ECE 257B: Principles of Wireless Networks

Lecture 3: Part 1: Review Wireless Channel

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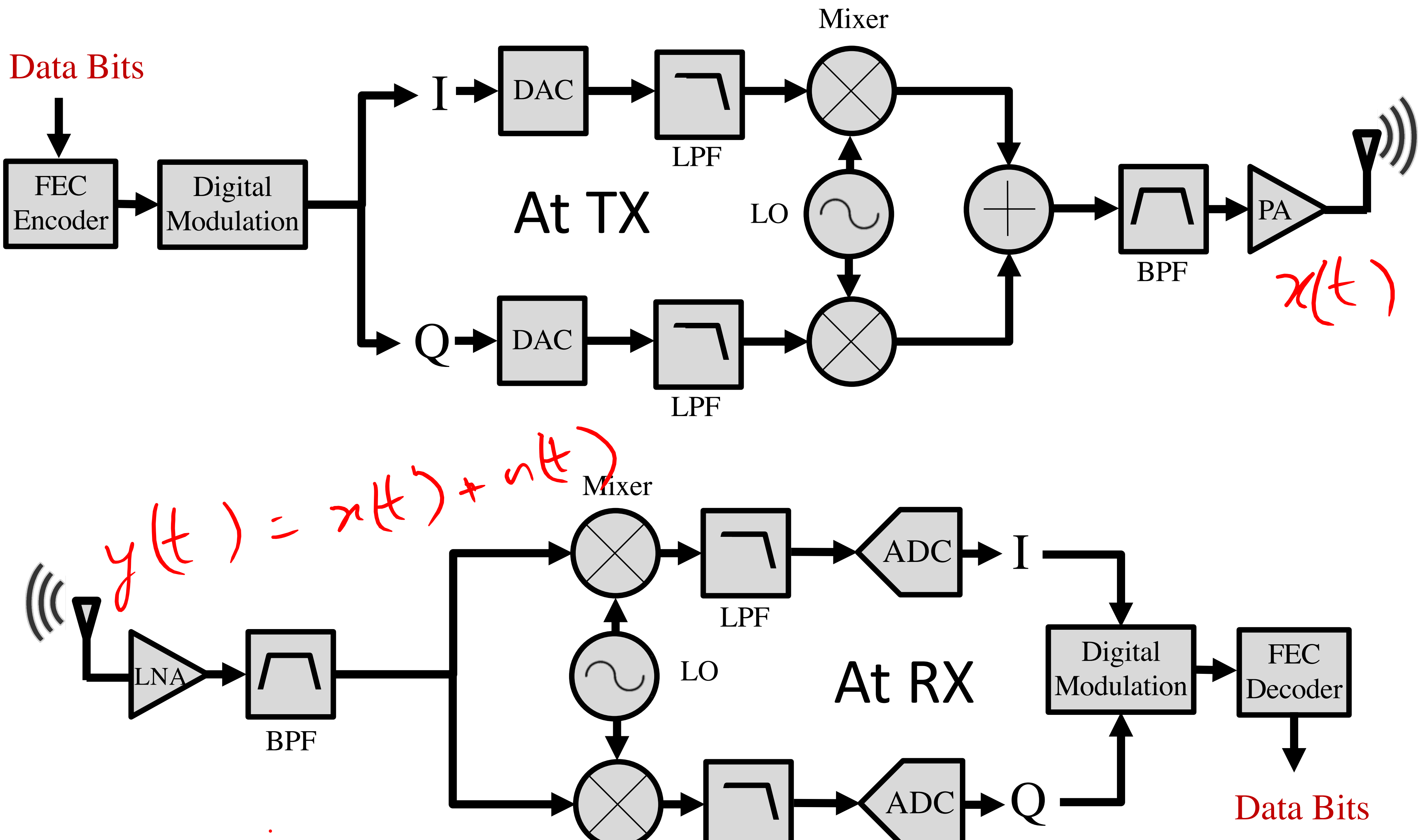
Previous Class: Wireless Communication

- How do we communicate information over wireless channels?
  - Passband Communication
  - Up-Conversion and Down conversion
  - Modulation
  - AWGN channel model
  - ML Decoder

Last Class in one Slide



Today’s Class: Wireless Channel

- Wireless vs Wired:
  – Fundamental difference is the channel, which provides features as mobility and broadcast.
- How do we model channel and it’s implication on waveform design?
  – pathloss and propagation delay
  – Multi-path
- Why OFDM?

Wireless Data Rates

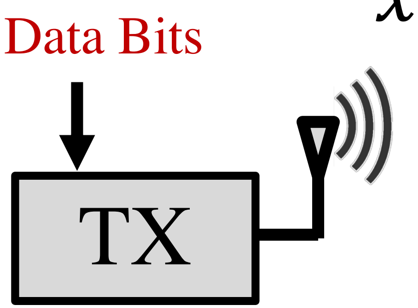
- *Data Rate*
  - *Bandwidth: Samples/sec*
  - *Modulation: Bits/sample*
  - *Coding Rate: Data Bits/Coded Bits*

$$Data\ Rate = Bandwidth \times Bits/sample \times Code\ Rate$$

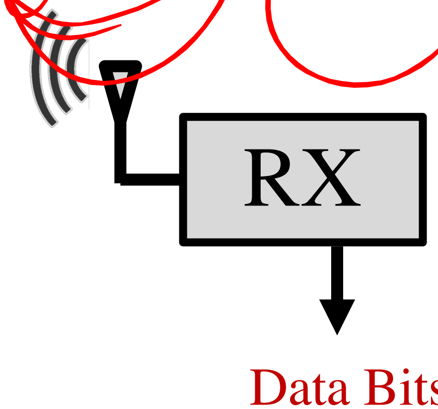
- *Capacity*
  - *Maximum Achievable Data Rate*
  - *Shannon Capacity Theorem:*

$$Capacity = Bandwidth \times \log_2(1 + SNR)$$

Wireless Channel



$x(t)$ —— d ——→ $y(t) = h\,x(t) + n(t)$



$$h \propto \frac{\lambda}{d} e^{j2\pi d/\lambda}$$

$$P_{Rx} = \frac{G_{Tx} G_{Rx} \lambda^2}{(4\pi d)^2} P_{Tx}$$

$\frac{1}{f^2}$ $\left(\frac{\lambda}{d}\right)^{\alpha}$

$\alpha = 2$

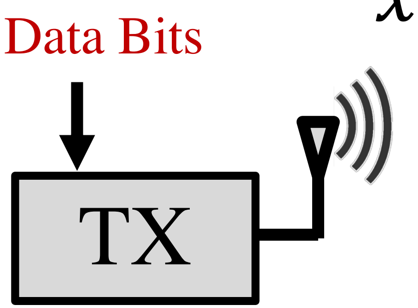
$\alpha = 3$

$\alpha = 4$

$$Path\ Loss\ (dB) = 10 \log_{10} P_{Tx}/P_{Rx}$$

$$SNR = \frac{|h|^2 \times |x(t)|^2}{|n(t)|^2} = \frac{|h|^2 P_{Tx}}{N}$$

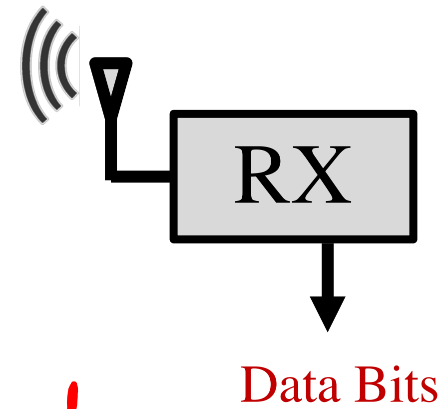
Wireless Channel



$x(t)$

$$y(t) = h\,x(t) + n(t)$$

wireless channel



$$h \propto \frac{\lambda}{d} e^{j2\pi d/\lambda}$$

wavelength = $\frac{c}{f_c}$

Antenna Gain

$\alpha > 2$

$$P_{Rx} = \frac{G_{Tx}\, G_{Rx}\, \lambda^2}{(4\pi d)^2} P_{Tx}$$

transmit power.

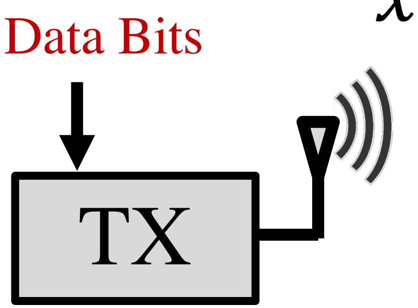
distance between TX & RX

① Attenuate

$$Path\ Loss\ (dB) = 10 \log_{10} P_{Tx}/P_{Rx}$$

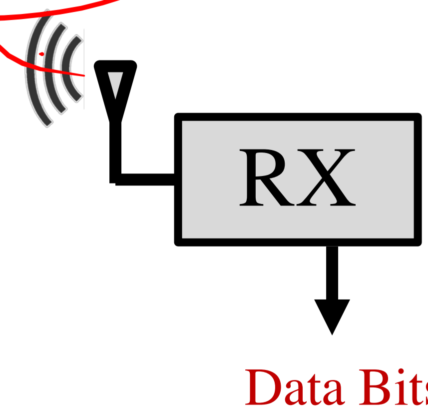
$$SNR = \frac{|h|^2 \times |x(t)|^2}{|n(t)|^2} = \frac{|h|^2 P_{Tx}}{N}$$

Wireless Channel



$x(t)$

$$y(t) = h\,x(t) + n(t)$$



$$h \propto \frac{\lambda}{d}\, e^{j2\pi d/\lambda}$$

$$x(t) = x_B(t)\cos(2\pi f_c t)$$

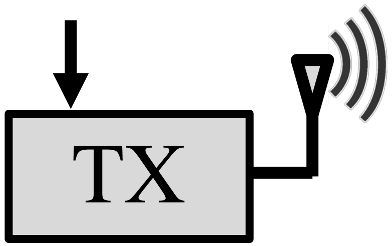
$$y(t) = x(t)\,h = h\,x_B(t-\tau)\cos(2\pi f_c(t-\tau))$$

$$\tau = 2$$

Wireless Channel

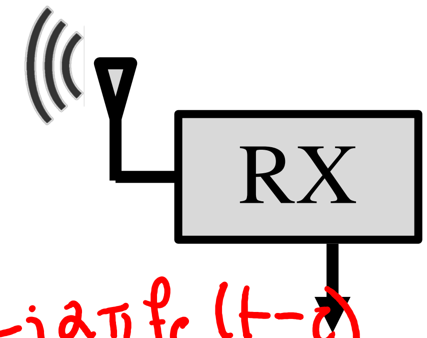
$x(t)$

Data Bits



$$h \propto \frac{\lambda}{d}\, e^{j2\pi d/\lambda}$$

$$y(t) = h\, x(t) + n(t)$$



Data Bits

$x(t)\, e^{j2\pi f_c t}$ $\longrightarrow$ $x(t-\tau)\, e^{-j2\pi f_c (t-\tau)}$

$e^{+j2\pi f_c \tau}\, x(t)\, e^{-j2\pi f_c t} \times e^{j2\pi f_c t}$

down conversion

$\tau = \frac{d}{c}$; $f_c = \frac{c}{\lambda}$

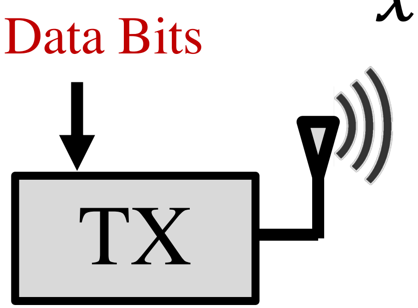
$= e^{+j2\pi \frac{d}{\lambda}}\, x(t)$

channel phase

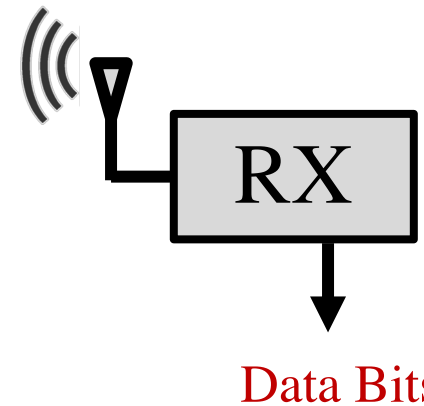
Channel Estimation & Correction

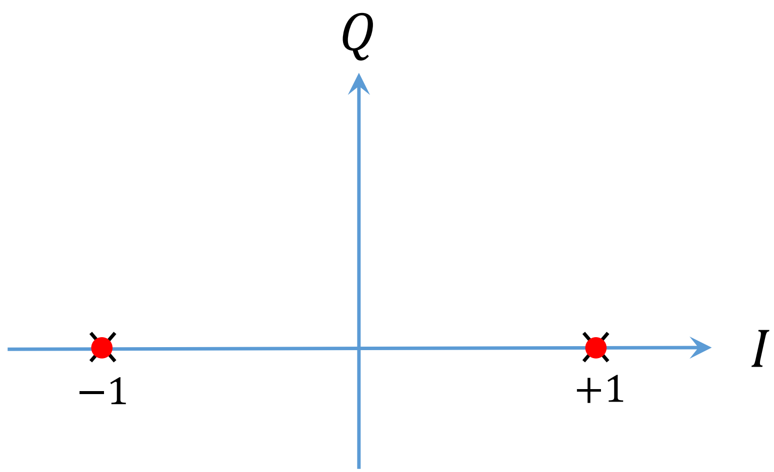
$x(t)$

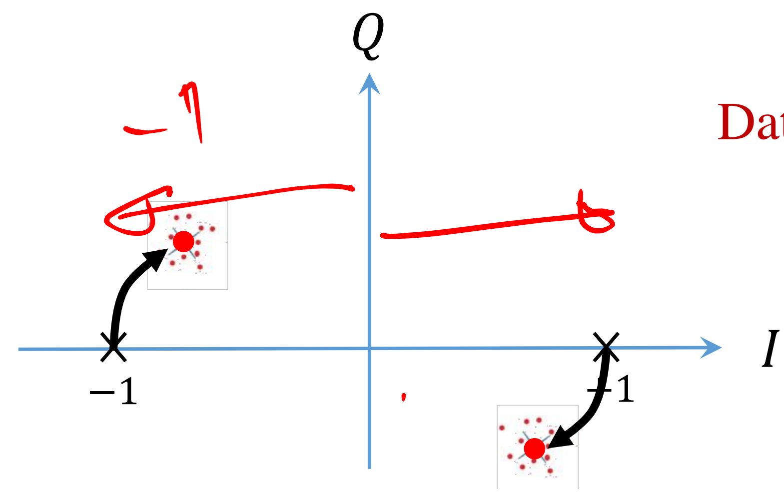
$y(t) = h\, x(t) + n(t)$

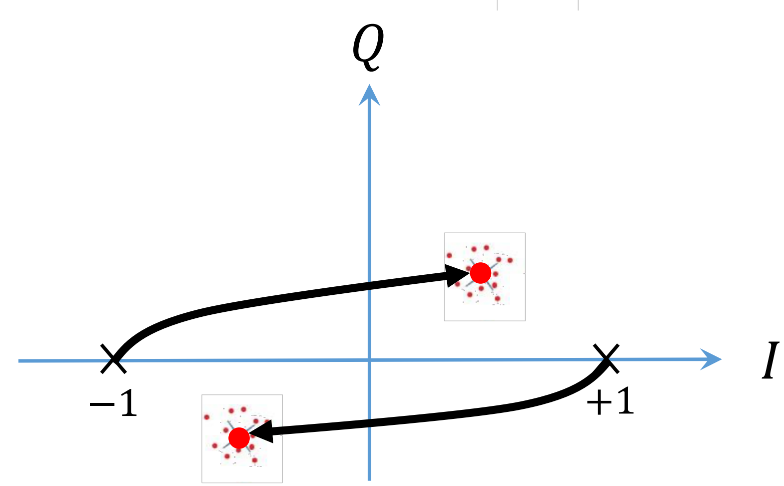


$$h \propto \frac{\lambda}{d}\, e^{j2\pi d/\lambda}$$







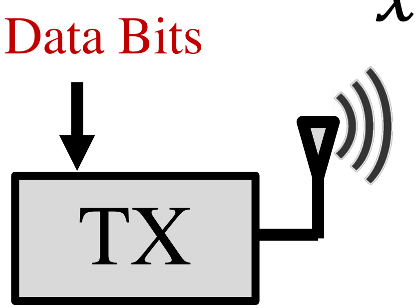


How to estimate and correct for channel?

Send Preamble Bits

Channel Estimation & Correction

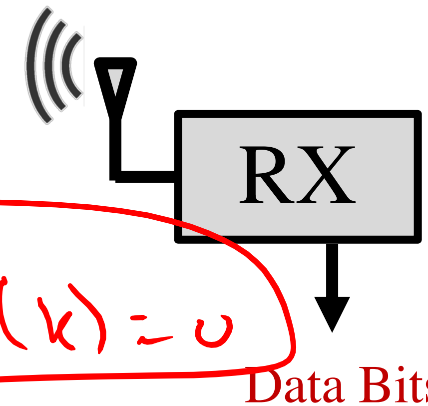
$\sum \|y(k) - \hat{h}x(k)\|^2$



$x(t)$

$$y(t) = h\,x(t) + n(t)$$

$$h \propto \frac{\lambda}{d}\, e^{j2\pi d/\lambda}$$



$y(k) - hx(k) = 0$

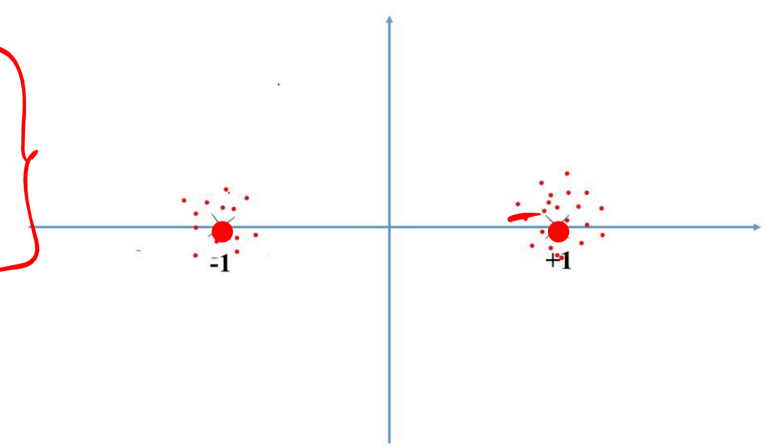
Preamble Bits: Known bits

$x(0) = 1 \longrightarrow y(0) = h + n(0)$

$x(1) = 1 \longrightarrow y(1) = h + n(1)$

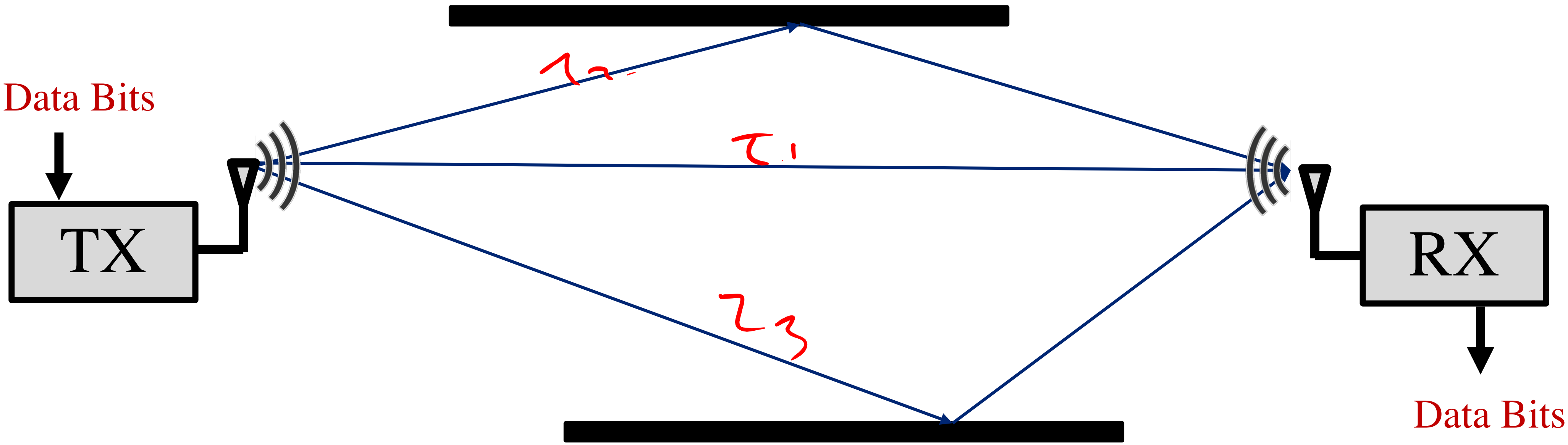
$x(2) = -1 \longrightarrow y(2) = -h + n(2)$

Estimate channel: $\tilde{h} = \sum_k \frac{y(k)}{x(k)}$



Correct channel: $\tilde{x}(t) = \frac{y(t)}{\tilde{h}}$

Multipath Wireless Channel



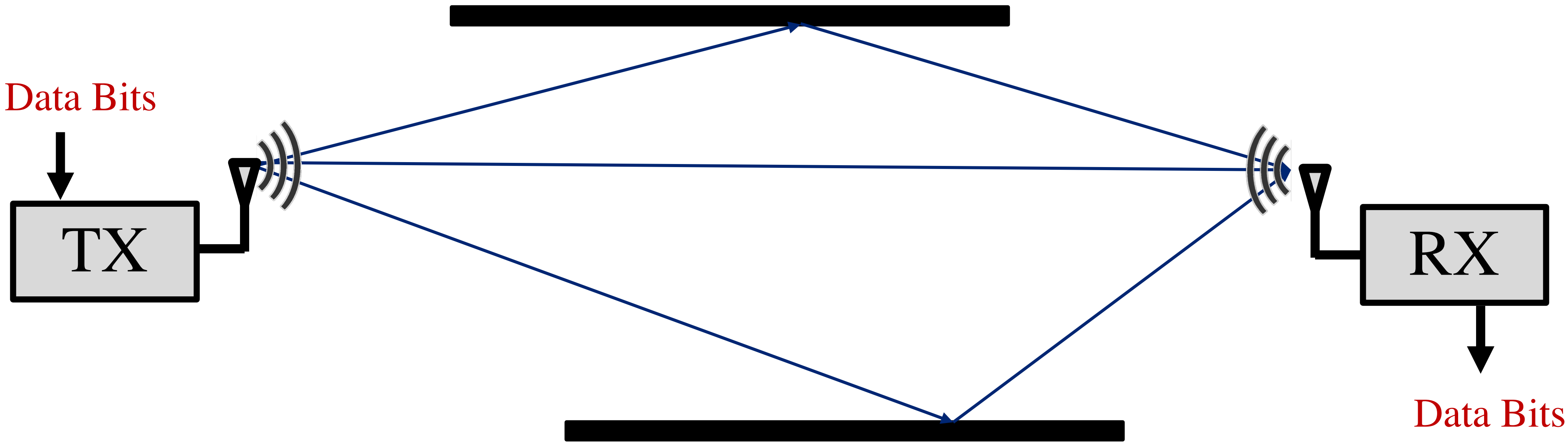
Multipath Propagation: radio signal reflects off objects ground, arriving at destination at slightly different times

$$y(t) = h_1 x(t - \tau_1) + h_2 x(t - \tau_2) + h_3 x(t - \tau_3)$$

$$\sim \sum h_k \delta(t - \tau_k)$$

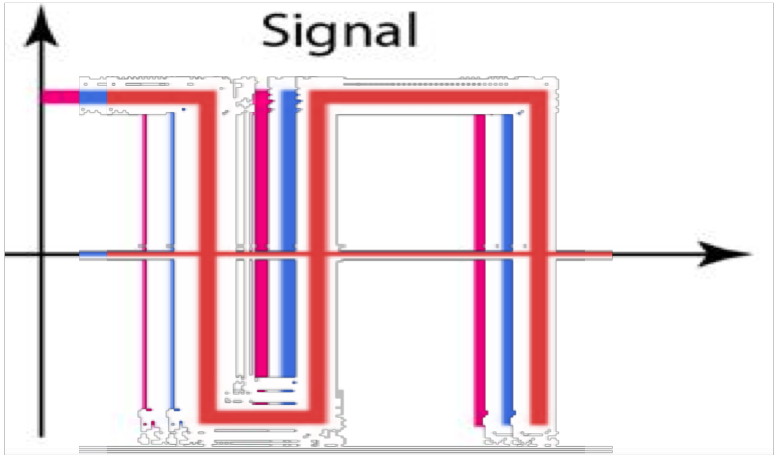
$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t)$$

Multipath Wireless Channel



- Inter-Symbol-Interference:
  Symbols arriving late interfere with following symbols.

- Channel Fading:
  Paths can sum up destructively or constructively



Multipath Wireless Channel

$\lambda = 12cm$

Example 2 paths with distance $d_1 = 1m, d_2 = 1.06m$:

$$h = h_1 + h_2 = \frac{\lambda}{d_1}\, e^{j2\pi d_1/\lambda} + \frac{\lambda}{d_2}\, e^{j2\pi d_2/\lambda}$$

$$h = \frac{\lambda}{d_1}\, e^{j2\pi d_1/\lambda}\left(1 + \frac{d_1}{d_2}\, e^{j2\pi(d_2 - d_1)/\lambda}\right)$$

$1/2$

$$\frac{d_1}{d_2} \approx 1 \qquad \frac{d_2 - d_1}{\lambda} \approx \frac{1}{2} \rightarrow h = 0$$

Multipath Wireless Channel

Example 2 paths with distance $d_1 = 1m, d_2 = 1.06m$:

$$h = h_1 + h_2 = \frac{\lambda}{d_1} e^{j2\pi d_1/\lambda} + \frac{\lambda}{d_2} e^{j2\pi d_2/\lambda}$$

$@f_1 = 2.5GHz\ (\lambda = 12\ cm)$:

$$h = 0.12\, e^{j\frac{2\pi}{3}} + 0.113\, e^{j\frac{5\pi}{3}} \approx 0.006$$

$@f_2 = 5GHz\ (\lambda = 6\ cm)$:

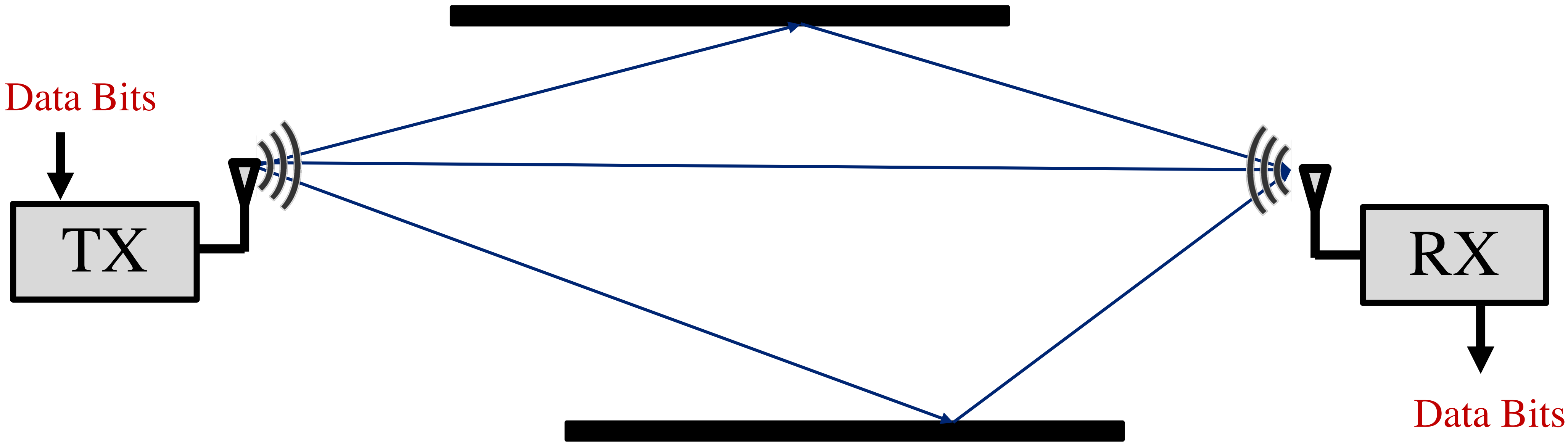
$$h = 0.06\, e^{j\frac{5\pi}{3}} + 0.05\, e^{j\frac{5\pi}{3}} \approx 0.116$$

17×

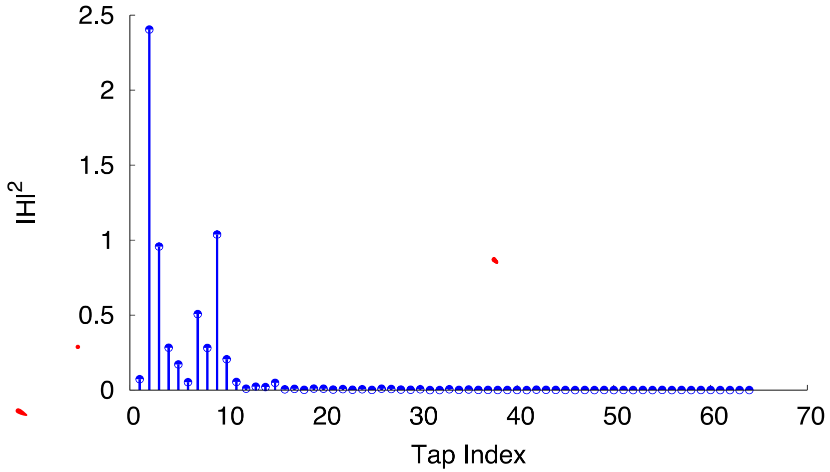
➔ 24dB

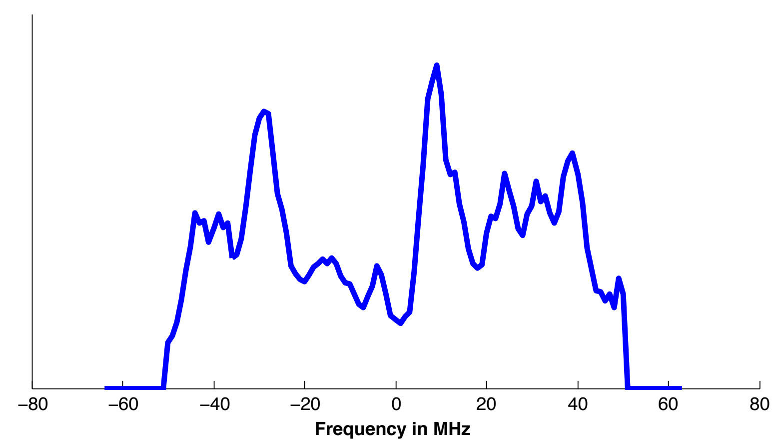
Frequency Selective Fading

Multipath Wireless Channel



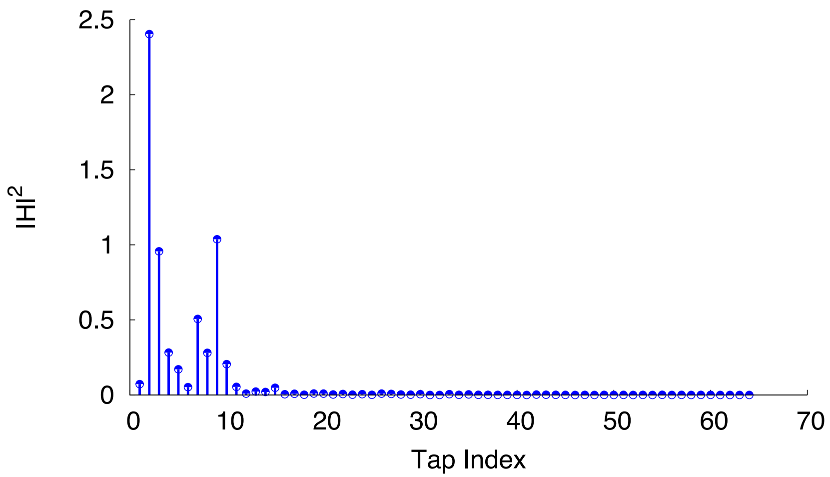
$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t) \Leftrightarrow H(f)X(f)$$

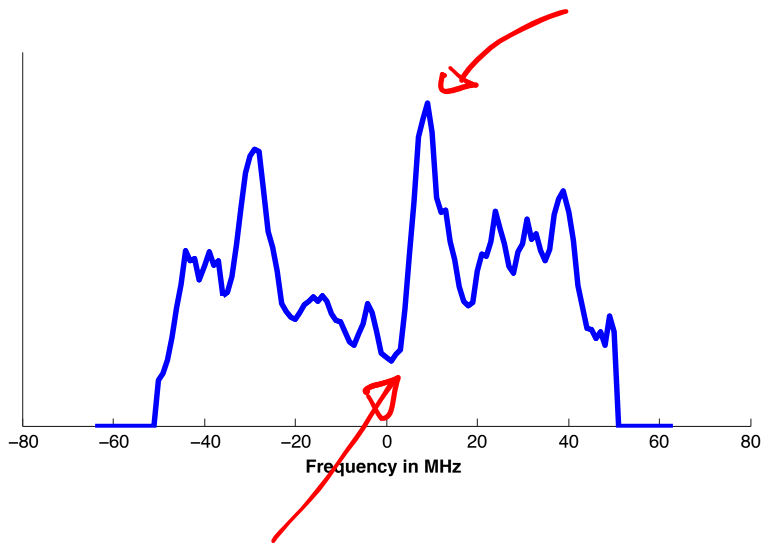




Wide Band vs Narrow Band Channel

$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t) \Leftrightarrow H(f)X(f)$$





Wide Band vs Narrow Band Channel

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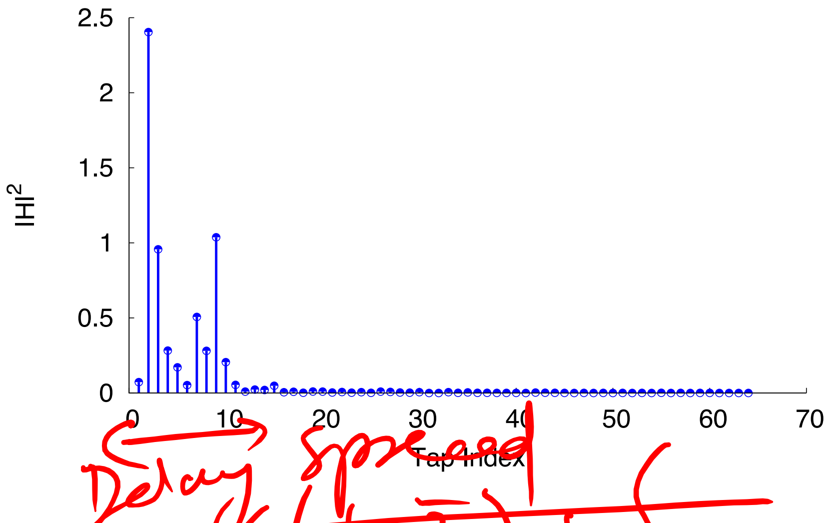
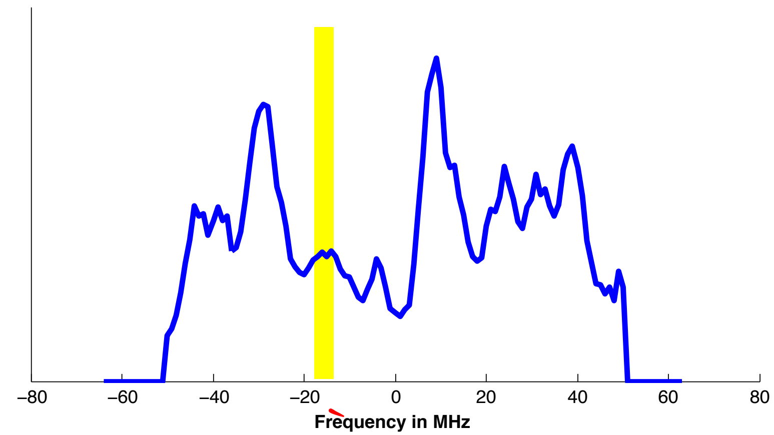
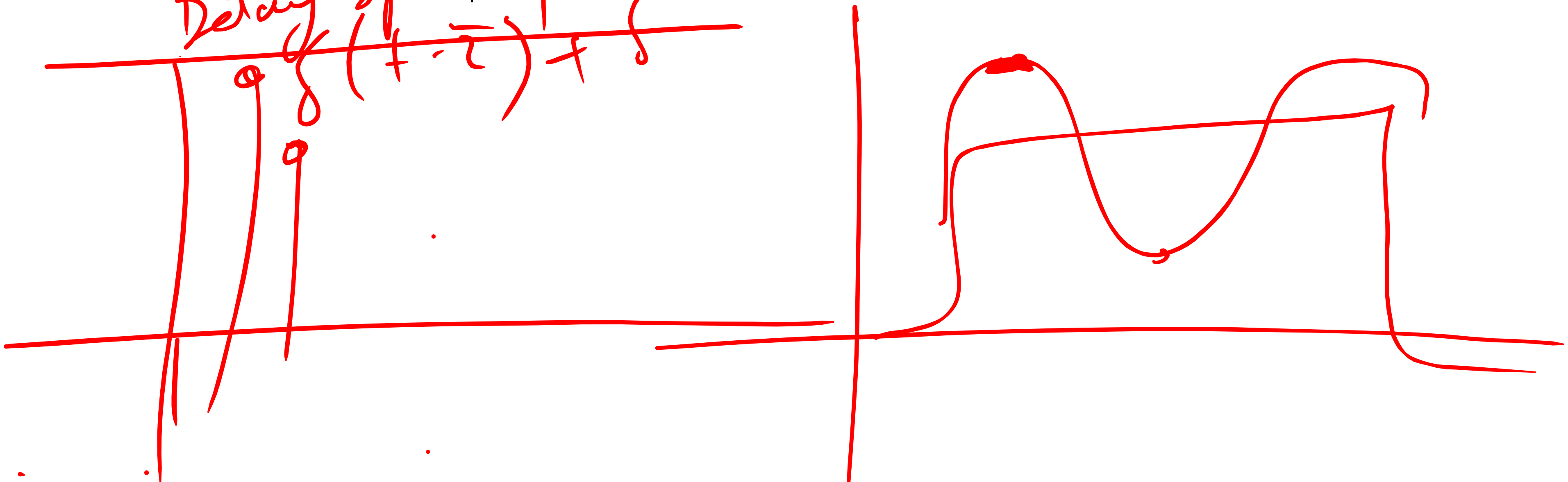
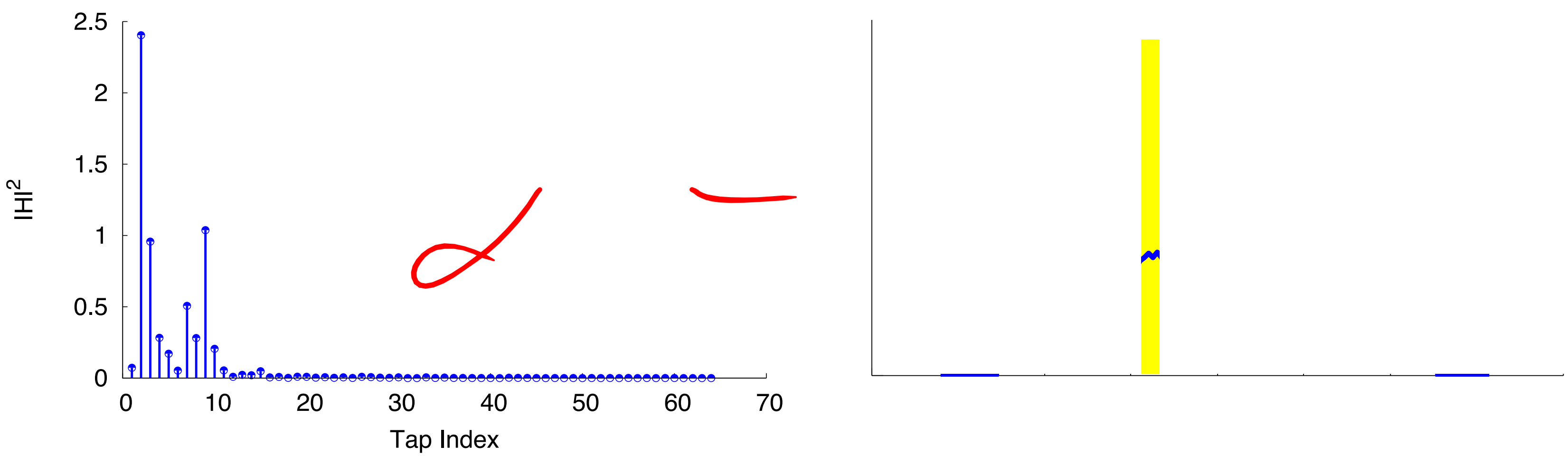






Wide Band vs Narrow Band Channel

$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t) \Leftrightarrow H(f)X(f)$$



$$y(t) = h(t) * x(t)$$

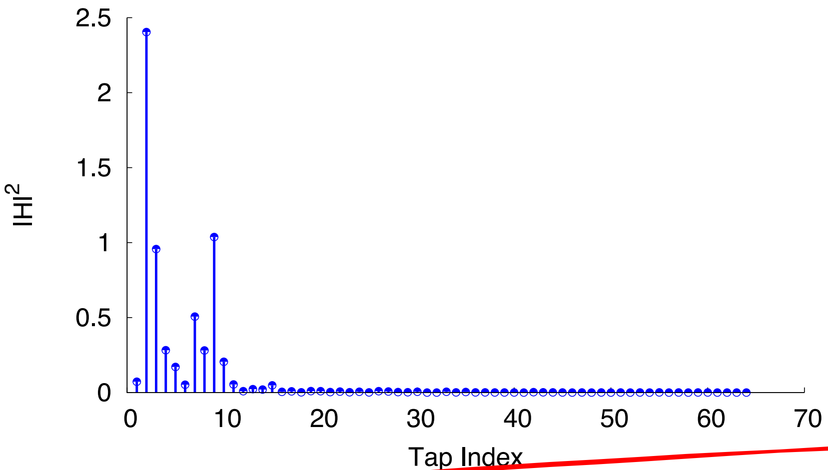
$$= \underbrace{g(t) * h(t)} * x(t)$$

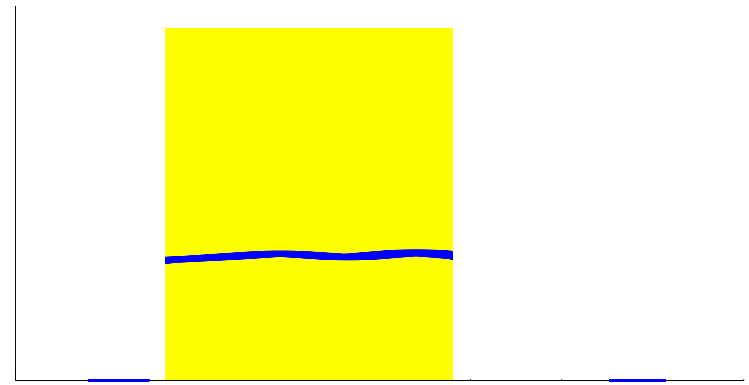
$$= \alpha\,\delta(t)$$

$$= \alpha\,\underline{x(t)}$$

Wide Band vs Narrow Band Channel

$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t) \Leftrightarrow H(f)X(f)$$





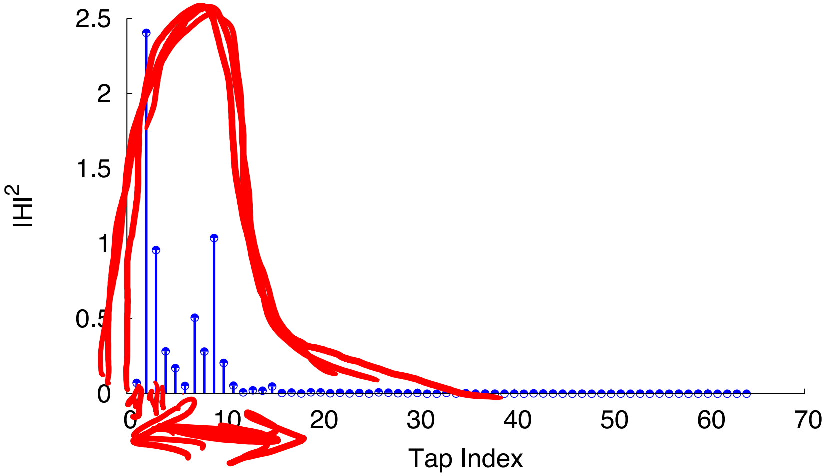
$$h = h_1 + h_2 = \frac{\lambda}{d_1} e^{j2\pi d_1/\lambda} + \frac{\lambda}{d_2} e^{j2\pi d_2/\lambda}$$

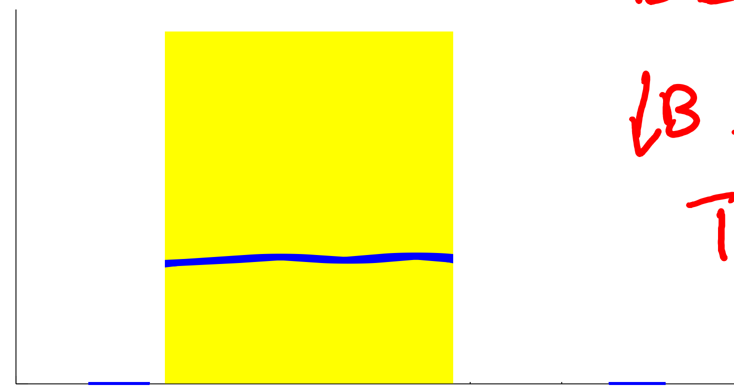
Narrow band channel:

- same $\lambda = c/f_c$ for all $f \rightarrow h = constant$
- $y(t) = h\, x(t) \Leftrightarrow h\, X(f)$
- Flat channel

Wide Band vs Narrow Band Channel

$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t) \Leftrightarrow H(f)X(f)$$





$$h = h_1 + h_2 = \frac{\lambda}{d_1} e^{j2\pi d_1/\lambda} + \frac{\lambda}{d_2} e^{j2\pi d_2/\lambda}$$

Narrow band channel:

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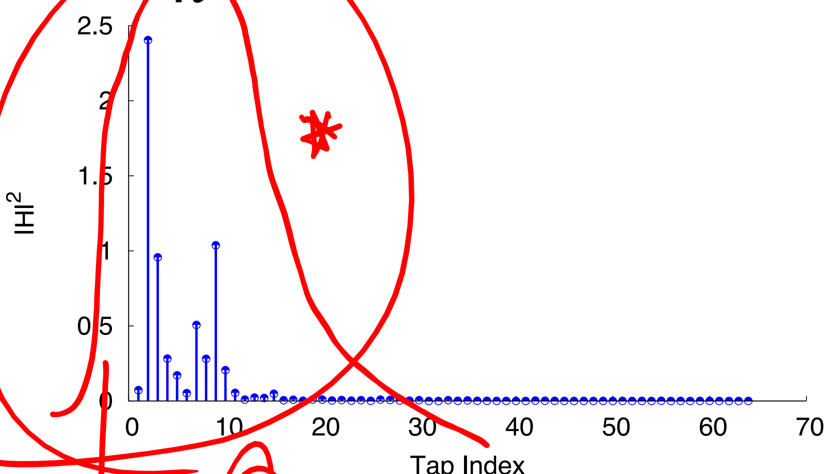
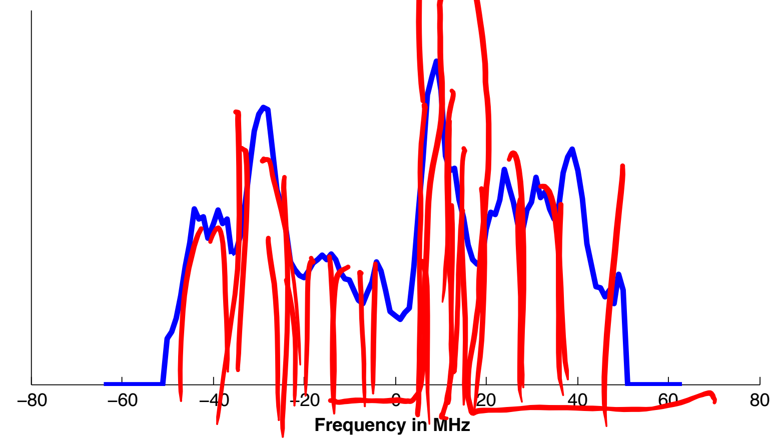
Wide Band vs Narrow Band Channel

$$y(t) = \sum_k h_k x(t - \tau_k) = h(t) * x(t) \Leftrightarrow H(f)X(f)$$





$$H(f) = h_1 + h_2 = \frac{\lambda}{d_1} e^{j2\pi d_1/\lambda} + \frac{\lambda}{d_2} e^{j2\pi d_2/\lambda}$$

Wide band channel:

- h is varies with f → Multi-tap channel
- $y(t) = h(t) * x(t) \Leftrightarrow H(f)X(f)$

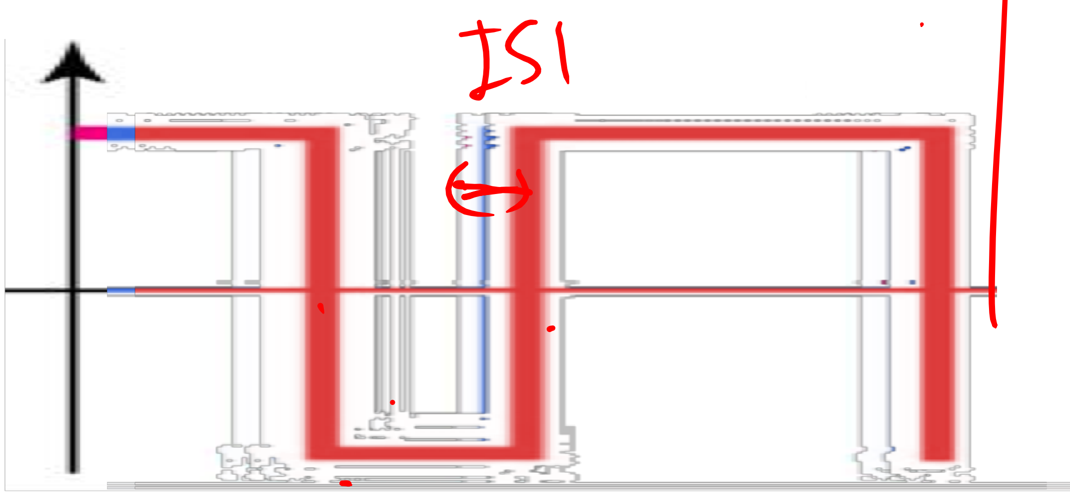
Wide Band vs Narrow Band Channel

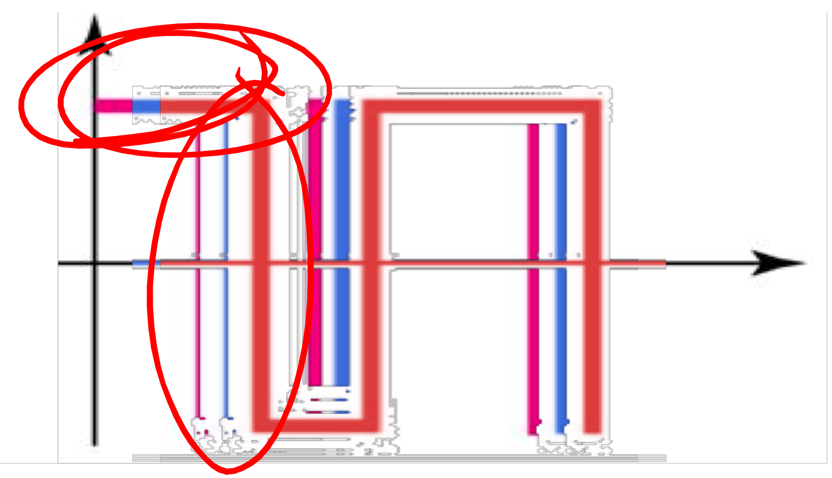
Narrow band channel:

- Flat channel
- $y(t) = h\, x(t)$
  $\Leftrightarrow h\, X(f)$

Wide band channel:

- Multi-tap channel
- $y(t) = h(t) * x(t)$
  $\Leftrightarrow H(f) X(f)$





Wide Band vs Narrow Band Channel

Narrow band channel:

- Flat channel
- $y(t) = h\,x(t)$
  $\Leftrightarrow h\,X(f)$

Wide band channel:

- Multi-tap channel
- $y(t) = h(t) * x(t)$
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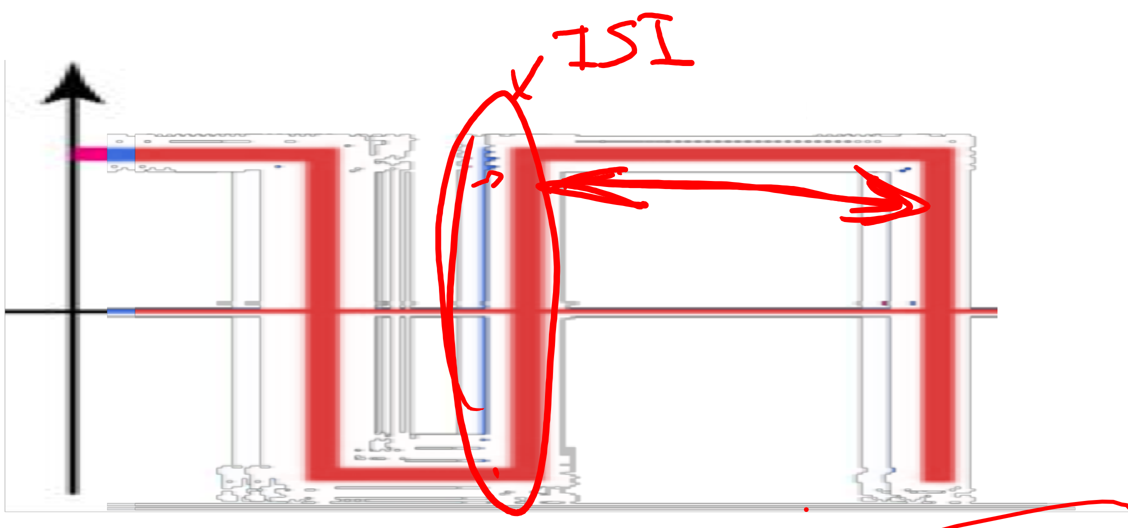

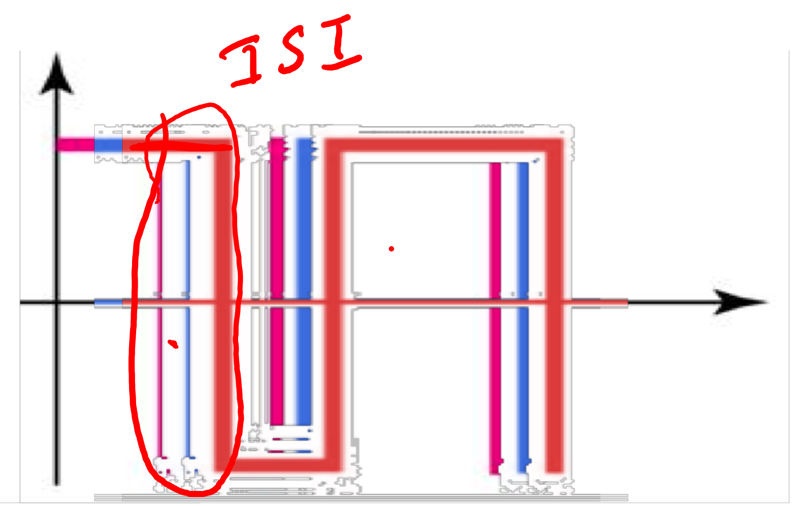

- Solution:

OFDM: Orthogonal Frequency Division Multiplexing

- Idea: transmit symbols in frequency not time.

NEXT LECTURE