EEN 1043/EE452 Wireless and Mobile Communication

Channel Characterization III

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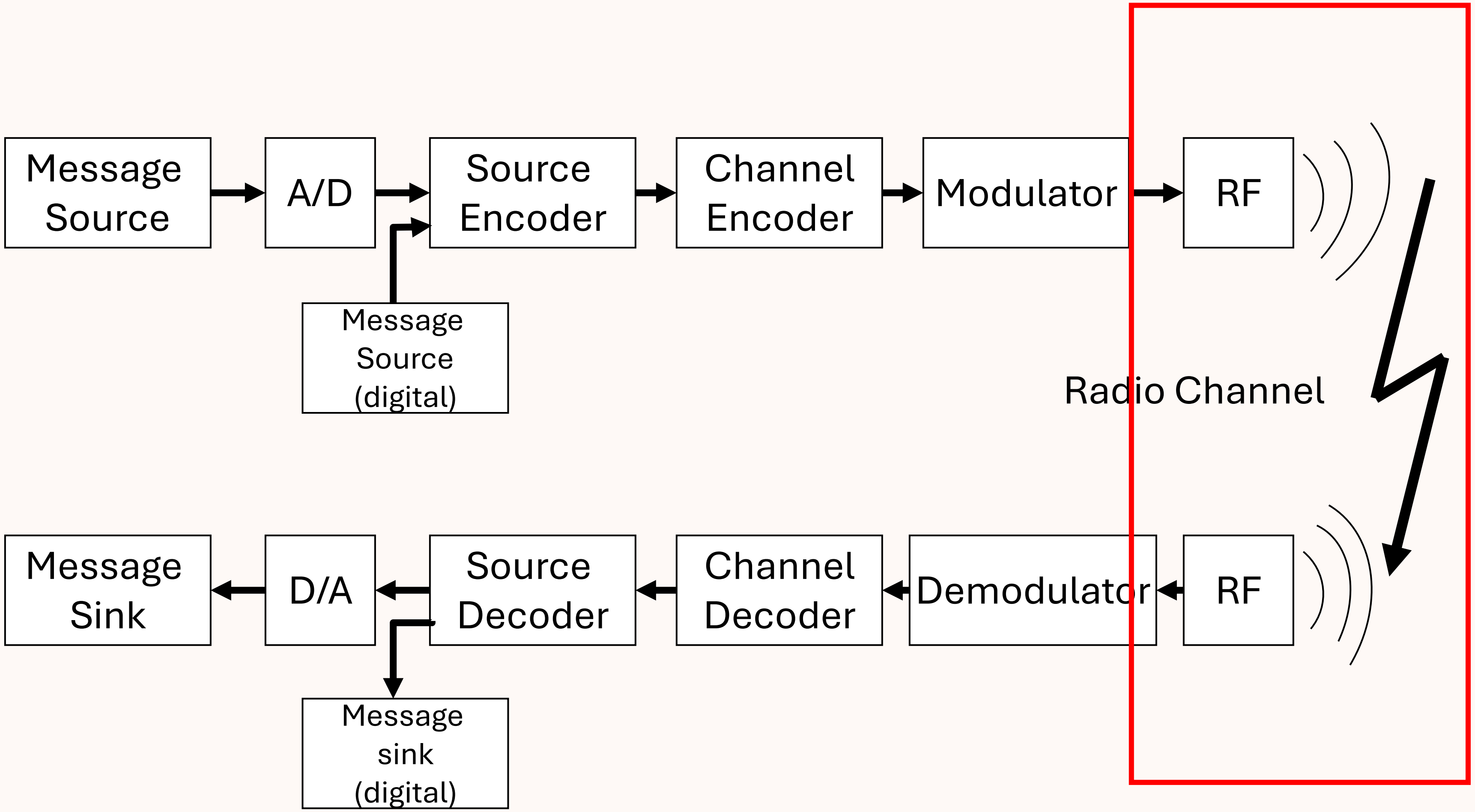
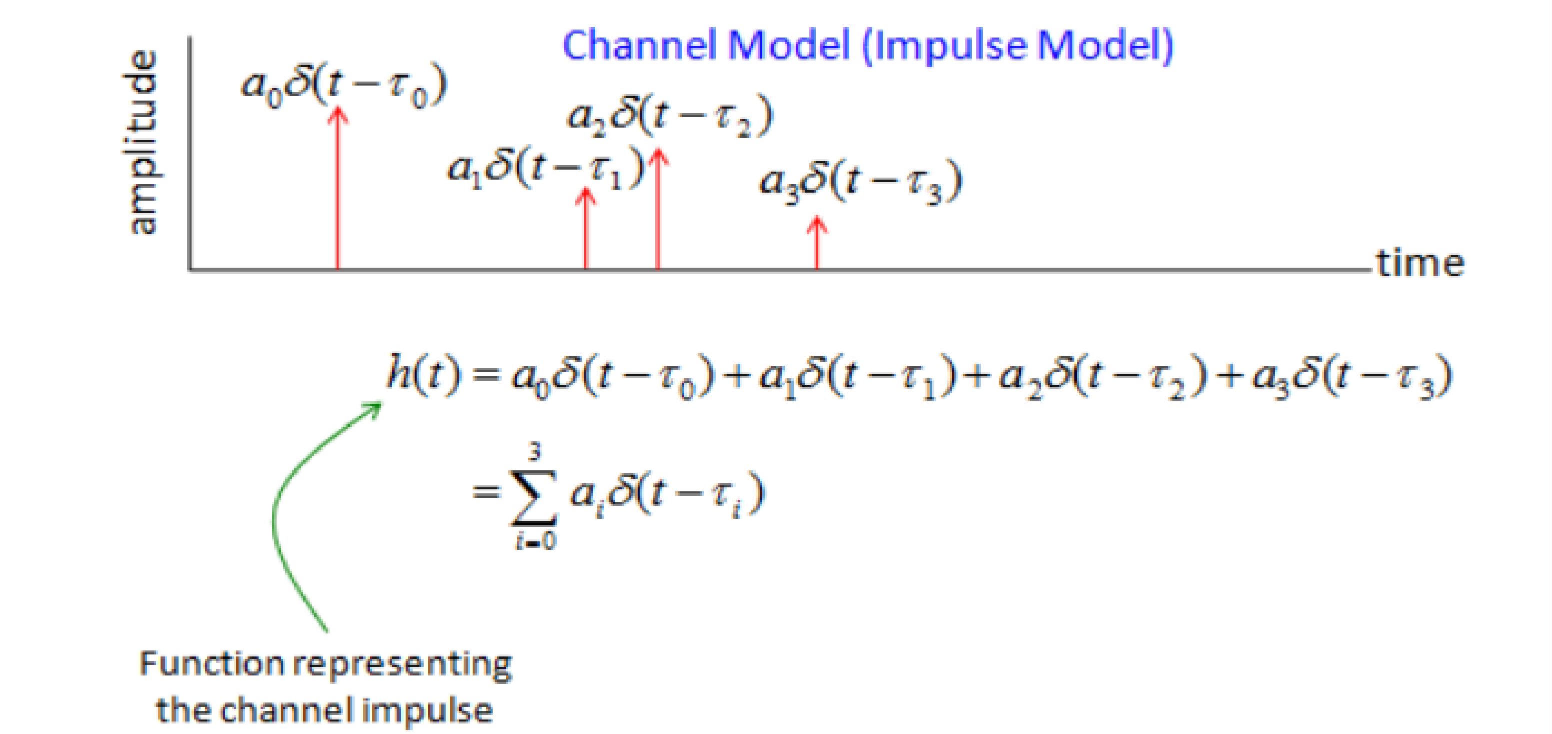
Radio Link


Message Source
A/D
Source Encoder
Channel Encoder
Modulator
RF
Message Source (digital)
Radio Channel
Message Sink
D/A
Source Decoder
Channel Decoder
Demodulator
RF
Message sink (digital)

Channel Impulse Response



Channel

- Channel adds noise (Additive White Gaussian Noise)

$$y(t) = x(t) + n(t)$$

- Channel delays the signal

$$y(t) = x(t - \tau) + n(t)$$

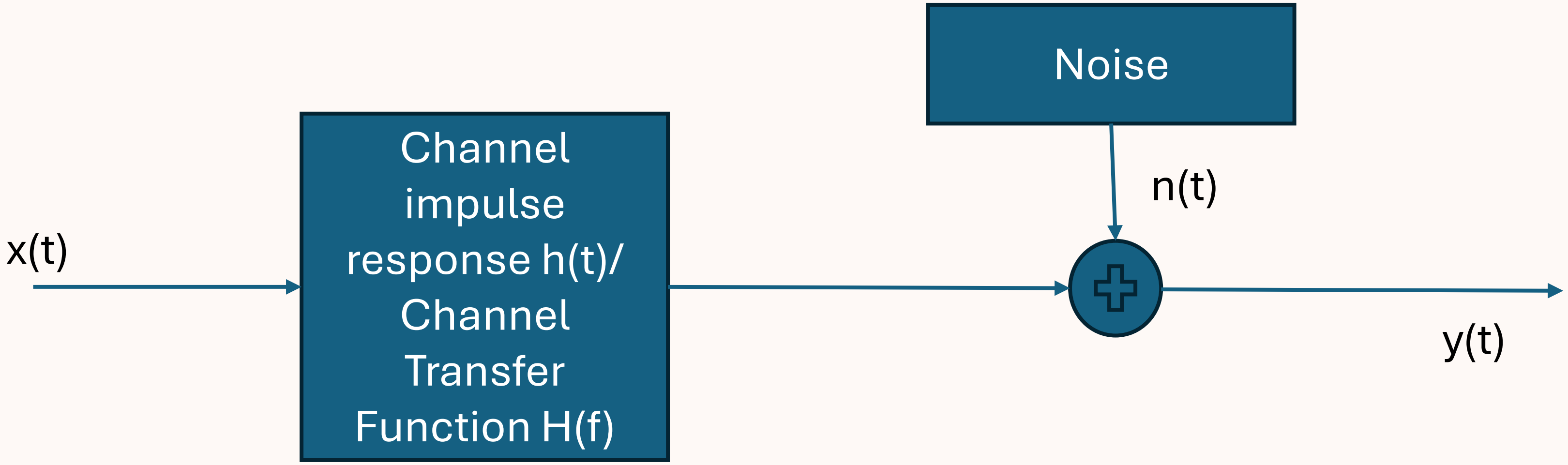
- Channel attenuates the signal

$$y(t) = hx(t - \tau) + n(t), \qquad h \, \boldsymbol{\alpha} \, \frac{\lambda}{d}$$

- Channel rotates the signal (add phase)

$$y(t) = hx(t - \tau) + n(t), \qquad h \, \boldsymbol{\alpha} \, \frac{\lambda}{d} e^{j\phi}$$

Channel



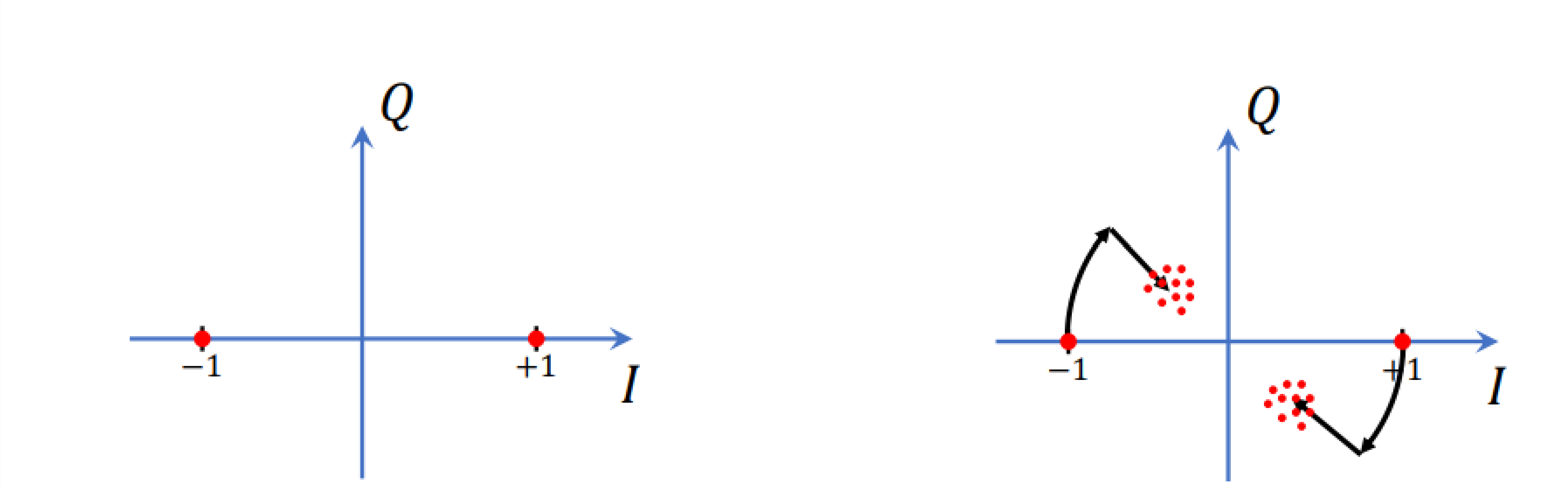
$$y(t) = hx(t-\tau) + n(t),$$

Channel

Consider BPSK modulation

0 -> -1

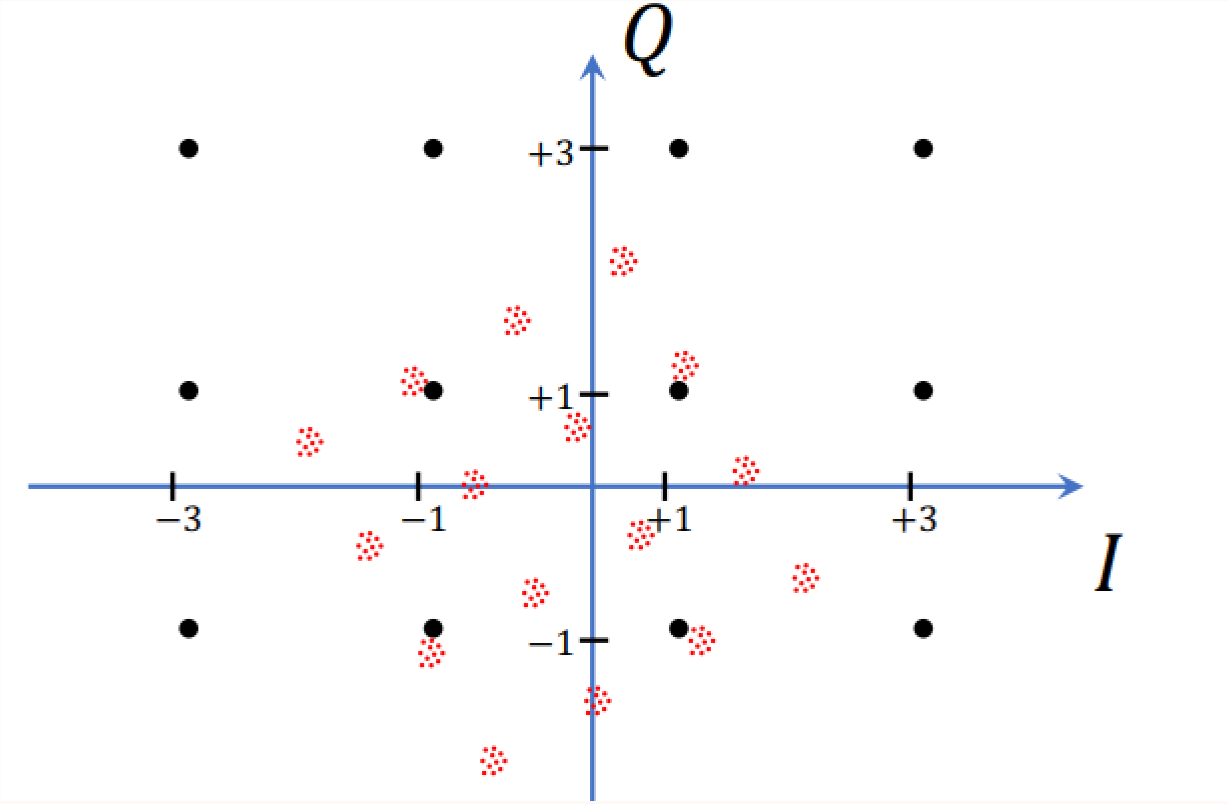
1 -> +1



$x(t)$ $\qquad\qquad$ $y(t) = h * x(t) + n(t)$

Channel

Consider 16-QAM



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

Multiple Path Channel

- The signal arrives at destination with multiple delays and attenuation

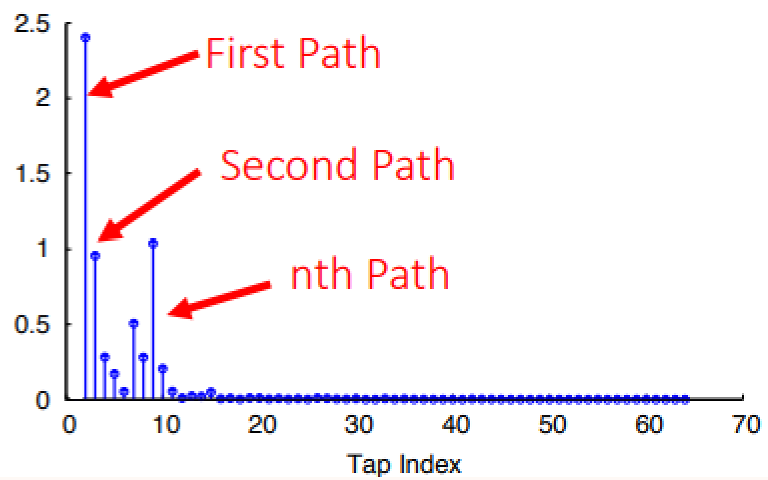
$$y(t) = \alpha_0 e^{\phi_0} x(t - \tau_0) + \alpha_1 e^{\phi_1} x(t - \tau_1) + \ldots. + \alpha_{L-1} e^{\phi_{L-1}} x(t - \tau_{L-1})$$

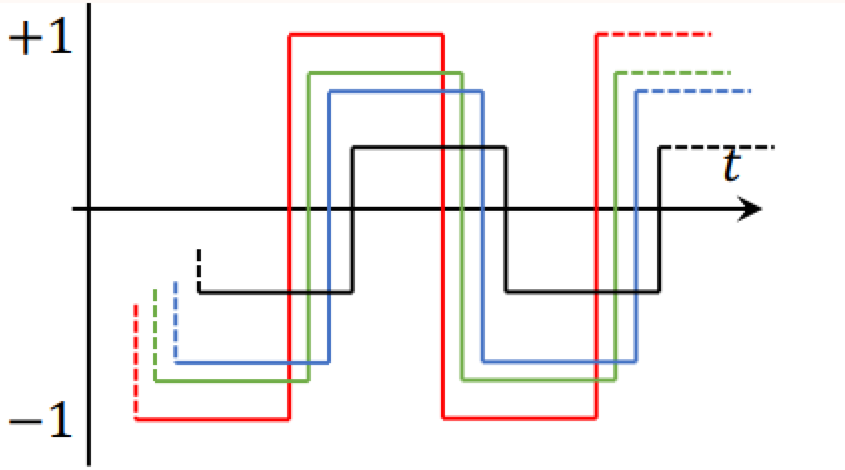
$$y(t) = \sum_k \alpha_k e^{\phi_k} \, x(t - \tau_k)$$

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

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

Multiple Path Channel: Inter Symbol Interference



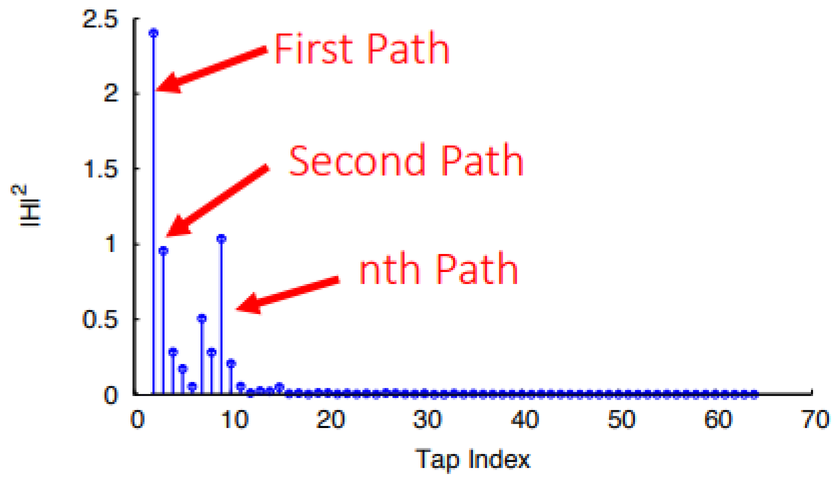


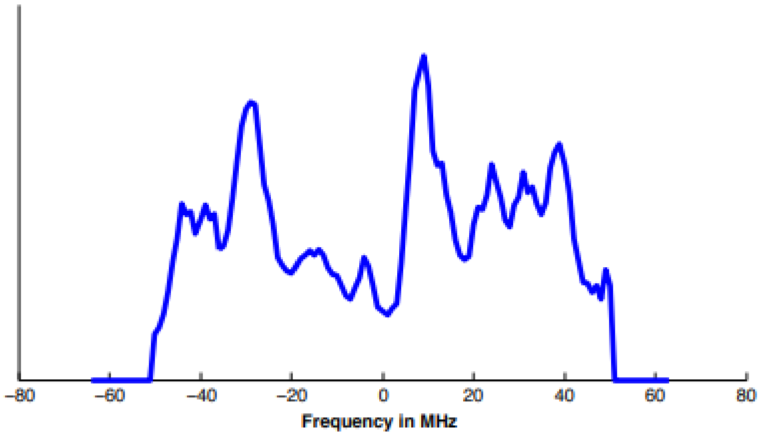
Multi Tap Channel => Inter Symbol Interference (ISI)
Symbols arriving along late paths interfere with following symbols.

Multiple Path Channel

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

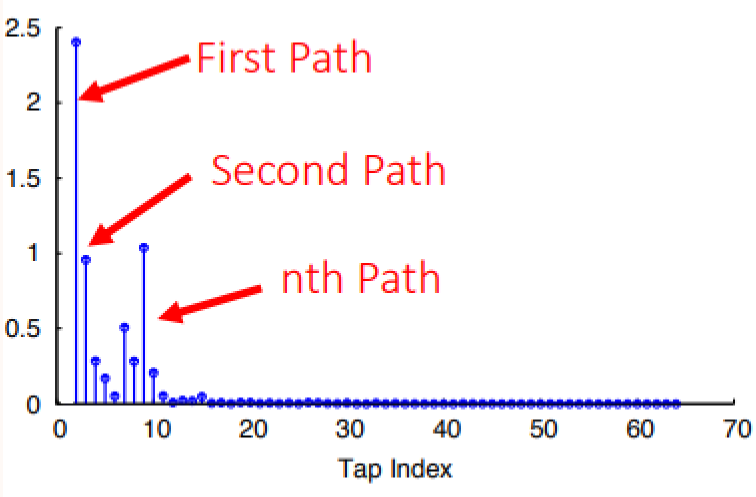
$Y(f) = H(f)X(f)$



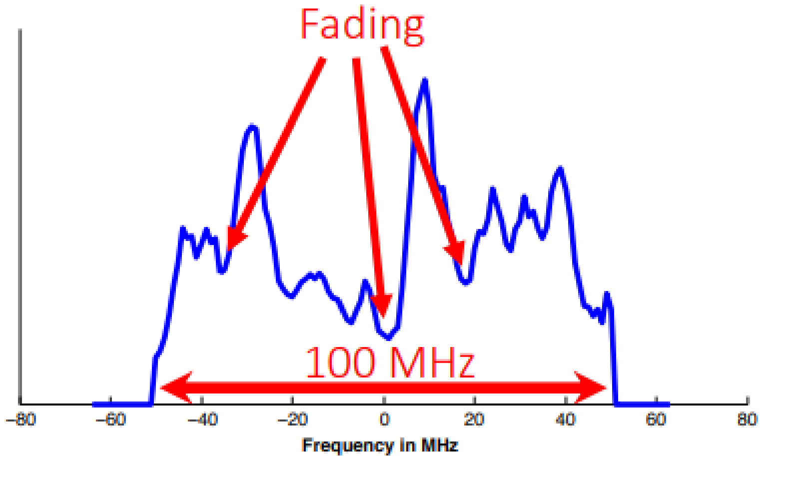


Multiple Path Channel

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



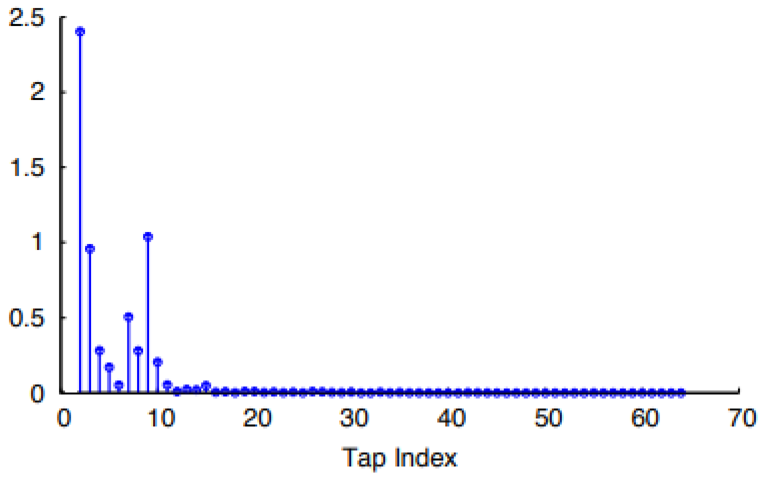
$$Y(f) = H(f)X(f)$$

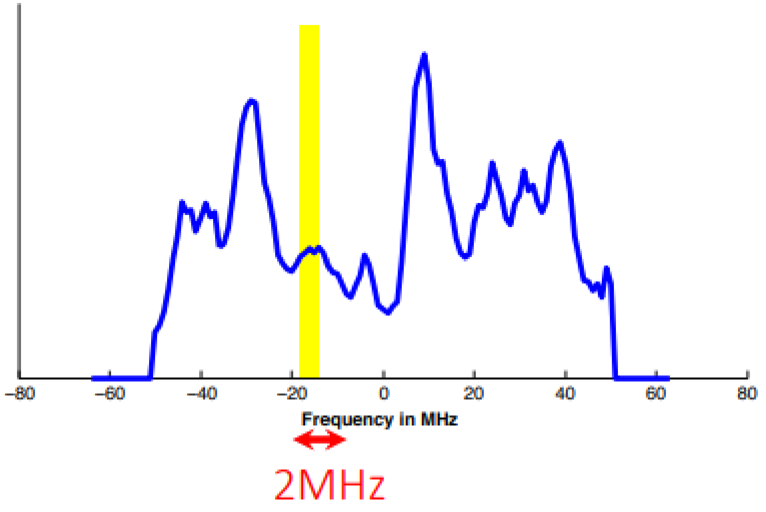


Frequency Selective Fading

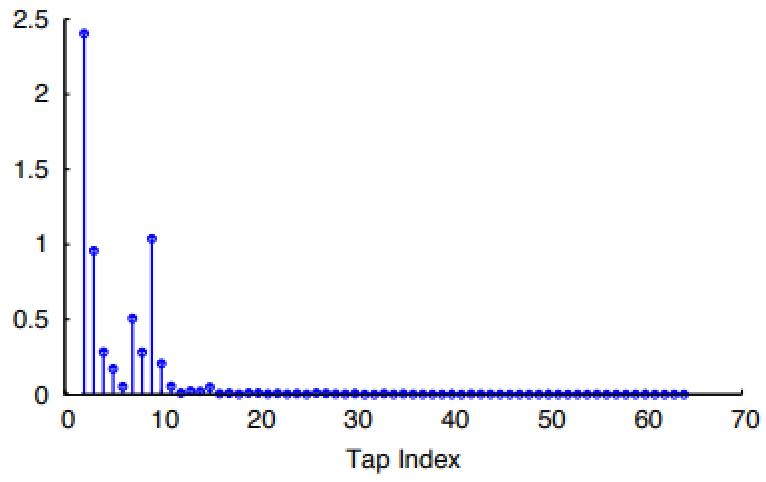
Symbols arriving along different paths sum up destructively

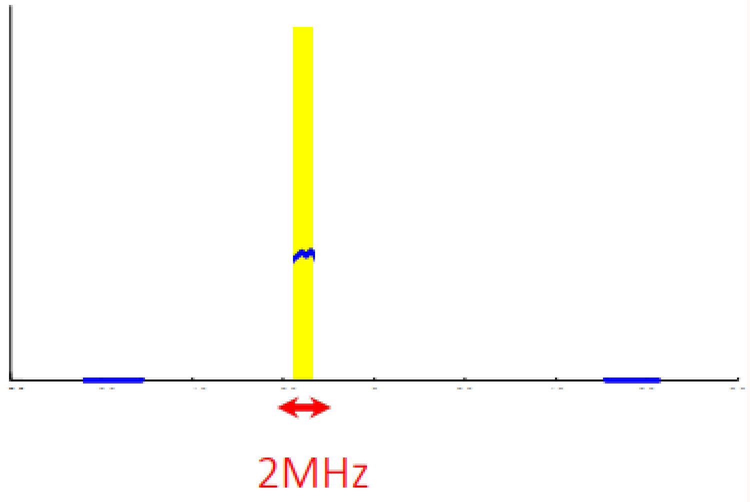
Multiple Path Channel: Narrowband Channel



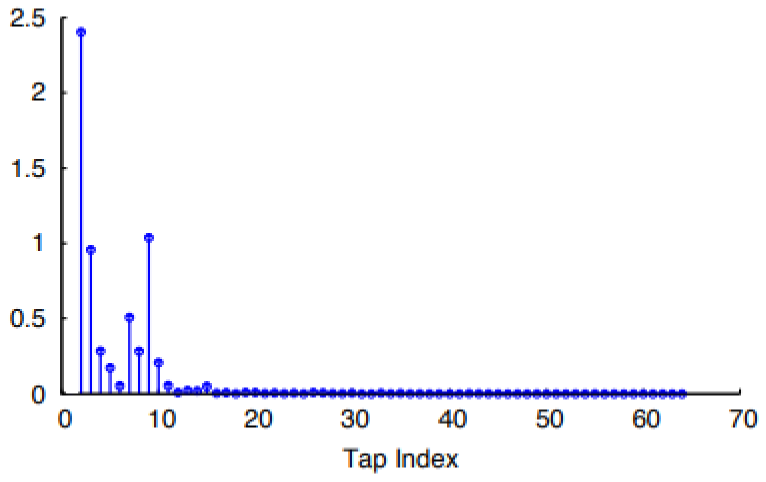


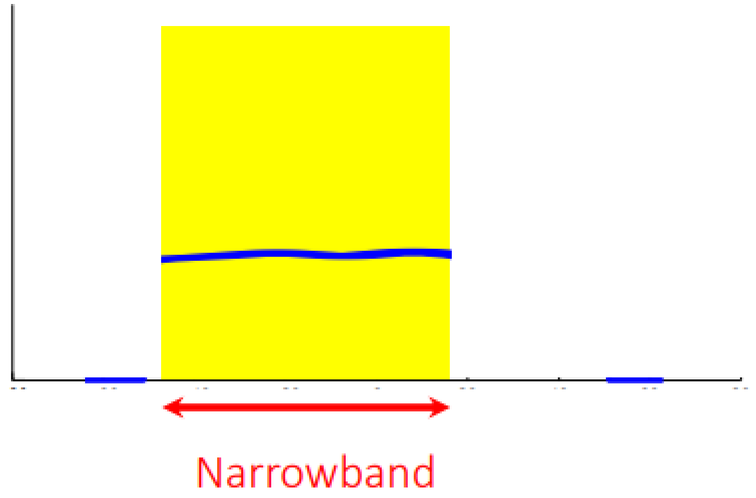
Multiple Path Channel: Narrowband Channel



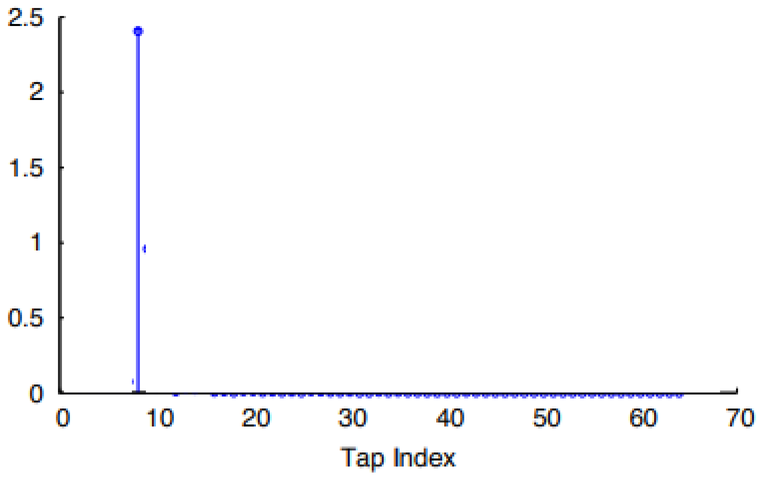


Multiple Path Channel: Narrowband Channel

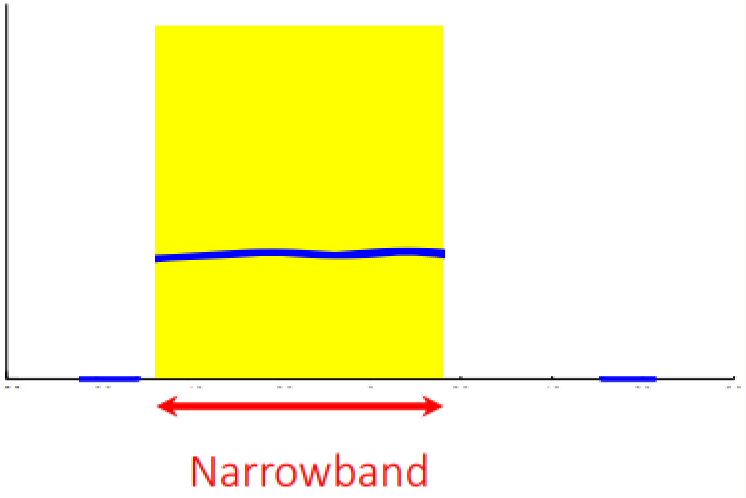




Multiple Path Channel: Narrowband Channel



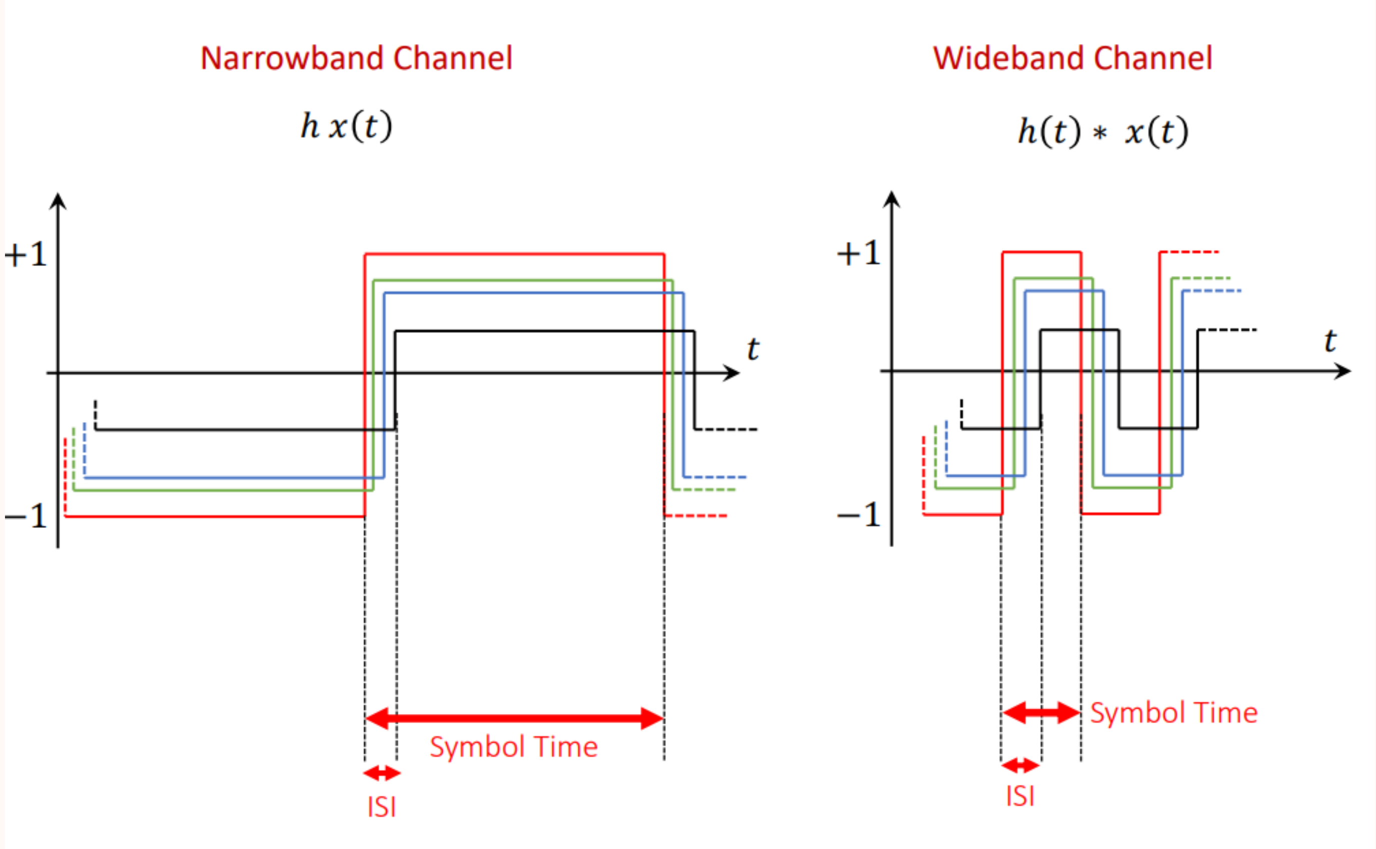
Symbol time: $T \propto \frac{1}{\text{Bandwidth}} \gg \tau_k$



Flat Channel

Narrowband Channel is Approximated by a Single Tap Channel

Multiple Path Channel: Narrowband Channel



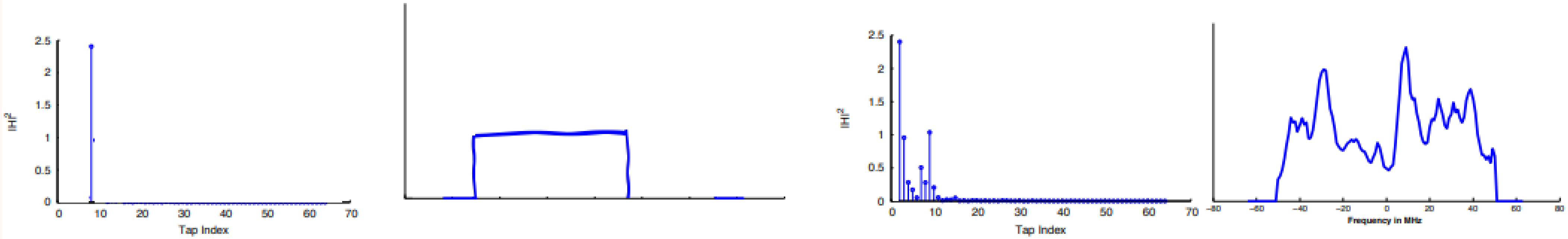
Wireless Channel

Narrowband Channel

$$h\,x(t) \quad \Leftrightarrow \quad h\,X(f)$$

Wideband Channel

$$h(t) * x(t) \quad \Leftrightarrow \quad H(f)\,X(f)$$



≈ Single Tap

≈ Flat Channel

Multi-tap Channel (ISI)

Frequency Selective Channel

Channel Equalization

- Channel equalization is the process of reducing amplitude, frequency and phase distortion in a radio channel with the intent of improving transmission performance.
- *Channel estimation* provides information about distortion of the transmission signal when it propagates through the channel.
- This information is then used by equalizers so that the fading effect and/or co-channel interference can be removed and the original transmitted signal can be restored.
- Channel Equalization is required to deal with ISI

Channel Equalization

- Estimating h(t)
- Correcting for h(t)

$$y(t) = h(t) * x(t)$$
$$\tilde{x}(t) = f(t) * y(t) = f(t) * h(t) * x(t)$$

Ideally $f(t) = h^{-1}(t)$

$$\tilde{x}(t) = f(t) * y(t) = h^{-1}(t) * h(t) * x(t) = x(t)$$

Channel Estimation and Correction

- Send training sequence (known bits)
- $x(0) = 1 \Rightarrow y(0) = 1 + \mathrm{n}(0)$
- $x(1) = 1 \Rightarrow y(1) = 1 + \mathrm{n}(1)$
- $x(2) = -1 \Rightarrow y(2) = -1 + \mathrm{n}(2)$

Estimate Channel

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

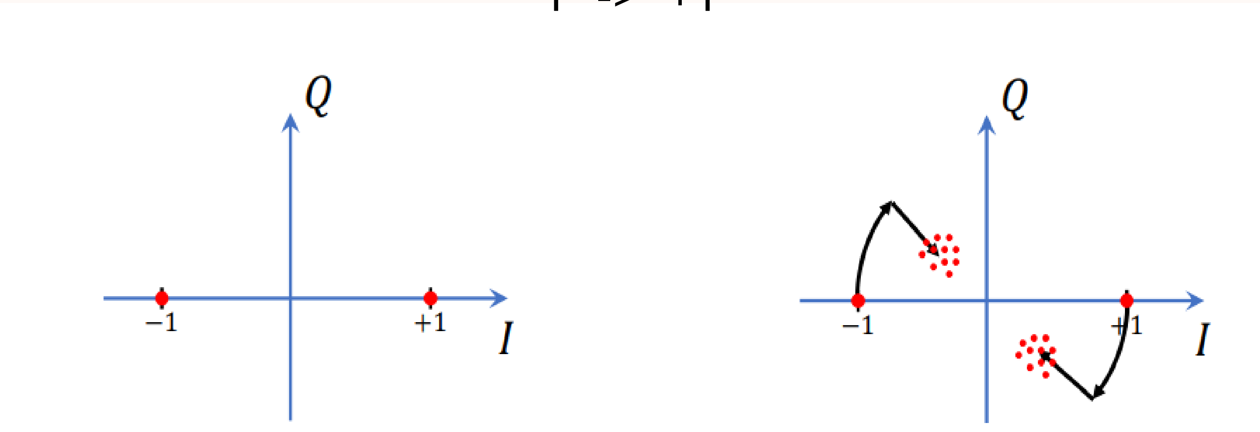
Channel Correction

$$\tilde{x}(t) = \frac{y(k)}{\tilde{h}}$$

Consider BPSK modulation

0 -> -1

1 -> +1



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

Channel Correction Mechanisms

- Forward Error Correction: The receiver only uses the information contained in the incoming digital transmission and corrects bit errors in the data

- Adaptive Equalization: Adjust equalization techniques based on the channel

- Adaptive Modulation and Coding: Choose modulation and coding based on the channel

Channel Correction Mechanisms

- Orthogonal Frequency Division Multiplexing: split signal into multiple lower bit rat streams that are transmitted over precisely spaced frequencies
- Spread Spectrum: Transmitted signal is spread over a wide frequency band

Summary

- The signal arrives at destination with multiple delays and attenuation

$$y(t) = \alpha_0 e^{\phi_0} x(t - \tau_0) + \alpha_1 e^{\phi_1} x(t - \tau_1) + \ldots. + \alpha_{L-1} e^{\phi_{L-1}} x(t - \tau_{L-1})$$

- Multipath effect will give rise to Inter Symbol Interference (ISI)

- Channel Equalization is required to deal with ISI