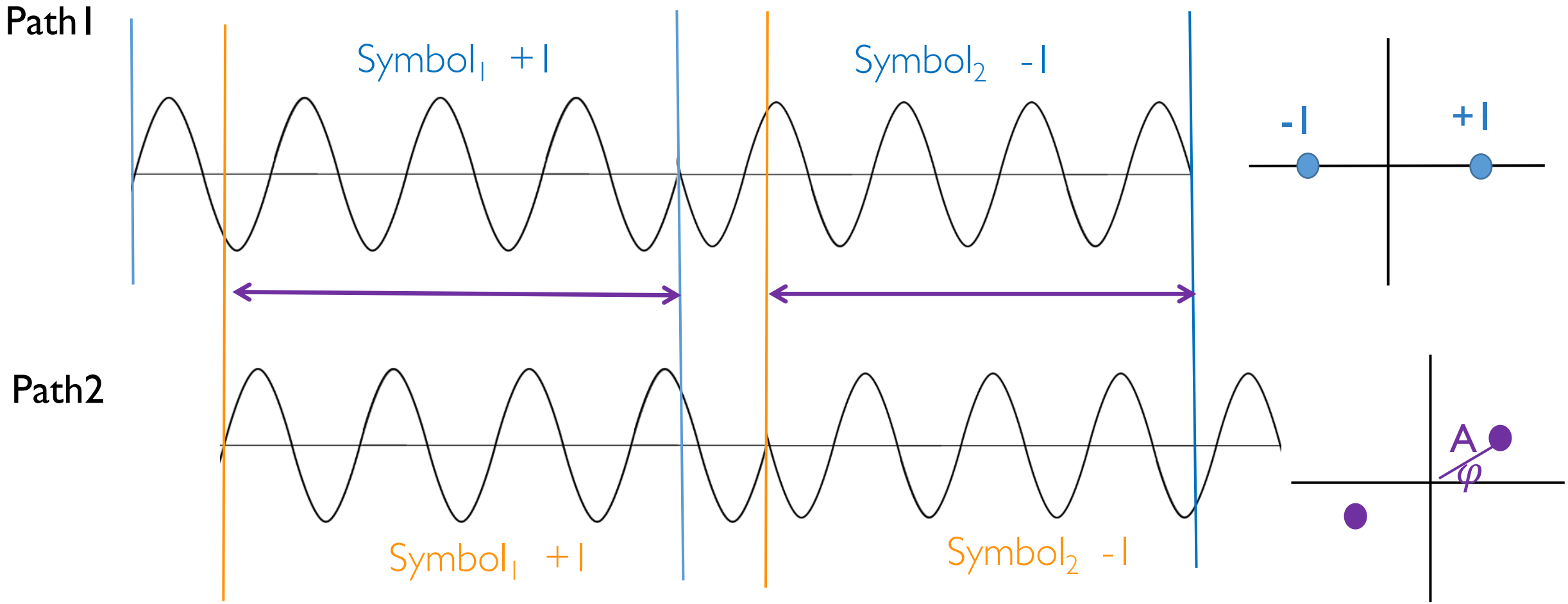
Signal from path1 and signal from path2 are added together at the receiver

Multipath illustration using BPSK



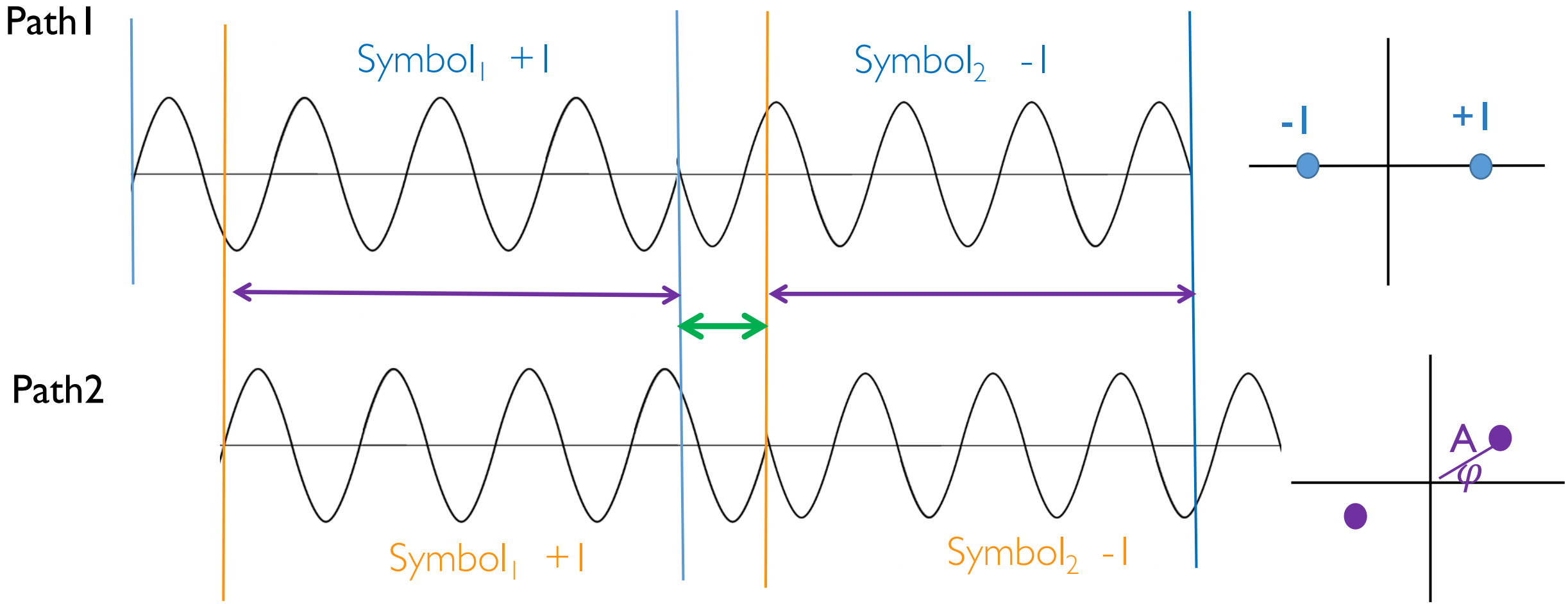
-sin(wt) + -sin(wt+ θ) = A sin (wt + φ) causes
change of amplitude A and shifted phase of φ

Multipath illustration using BPSK



Both Path 1 signals and path 2 signal in PURPLE are continuous thus can be ”equalized”

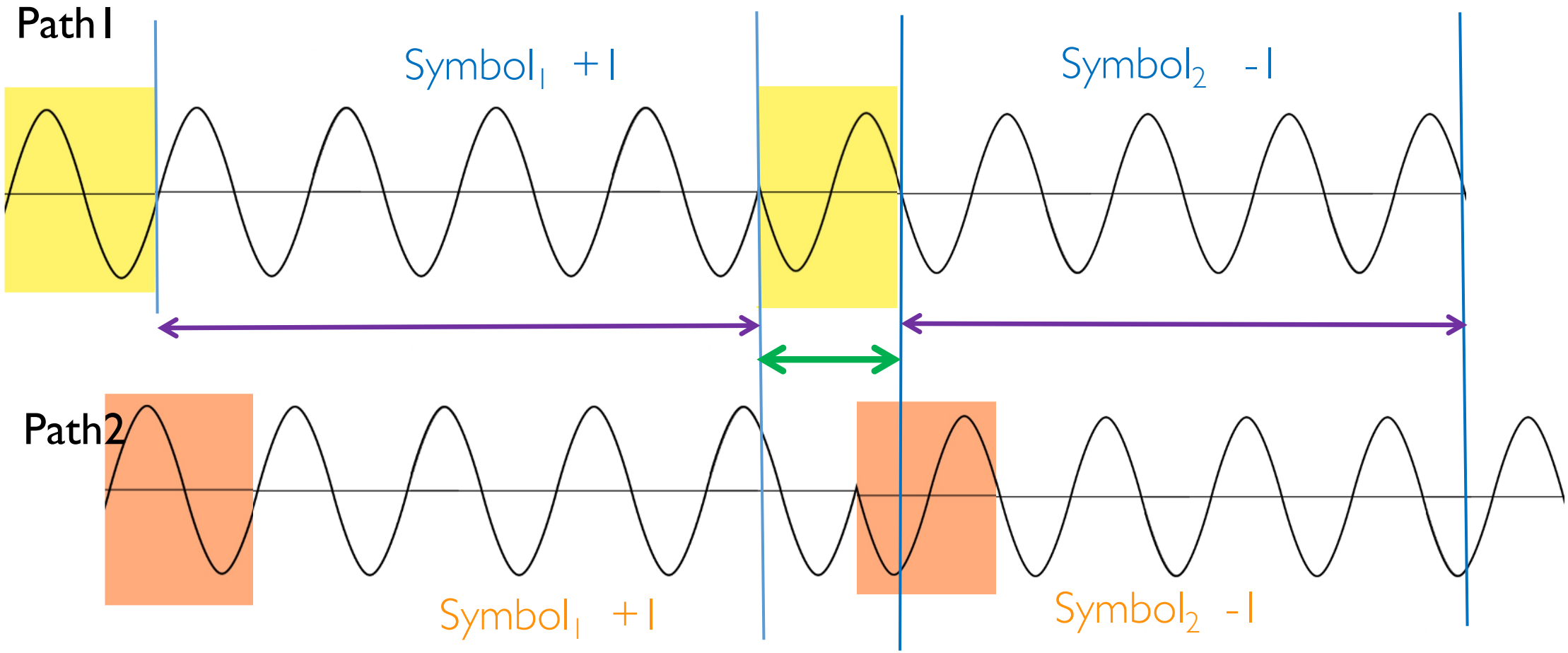
Multipath illustration using BPSK



Both Path 1 signals and path 2 signal in PURPLE are continuous thus can be ”equalized”

However, they are DISCONTINUOUS in GREEN section which cannot be “equalized”

Add cyclic prefix for each symbol

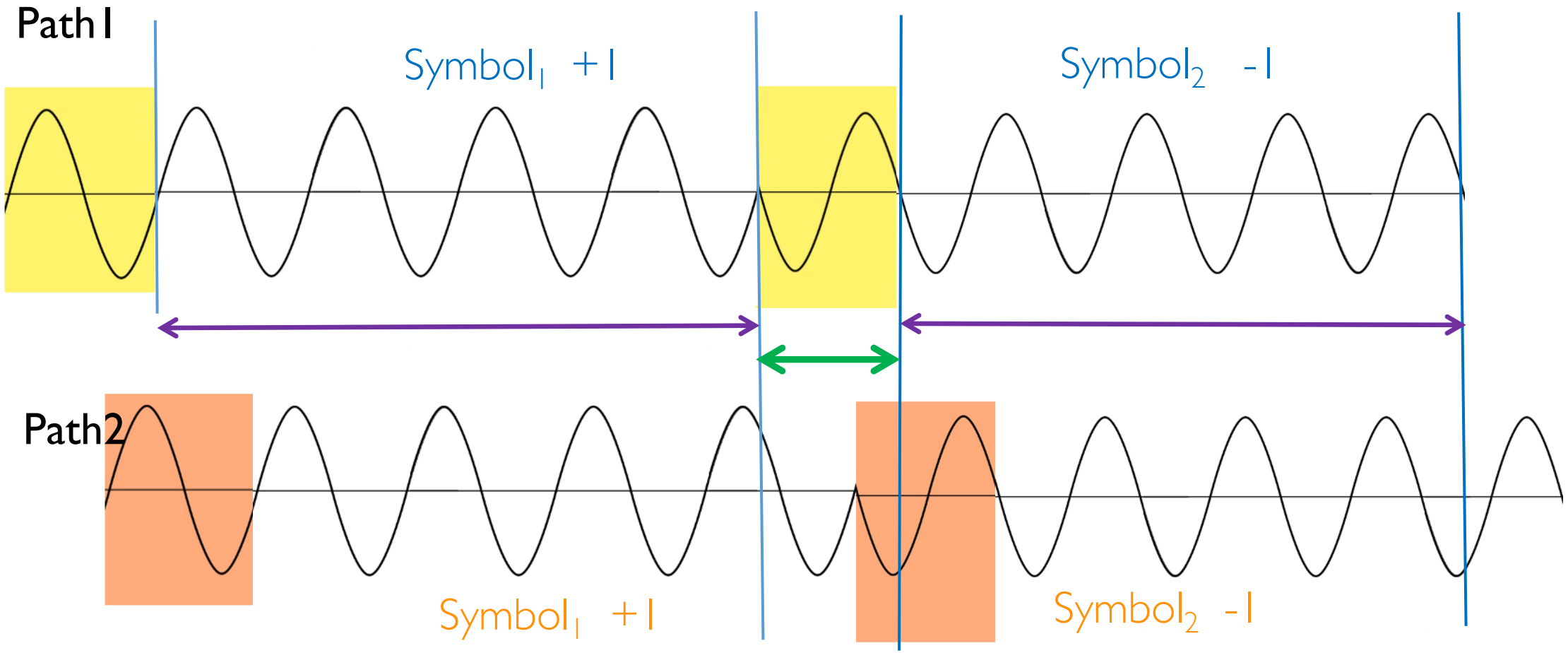


Both Path 1 signals and path 2 signal in PURPLE are continuous thus can be ”equalized”

Receiver still receives 4 cycles per symbol and performs equalization

We can safely discard GREEN section since it is repeated

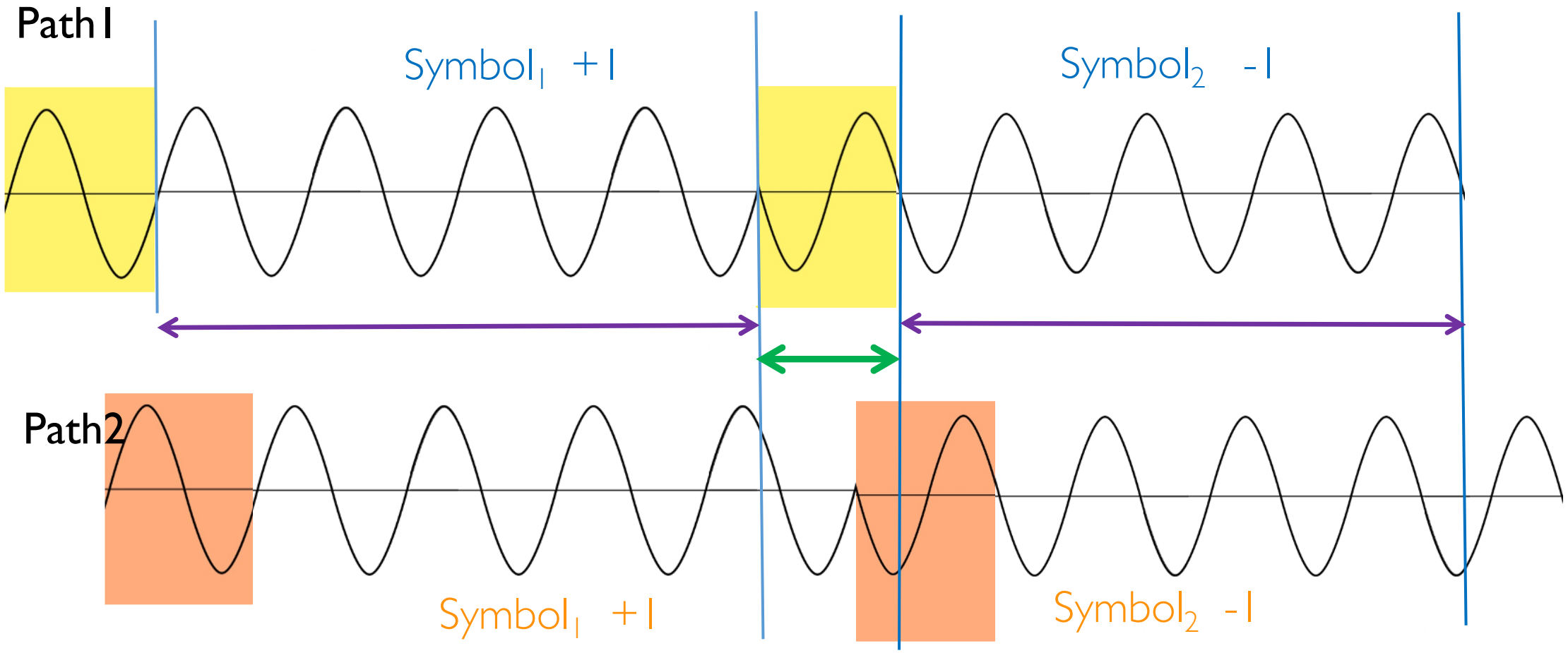
Add cyclic prefix for each symbol



More than one cycles maybe repeated depending on the delay of path 2 signal

How much should we pad as cyclic prefix?

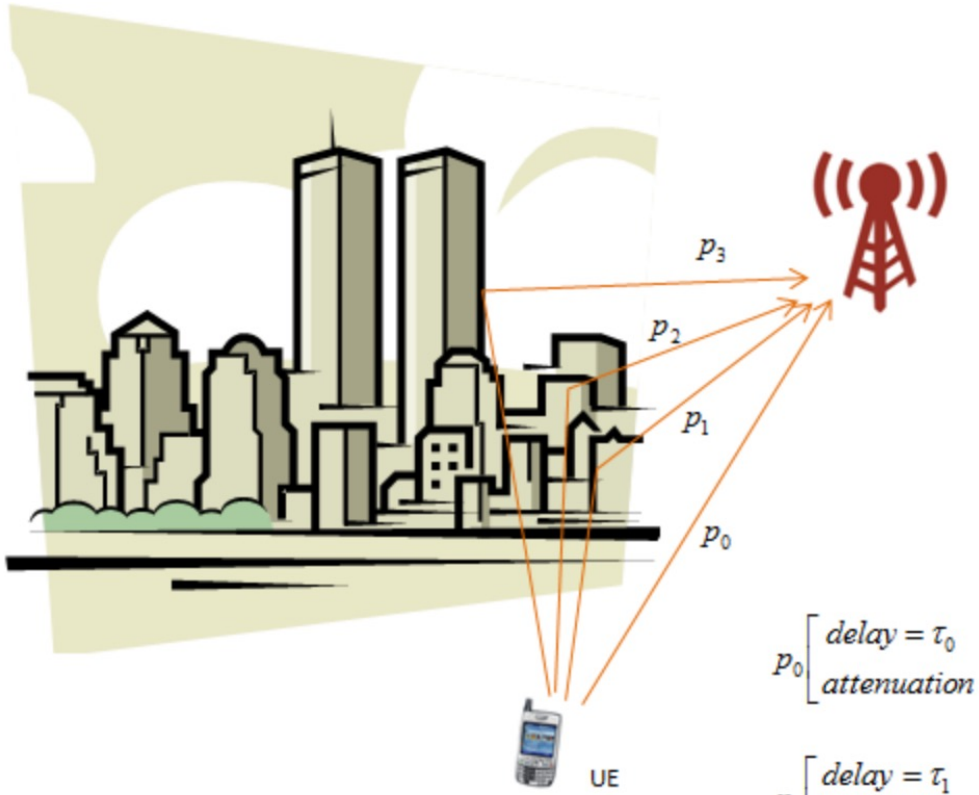
Cyclic prefix should span over maximum delay spread



More than one cycles maybe repeated depending on the delay of path 2 signal

How much should we pad as cyclic prefix?

Depends on the delay spread!

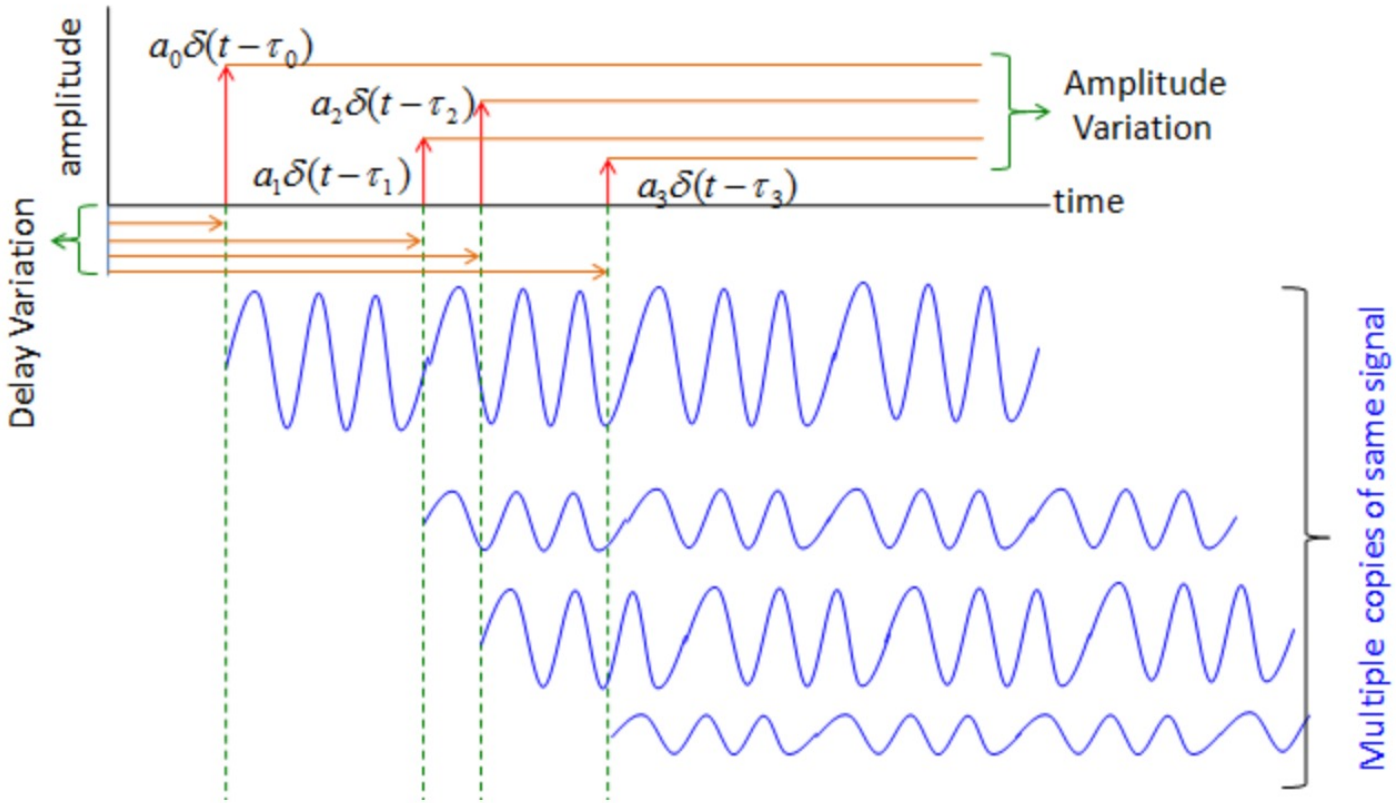


$$p_0 \begin{bmatrix} delay = \tau_0 \\ attenuation = a_0 \end{bmatrix}$$

$$p_1 \begin{bmatrix} delay = \tau_1 \\ attenuation = a_1 \end{bmatrix}$$

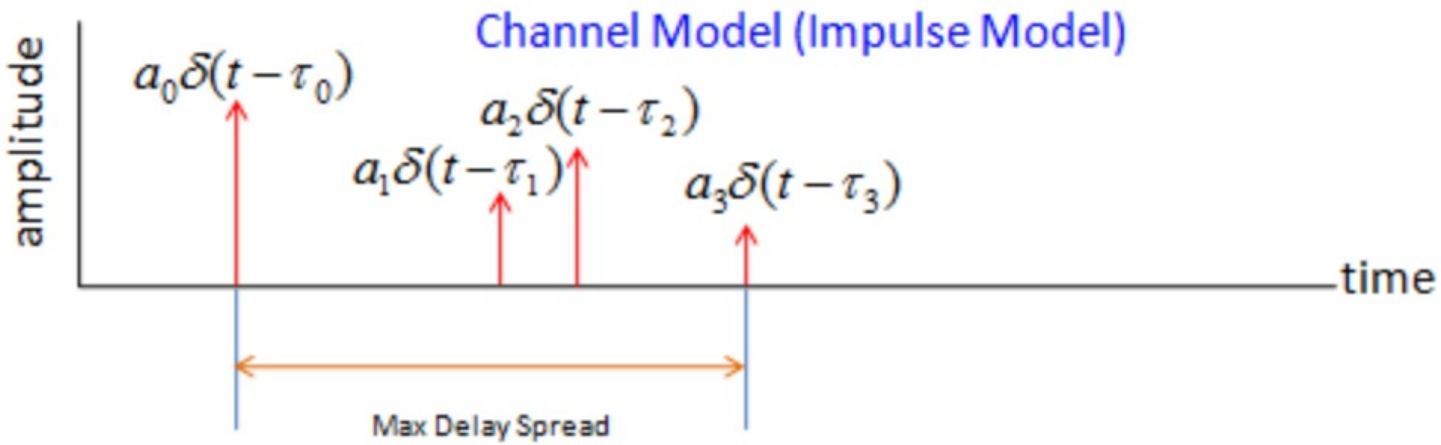
$$p_2 \begin{bmatrix} delay = \tau_2 \\ attenuation = a_2 \end{bmatrix}$$

$$p_3 \begin{bmatrix} delay = \tau_3 \\ attenuation = a_3 \end{bmatrix}$$



Maximum delay spread is the time difference btw the first path and the last path

Max Delay Spread

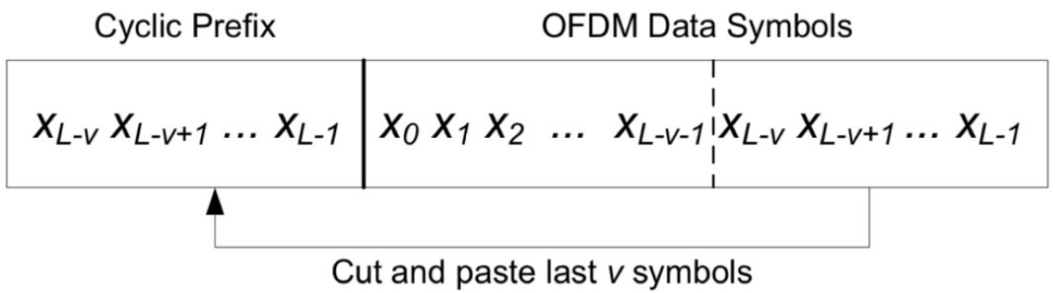


Cyclic prefix should span maximum delay spread

Outline

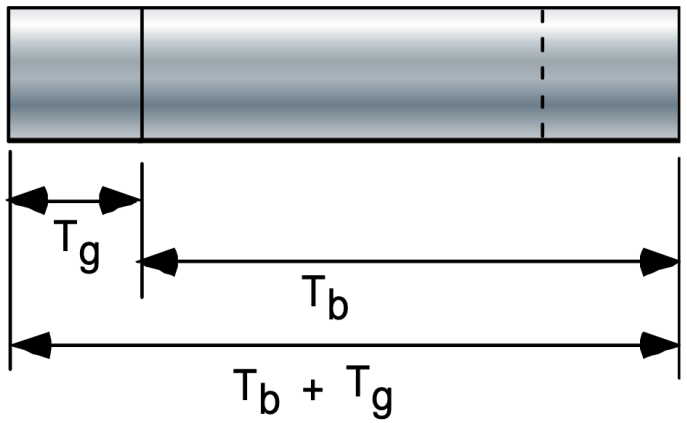
1. BPSK recap
2. Multipath and Cyclic Prefix
3. OFDM's Cyclic Prefix

OFDM Cyclic prefix



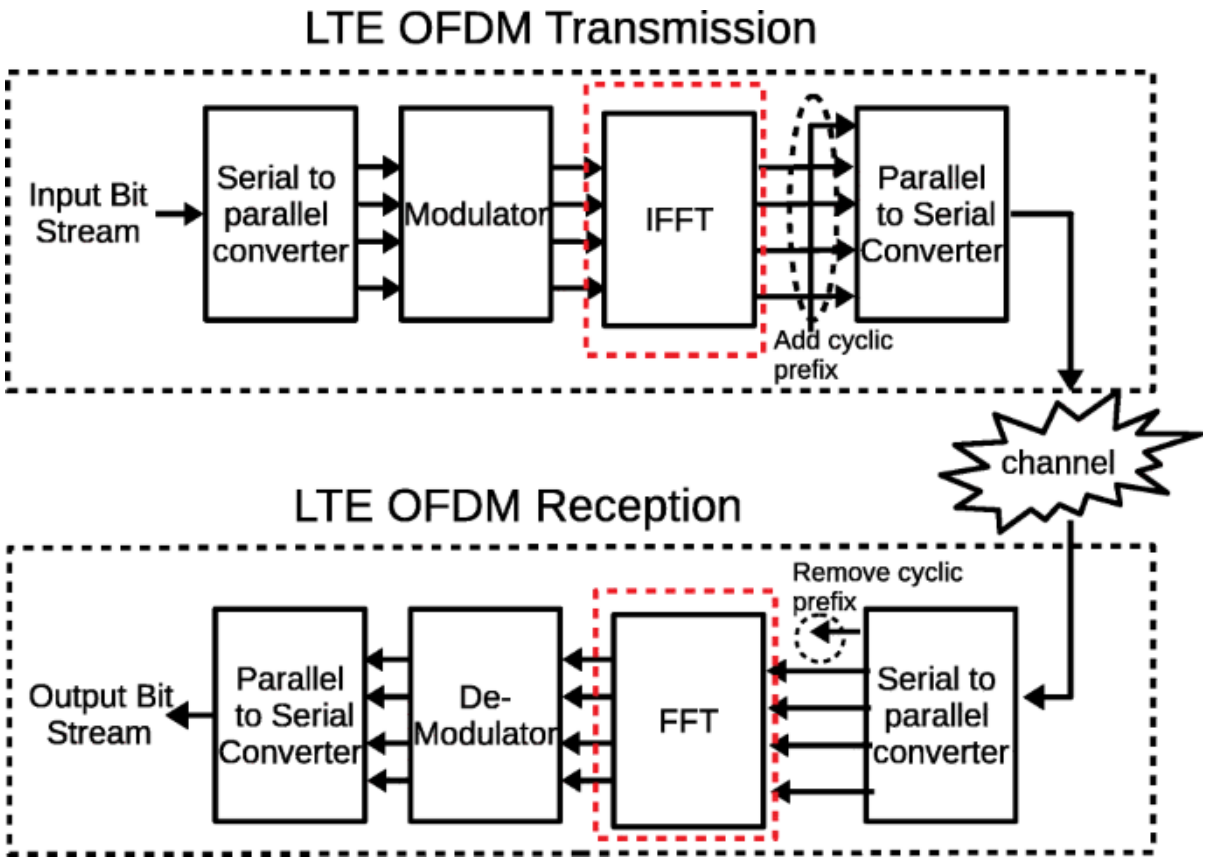
- If max channel delay spread = τ_{max}
  - Say v samples spans τ_{max}
- The last v samples are added as cyclic prefix
  - v redundant samples are sent for each symbol with L samples
- Penalties
  - Required bandwidth increases from B to B $\frac{L+v}{L}$
  - This means more power needed: 10 $\log_{10} \frac{L+v}{L}$ dB more
  - Rate loss: $\frac{L}{L+v}$

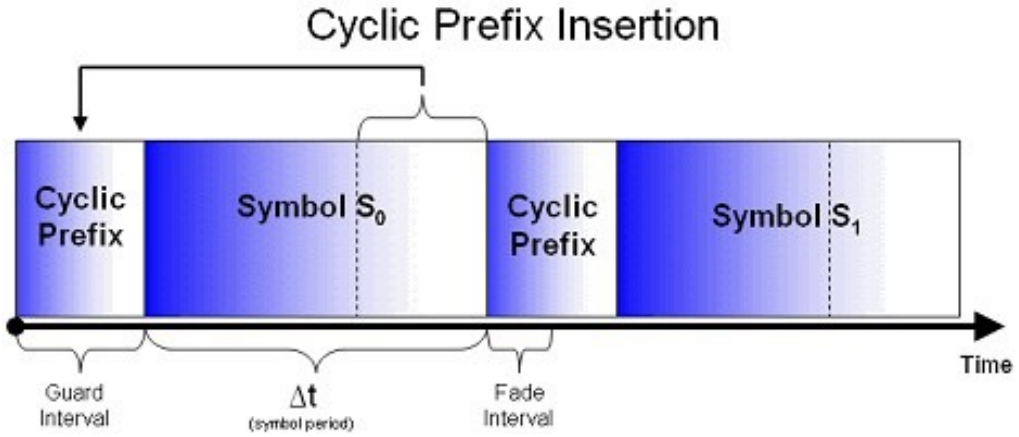
SNR Loss due to Cyclic Prefix



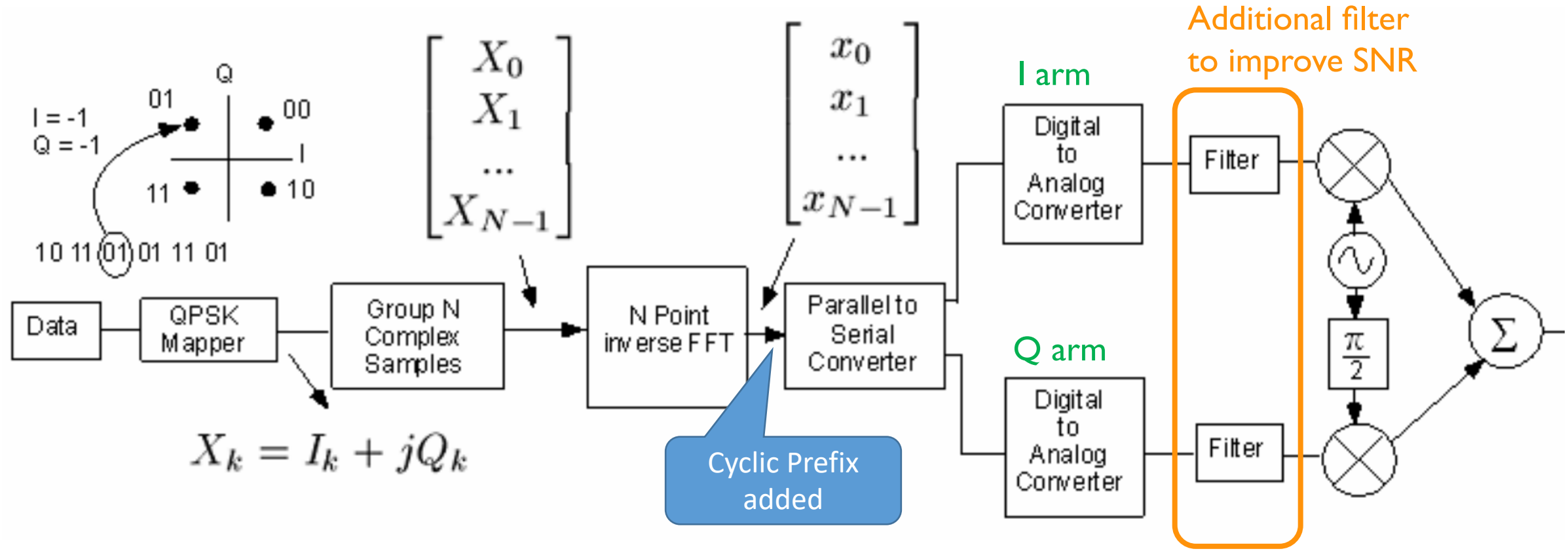
$$10\log_{10}(1-\frac{T_g}{T_b+T_g})\quad dB$$

OFDM: Cyclic prefix is inserted after IFFT for each symbol

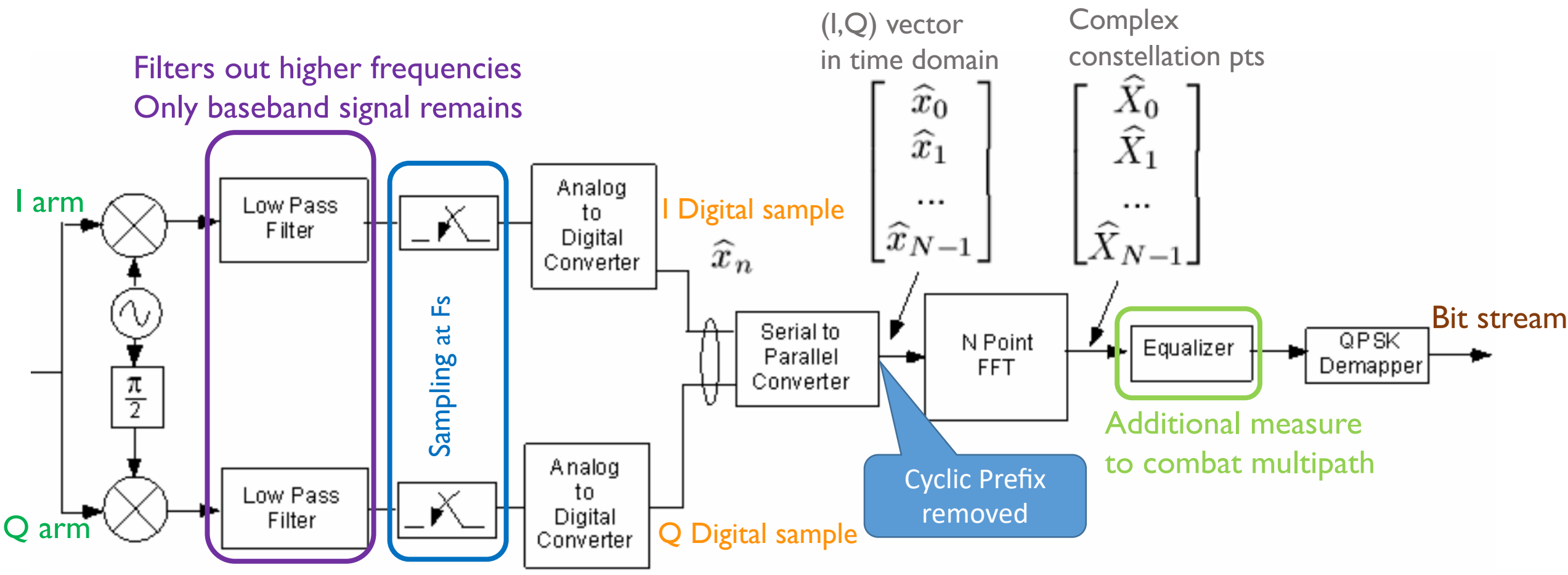




Fuller Story: OFDM sender with I/Q modulation



Fuller Story: OFDM receiver with I/Q modulation



Backup Slides

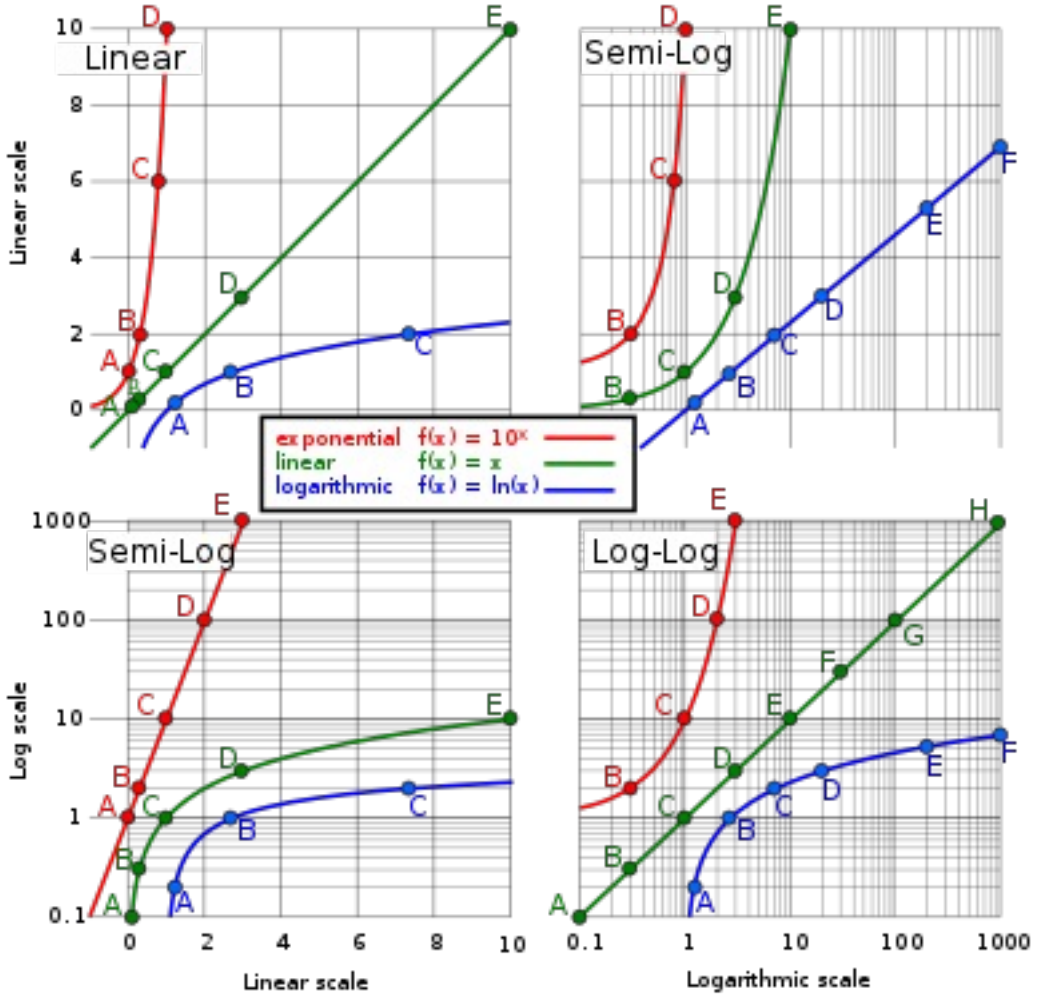
What is a dB (decibel)?

- $10 \times \log_{10} (\frac{P1}{P2})$
- The ratio between two power levels in logarithmic scale
  - P1 and P2 should be of the same unit that represents power

p1	p2	$\frac{P1}{P2}$	dB
1	1	1	0 dB
2	1	2	3 dB
10	1	10	10 dB
0.5	1	0.5	-3 dB
100	1	100	20 dB
1000	1	1000	300 dB

Why logarithmic scale?

Using log-scale enables to express data with large variations in one graph



dB is a ratio not an absolute quantity

- **We can say this signal is 3 dB greater than the other signal**
  - Meaning it has twice greater signal
- **We cannot say this signal level is 3 dB**
  - Makes no sense without a reference point

To convert dB into an absolute quantity
we must specify a reference point!

The suffix dB_ implies the reference

- **dBm: reference is 1 milliwatt (mW)**
  - 50 dBm means compared to 1 milliwatt, 10 $\log_{10}$ (ratio) is 50
  - To calculate the ratio two values must be in the same unit
  - Given 10 $\log_{10}$ (X W/0.001W) = 50, what is X?
  - X = 100 W = 10^50/10 x 0.001
- **dBμ: reference is 1 microwatt (μW)**
  - 50 dBμ means compared to 1 microwatt, 10 log10 (ratio) is 50
  - Given 10 $\log_{10}$ (Y W/0.000001W) = 50, what is Y?
  - Y = 0.1 W = 10^50/10 x 0.000001

To convert dB into an absolute quantity we must specify a reference point!