Wireless and Mobile Communications (ECE 459)

© Samy S. Soliman

Communications and Computer Engineering Department - Cairo University, Egypt
Zewail City - University of Science and Technology, Egypt

Email: *samy.soliman@cu.edu.eg*
Website: http://scholar.cu.edu.eg/samysoliman

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Outline

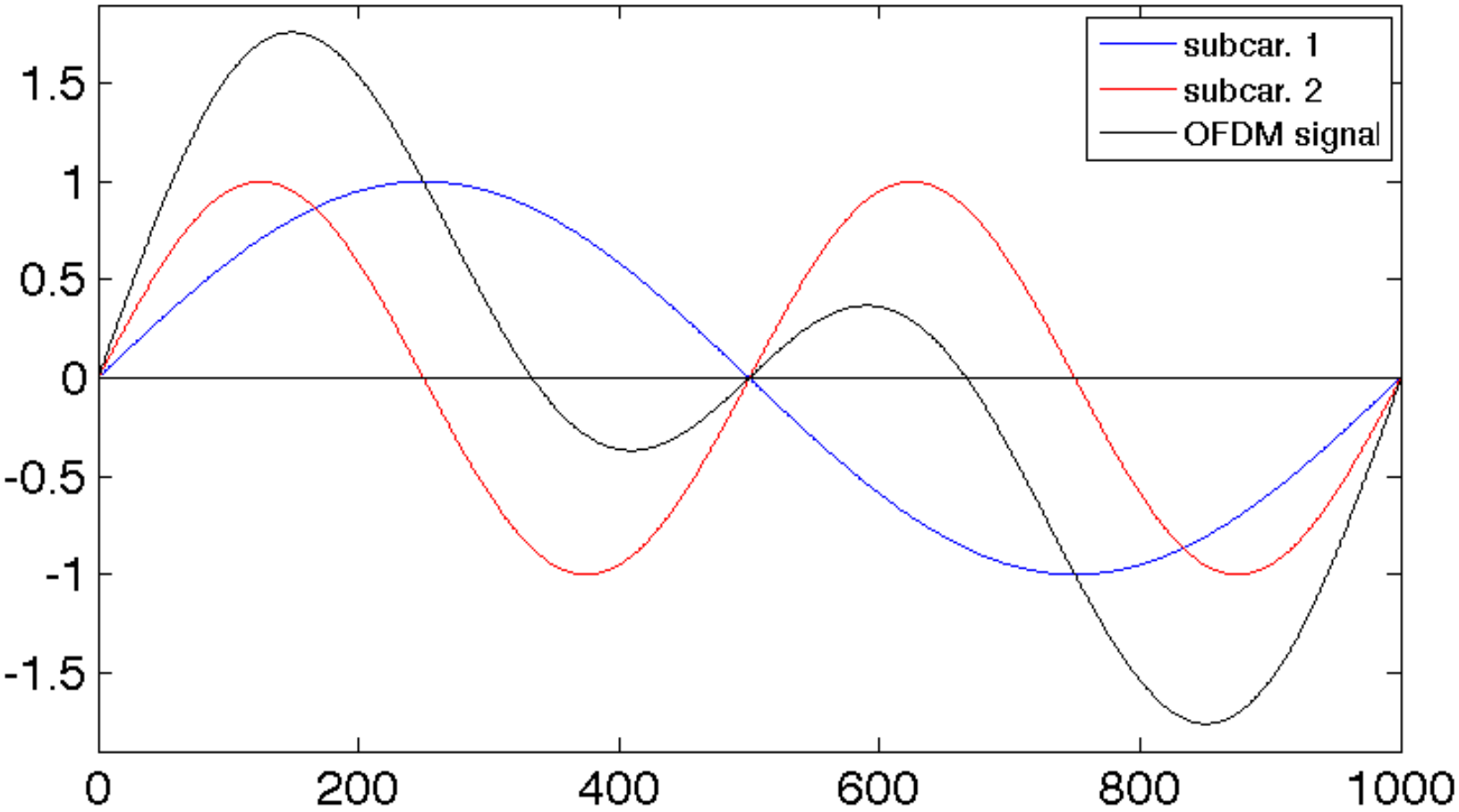
Orthogonal Frequency Division Multiplexing (OFDM)

Advantages and Disadvantages of OFDM

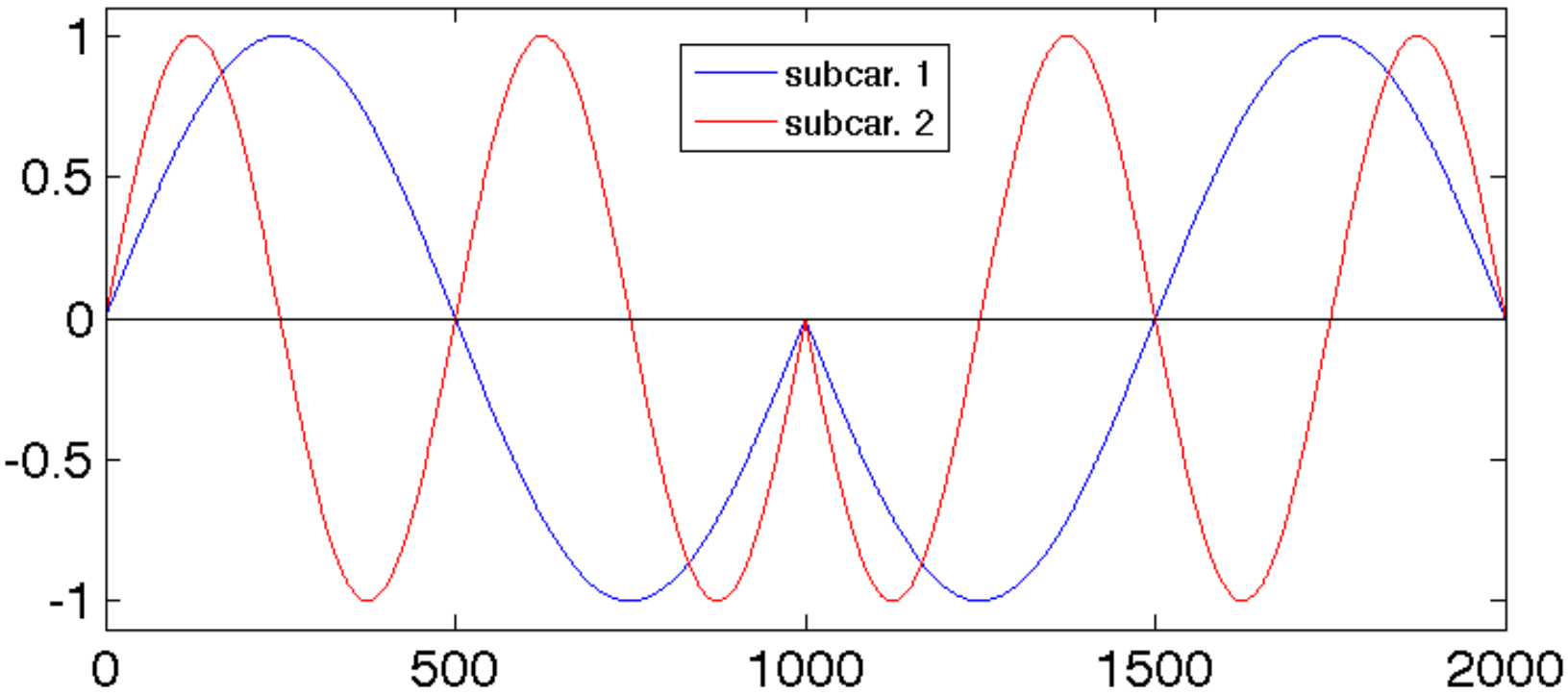
Guard Time and Cyclic Prefix

OFDM Signal

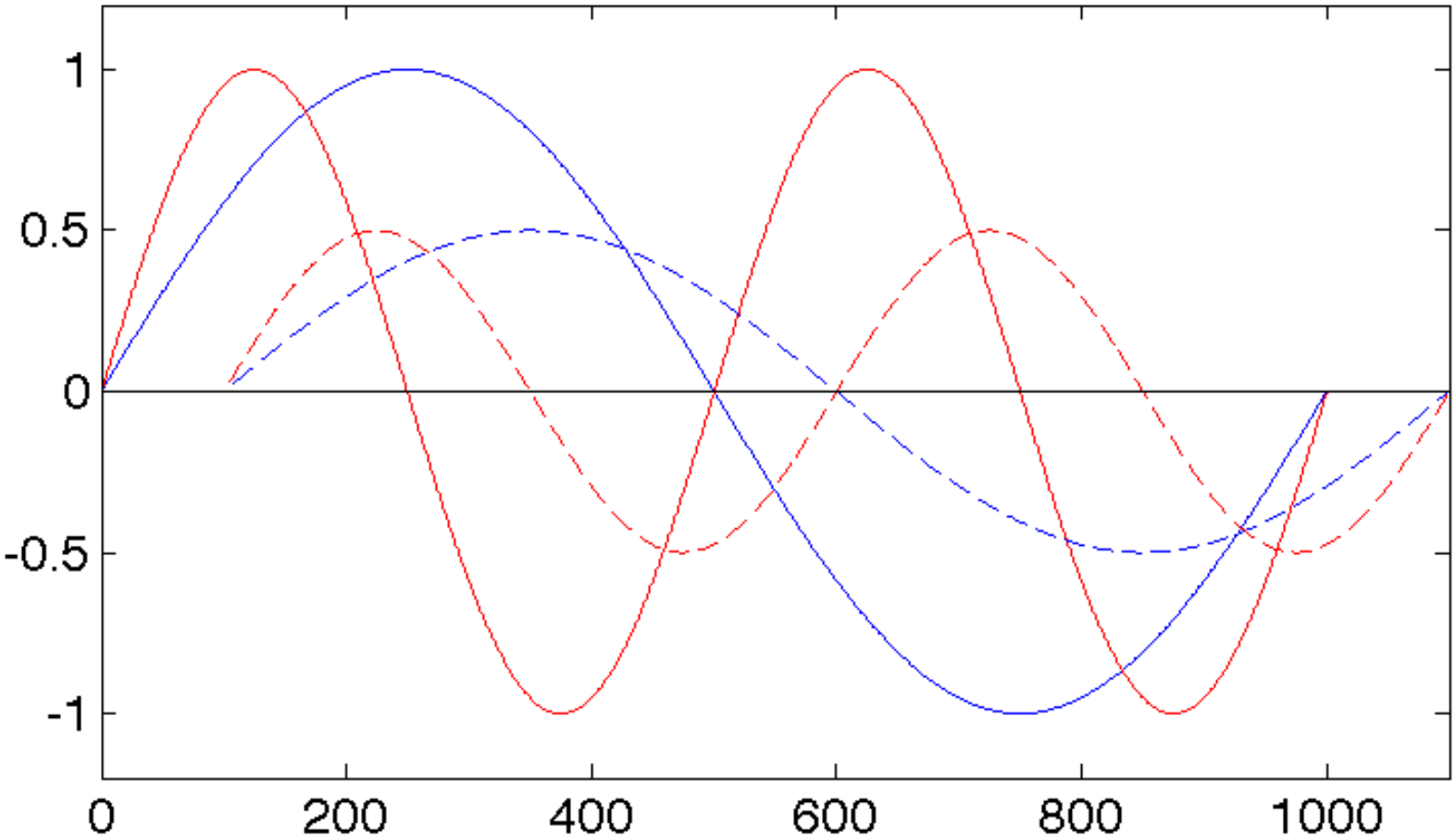
Each OFDM symbol is composed of N sub-carriers (tones).



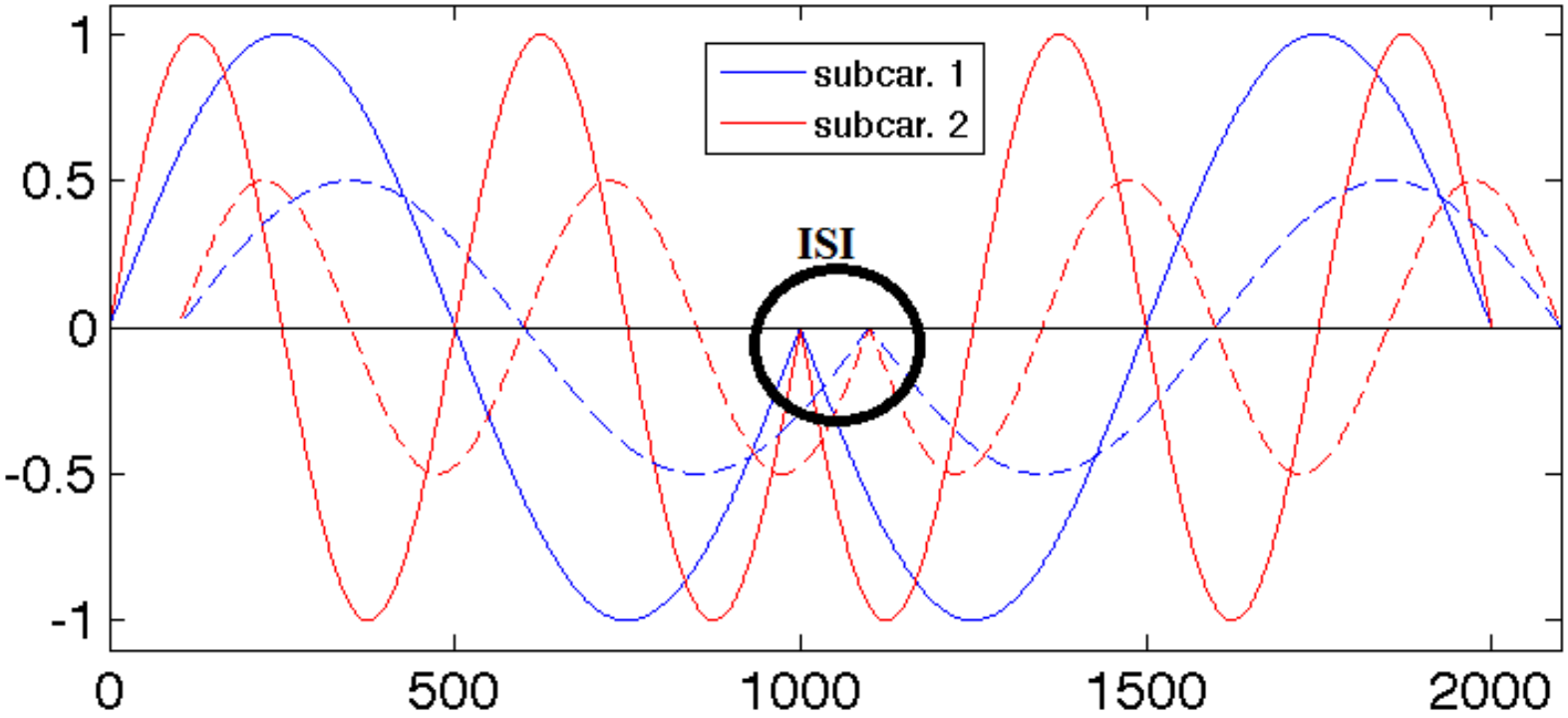
OFDM Signal - Two Symbol Duration



Effect of Multipath Fading - One Symbol Duration



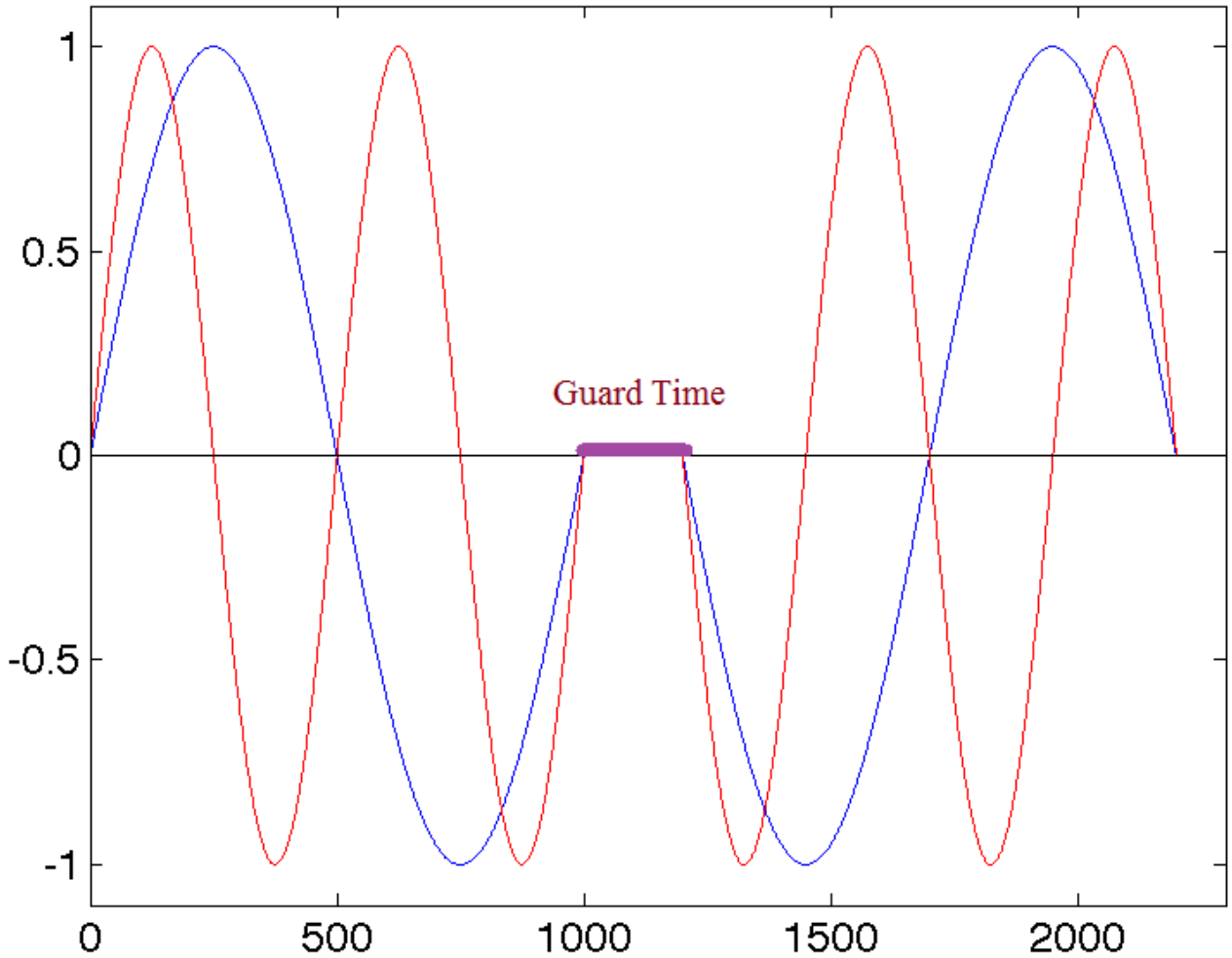
Effect of Multipath Fading - Two Symbol Duration



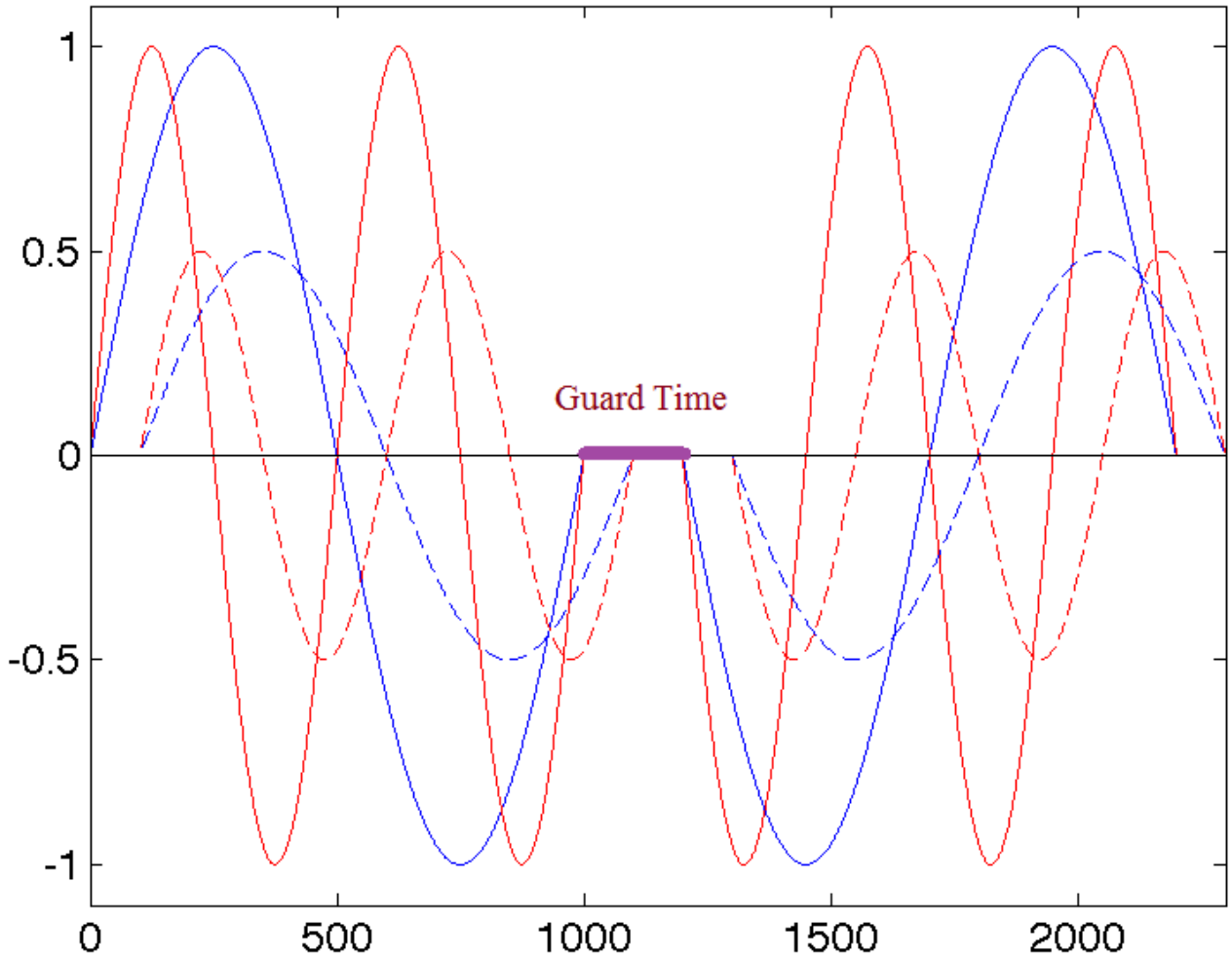
Inter Symbol Interference (ISI)

Note that the symbol duration in OFDM is extended by a factor of N compared to single carrier systems. This reduces the relative multipath spread, but does not completely remove ISI.

Guard Time



Guard Time - Removal of ISI



Guard Time

1. The guard time is chosen larger than the average delay spread, or equal to the maximum delay spread, such that multipath component for one symbol does not interfere with the next symbol.
2. **Guard Time**

$$\begin{aligned} T_G &= \alpha T_m|_{\text{average}} \\ \text{or } T_G &= T_m|_{\max} \end{aligned}$$

3. **Efficiency**

$$\eta = \frac{NT}{NT + T_G}$$

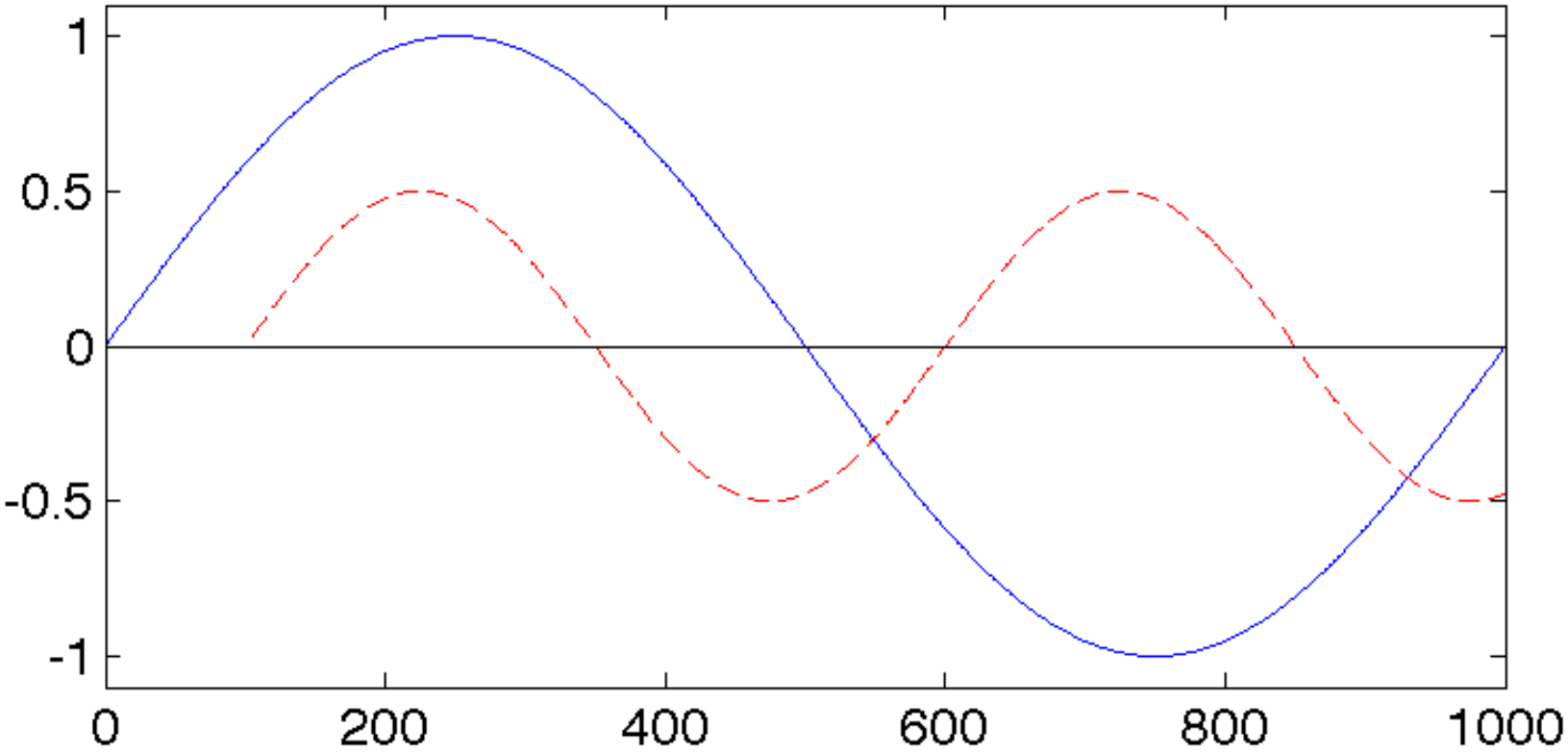
Where:

N = Number of sub-carriers/tones

T = Symbol duration for single carrier systems $= \frac{1}{W}$

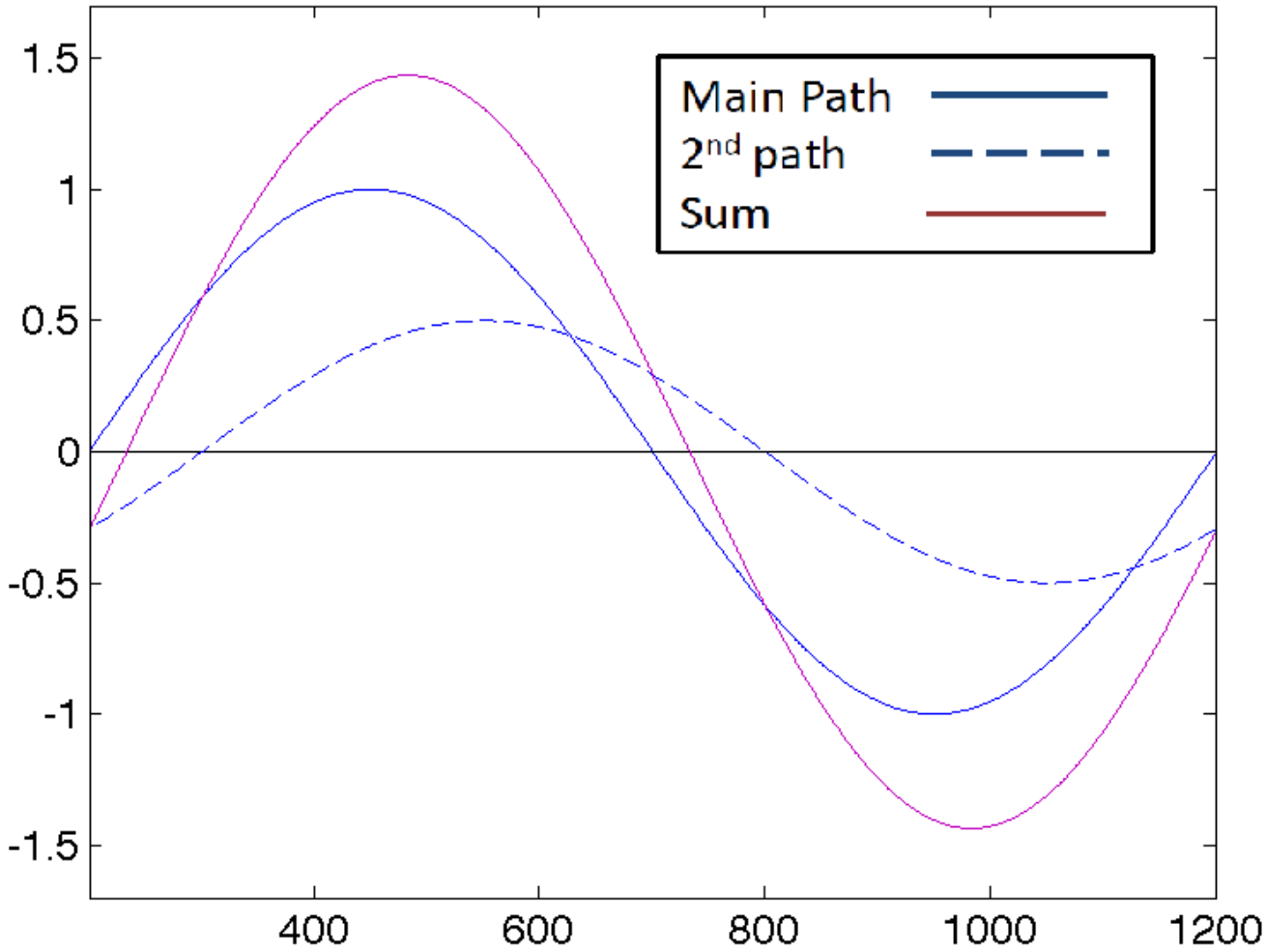
W = Transmission bandwidth

Inter Carrier Interference

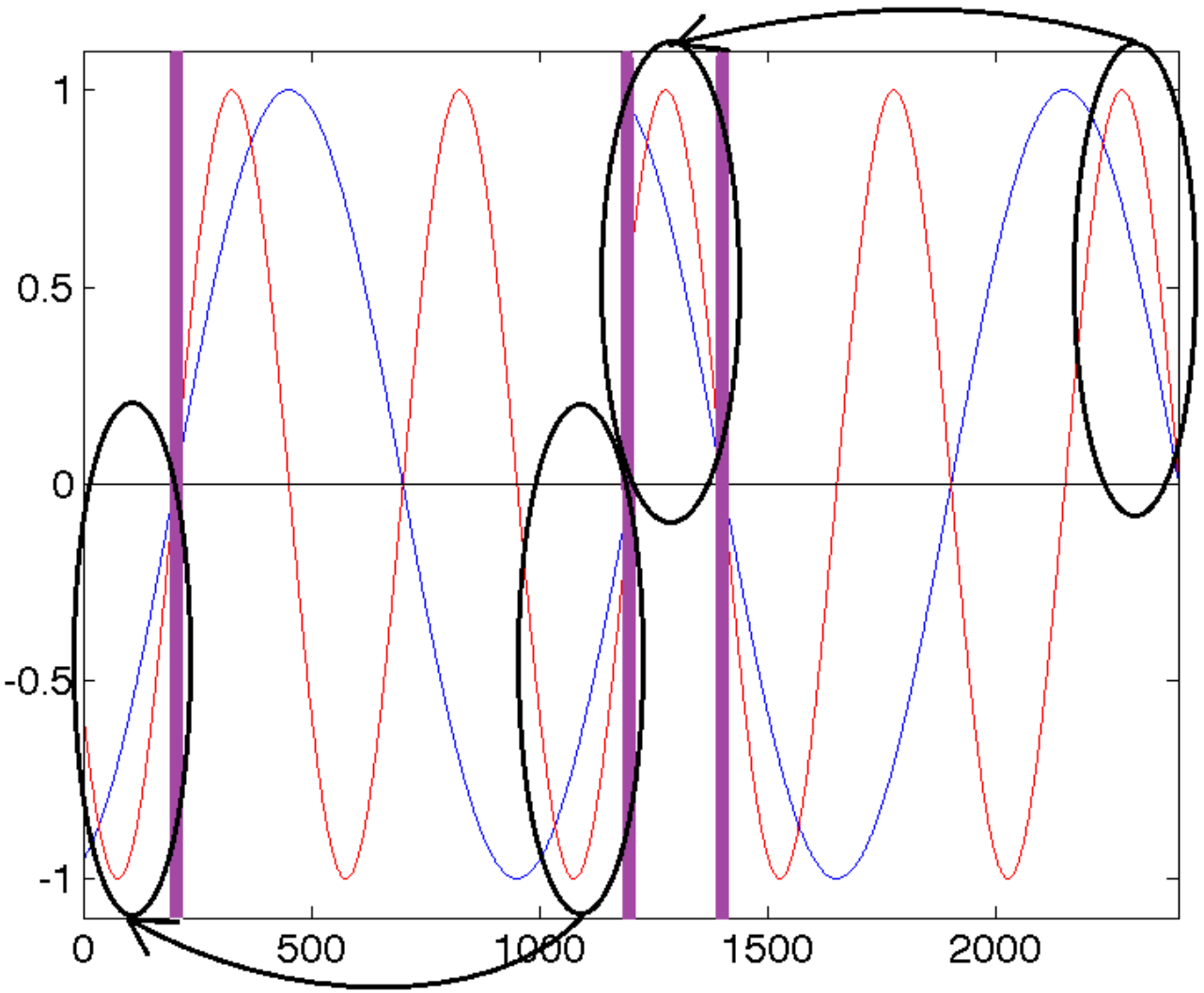


ICI is the cross talk between different sub-carriers which means they are no longer orthogonal.

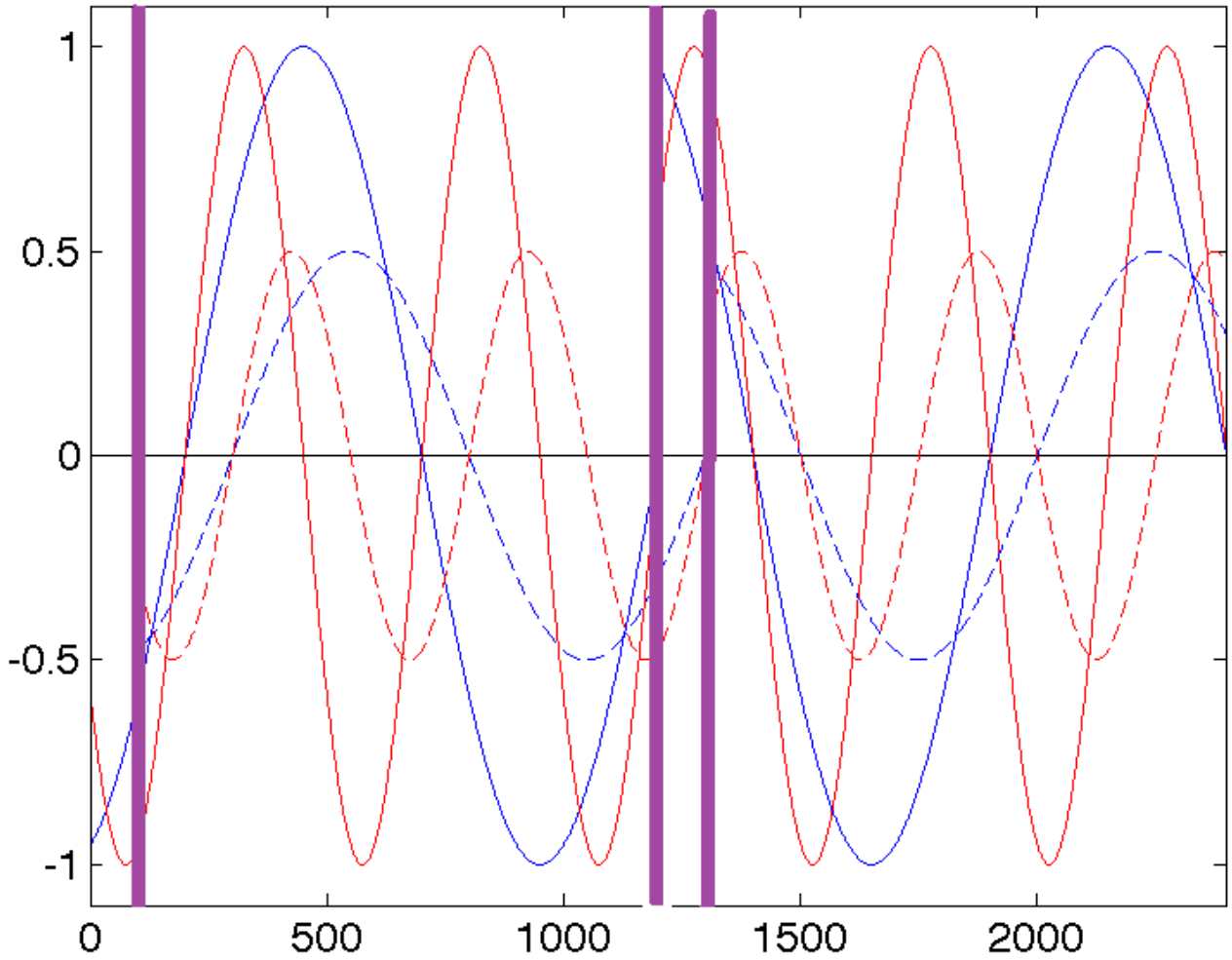
Orthogonality of Sub-Carriers - Multipath Fading



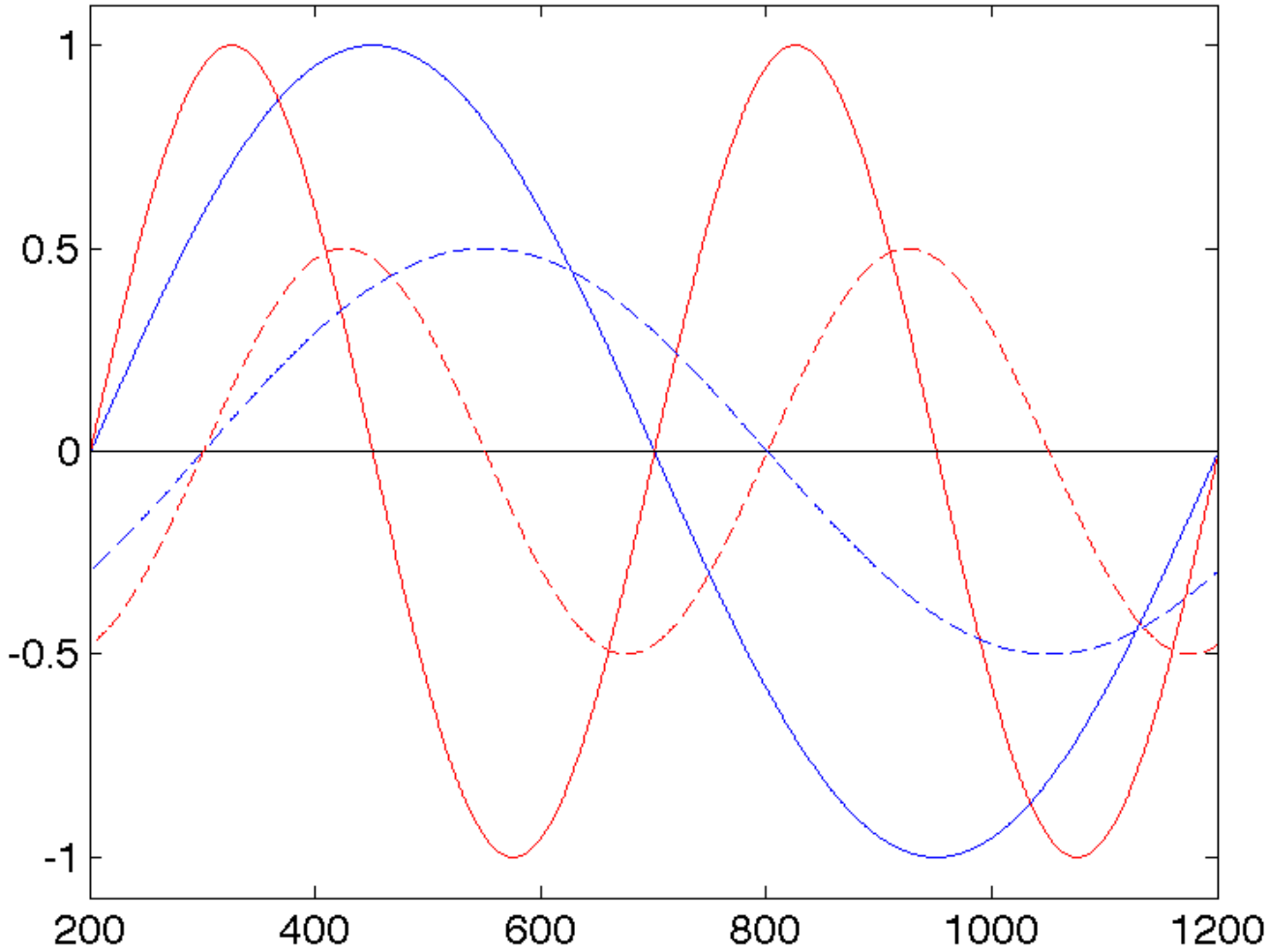
Cyclic Prefix



Cyclic Prefix + Multipath Fading



Cyclic Prefix - ICI Removal

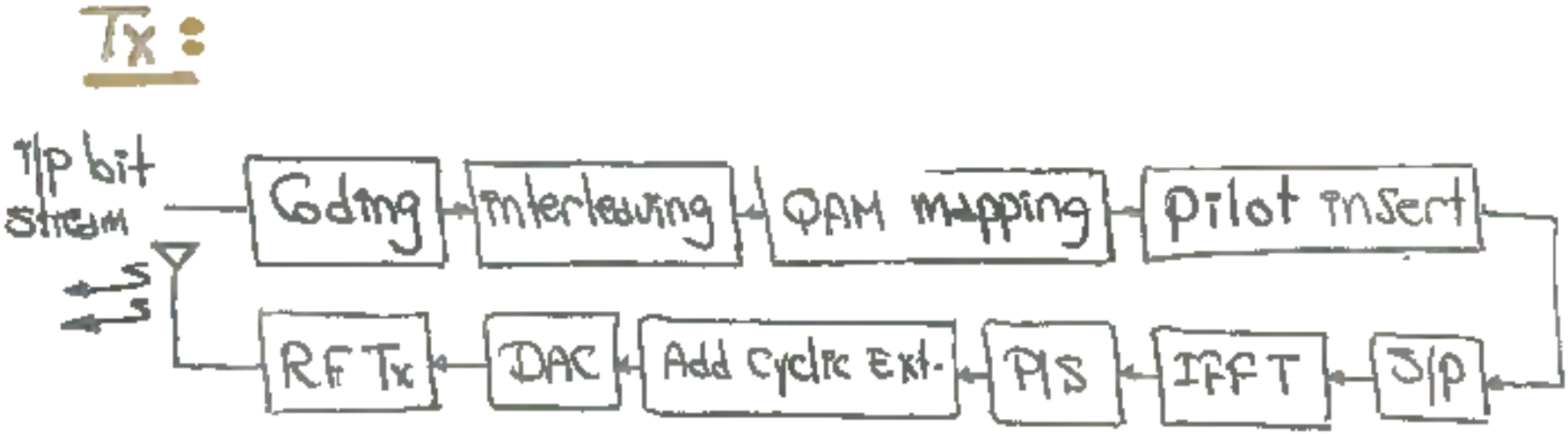


Cyclic Prefix - ICI Removal

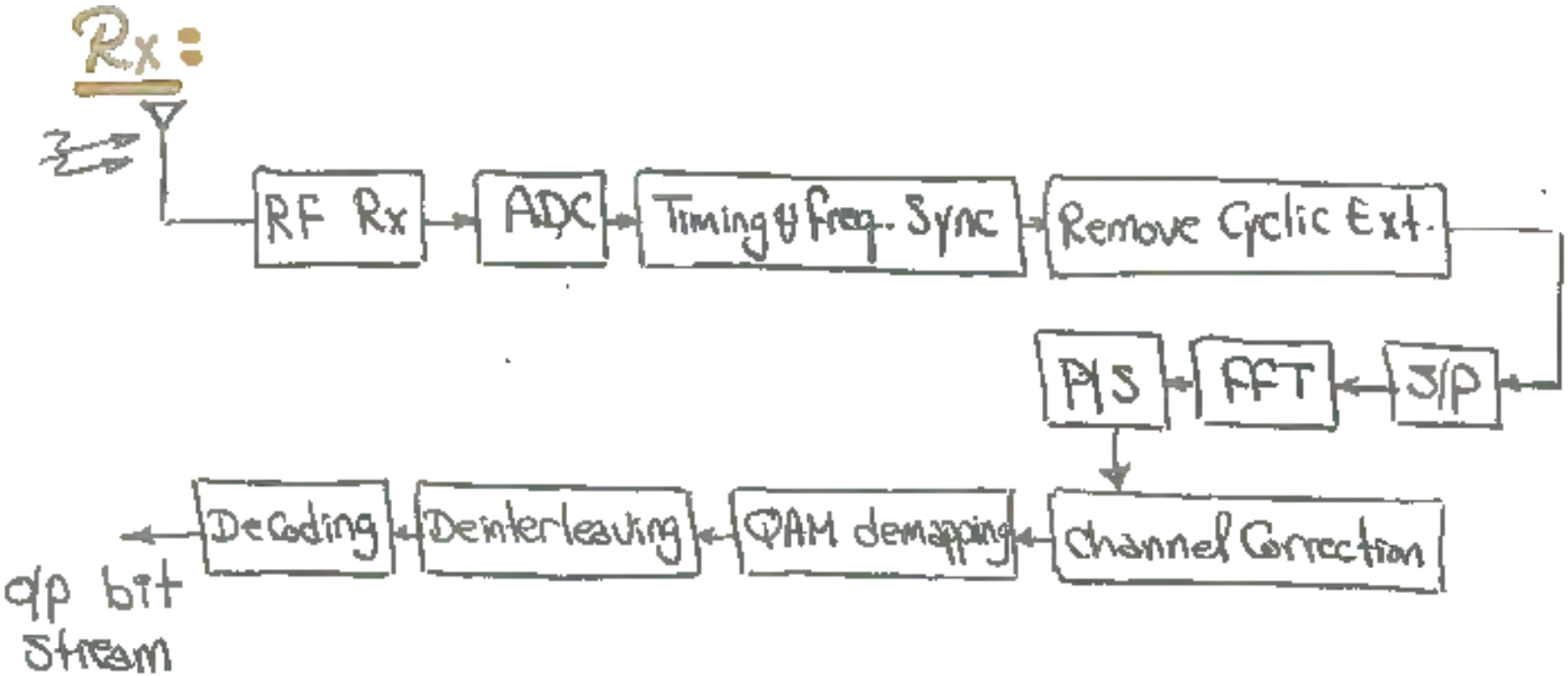
1. To eliminate ICI , OFDM symbols are cyclically extended in the guard time. This ensures that delayed replicas of the OFDM symbol always have an integer number of cycles within the symbol interval.
2. Energy is wasted in the cyclic prefix samples.

OFDM Signal Processing

OFDM - Transmitter Block Diagram



OFDM - Receiver Block Diagram



OFDM - Tx/Rx

OFDM Tx/Rx Building Blocks

1. Coding/Decoding
2. Interleaving/De-interleaving
3. QAM Mapping/De-mapping
4. Pilot Insertion/Channel Correction
5. Add/Remove Cyclic Extension
6. IFFT/FFT
7. DAC/ADC

OFDM System Design

OFDM System Design

Given Parameters

1. Total available bandwidth (BW)
2. Data bit rate (R_b)
3. Channel delay spread (T_{av} or T_{max})

Design

1. Guard Time/Cyclic Prefix Time
2. OFDM Symbol Time
3. Subcarrier frequency separation
4. Maximum number of subcarriers
5. Modulation scheme + Coding
6. FFT size

OFDM System Design

Guard Time

$$T_G = T_{\max}, \quad \text{or} \quad T_G = 4T_{\text{av}}$$

OFDM Symbol Time

$$\begin{aligned} T_{\text{OFDM-Data}} &= 5T_G \\ T_{OFDM} &= T_{\text{OFDM-Data}} + T_G \end{aligned}$$

OFDM Symbol Efficiency

$$\eta = \frac{T_{\text{OFDM-Data}}}{T_{\text{OFDM-Data}} + T_G} = \frac{NT}{NT + T_G}$$

OFDM System Design

Inter-carrier Frequency Separation

$$\Delta f = \frac{1}{T_{\text{OFDM-Data}}}$$

Maximum number of Sub-carriers

$$N_{\text{max}} = \frac{\text{BW}}{\Delta f} = \text{BW} \times T_{\text{OFDM-Data}}$$

Number of bits per OFDM symbol

For all sub-carriers together

$$\text{bits/symbol} = R \times T_{\text{OFDM}}$$

OFDM System Design

Number of bits per OFDM sub-carrier

$$\text{bits/carrier} = \left\lceil \frac{\text{bits/symbol}}{N_{\max}} \right\rceil \quad \Rightarrow \text{Modualtion and Coding}$$

Actual number of data sub-carriers

$$N = \frac{\text{bits/symbol}}{\text{bits/carrier}}$$

Note that the remaining $(N_{\max} - N)$ sub-carriers can be used for pilot insertion

FFT Size

$$L = 2^m \geq N_{\max}$$

Note that the remainder $(L - N_{\max})$ FFT inputs can be zero padded.

OFDM System Design

Example

Design an OFDM system given

1. Available channel BW $= 15$ MHz
2. Required data bit rate $= 20$ Mbps
3. Channel average delay spread $= 200$ ns

References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Thank You

Questions ?

samy.soliman@cu.edu.eg

http://scholar.cu.edu.eg/samysoliman