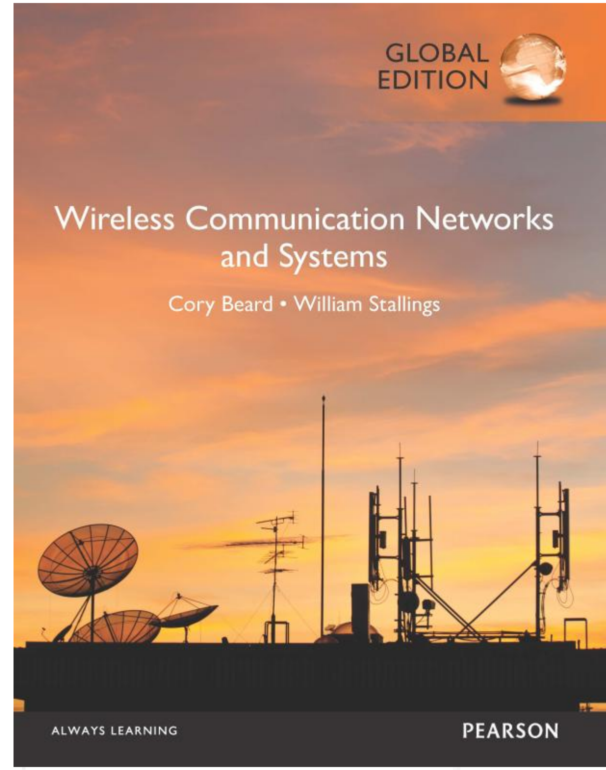
MOBILE SYSTEM-HT25 LECTURE 6: THE WIRELESS CHANNEL-PART II

Azra Abtahi

Email: azra.abtahi-fahliani@mau.se

Faculty of Technology and Society Department of Computer Science and Media Technology Malmö University

Most slides are primarily adapted from Beard & Stallings (2016), Wireless Communication Networks and Systems (Chapter 6)



Wireless Communication Networks and Systems

1st edition, Global edition

Cory Beard, William Stallings

LOS WIRELESS TRANSMISSION IMPAIRMENTS

- Attenuation and attenuation distortion
- Free space loss
- Noise
- Multipath
- Refraction
- Mobility

ATTENUATION

- Strength of signal falls off with distance over transmission medium

Partially because of obstacles.

  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion

$$\lambda = \frac{v}{f}$$

$v =$ Speed of the wave

FREE SPACE LOSS

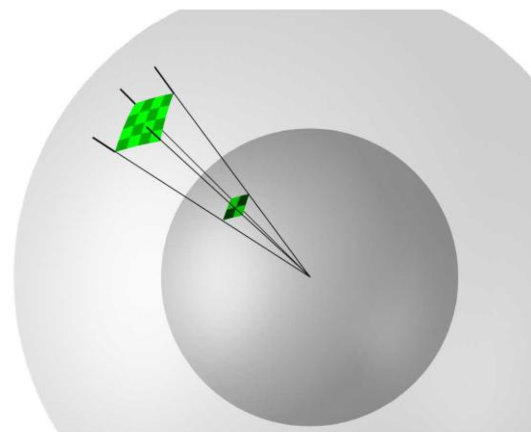
- Even in perfect free space with no obstacles, energy spreads. For ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

That's why satellites need powerful antennas even with nothing blocking the path.

- P_t = signal power at transmitting antenna
- P_r = signal power at receiving antenna
- λ = carrier wavelength
- d = propagation distance between antennas
- c = speed of light (3×10^8 m/s)

where d and λ are in the same units (e.g., meters



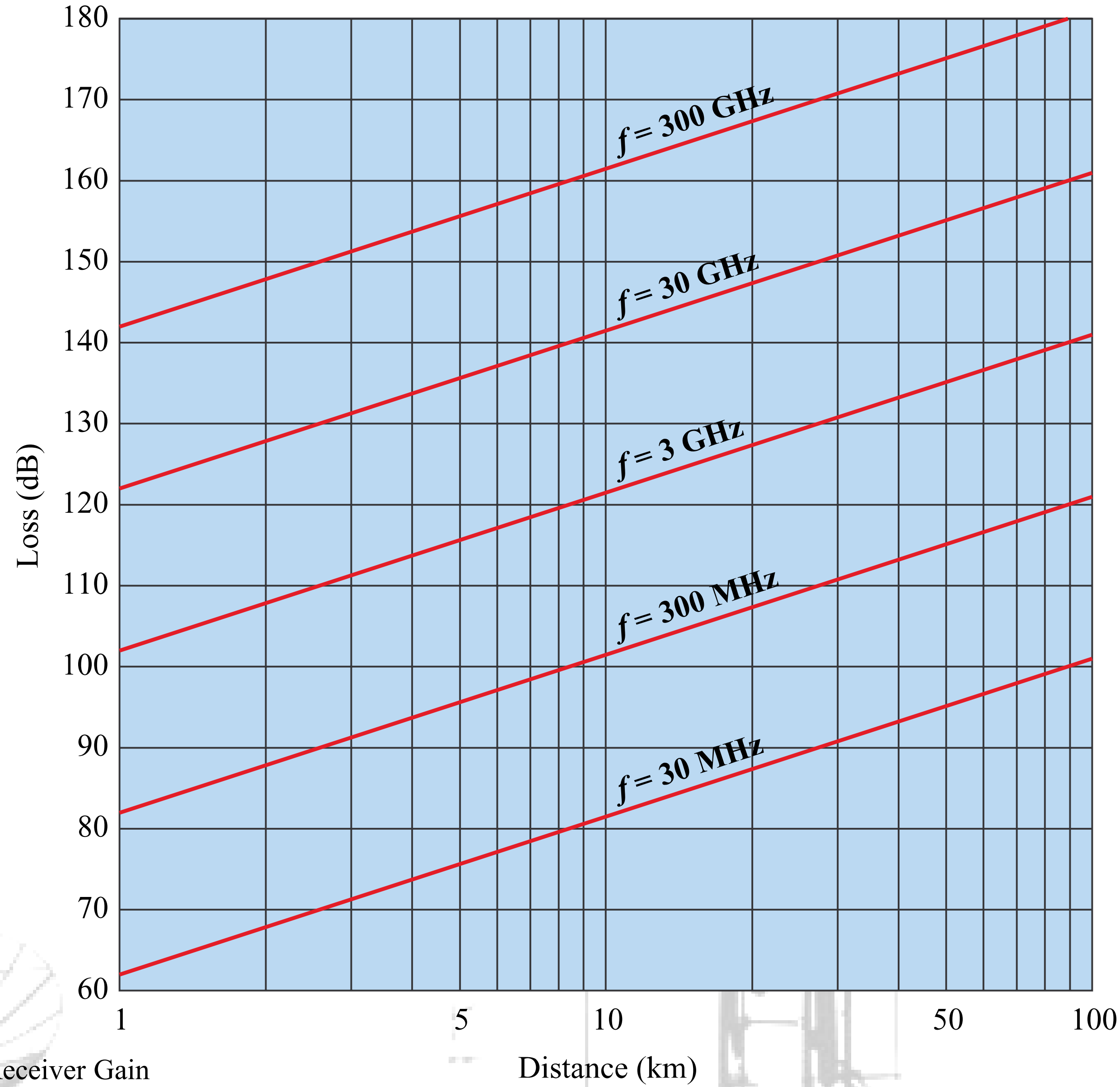
FREE SPACE LOSS

- Free space loss equation can be recast:

$$L_{dB} = 10\log\frac{P_t}{P_r} = 20\log\left(\frac{4\pi d}{\lambda}\right)$$

$$= -20\log(\lambda) + 20\log(d) + 21.98\ \text{dB}$$

$$= 20\log\left(\frac{4\pi f d}{c}\right) = 20\log\boxed{(f)} + 20\log\boxed{(d)} - 147.56\ \text{dB}$$



Receiver Gain

$$P_r = P_t + G_t + G_r - L_{FSPL}$$

Transmitter Gain

6.8 FREE SPACE LOSS

PATH LOSS EXPONENT IN PRACTICAL SYSTEMS

- Real environments (cities, indoors) cause greater loss.
- The more obstacles, the higher the path loss exponent. So, range drops faster than in open fields:

$$\frac{P_t}{P_r} = \left(\frac{4\pi}{\lambda}\right)^2 d^n = \left(\frac{4\pi f}{c}\right)^2 d^n$$

$$\boxed{L_{dB} = 20\log\left(f\right) + 10n\log\left(d\right) - 147.56 \text{ dB}}$$

PATH LOSS EXPONENT IN PRACTICAL SYSTEMS

Table 6.5 Path Loss Exponents for Different Environments [RAPP02]

Environment	Path Loss Exponent, *n*
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

DISCUSSION TIME I

Signals weaken as they travel, but by how much?

Work with your group to estimate how much power we lose if distance increases from 100 m to 1 km — ten times farther, when

- $n = 3$ (urban area), and
- $n = 4$ (indoor obstructed)

Is the loss small or huge (How much does the signal become weaker)? Why can't we just increase power to fix the problem? Then what can we do to compensate the lost?

$$\boxed{L_{dB} = 20\log\left(f\right) + 10n\log\left(d\right) - 147.56 \text{ dB}}$$

CLASS DISCUSSION

- Increasing distance by 10× adds about **20 dB of path loss in Free space** — the signal becomes **100× weaker.**
- Urban (n ≈ 3): 30 dB extra loss → 1,000× less power
- Indoor obstructed (n ≈ 4): 40 dB extra loss → 10,000× less power

Boosting power helps but is limited by **battery life, regulations, etc.**

Instead, engineers use **repeaters/amplifiers, better antennas, error-control coding, and smart modulation, etc. (we discuss some of them)** to maintain reliable communication.

A **repeater** receives a weak or noisy signal, **cleans it up**, and then **retransmits** it. An **amplifier** boosts the **power level** of a signal — *including* any noise the signal carries.

CATEGORIES OF NOISE

- Thermal Noise
- Intermodulation noise
- Crosstalk
- Impulse Noise

THERMAL NOISE

- Thermal noise due to agitation of electrons
- Present in all electronic devices and transmission media
- Cannot be eliminated
- Function of temperature

THERMAL NOISE

- Amount of thermal noise to be found in a bandwidth of 1Hz in any device or conductor is:

$$N_0 = \mathrm{k}T\,(\mathrm{W/Hz})$$

  - N_0 = noise power density in watts per 1 Hz of bandwidth
  - k = Boltzmann's constant = 1.3803×10^{-23} J/K
  - T = temperature, in Kelvins (absolute temperature)

THERMAL NOISE

- Noise is assumed to be independent of frequency
- Thermal noise present in a bandwidth of B Hertz (in watts):

$$N = \mathrm{k}TB$$

or, in decibel-watts

$$N = 10\log \mathrm{k} + 10\log T + 10\log B$$

NOISE TERMINOLOGY

- **Intermodulation noise** – occurs if signals with different frequencies share the same medium
  - Interference caused by a signal produced at a frequency that is the sum or difference of original frequencies
- **Crosstalk** – unwanted coupling between signal paths
- **Impulse noise** – irregular pulses or noise spikes
  - Short duration and of relatively high amplitude
  - Caused by **external electromagnetic disturbances** (Lightning strikes, Power line spikes, …), or faults and flaws in the communications system

EXPRESSION E_b/N_0

- Ratio of **signal energy per bit** to **noise power density per Hertz**

$$\frac{E_b}{N_0} = \frac{S/R}{N_0} = \frac{S}{\mathrm{k}TR}$$

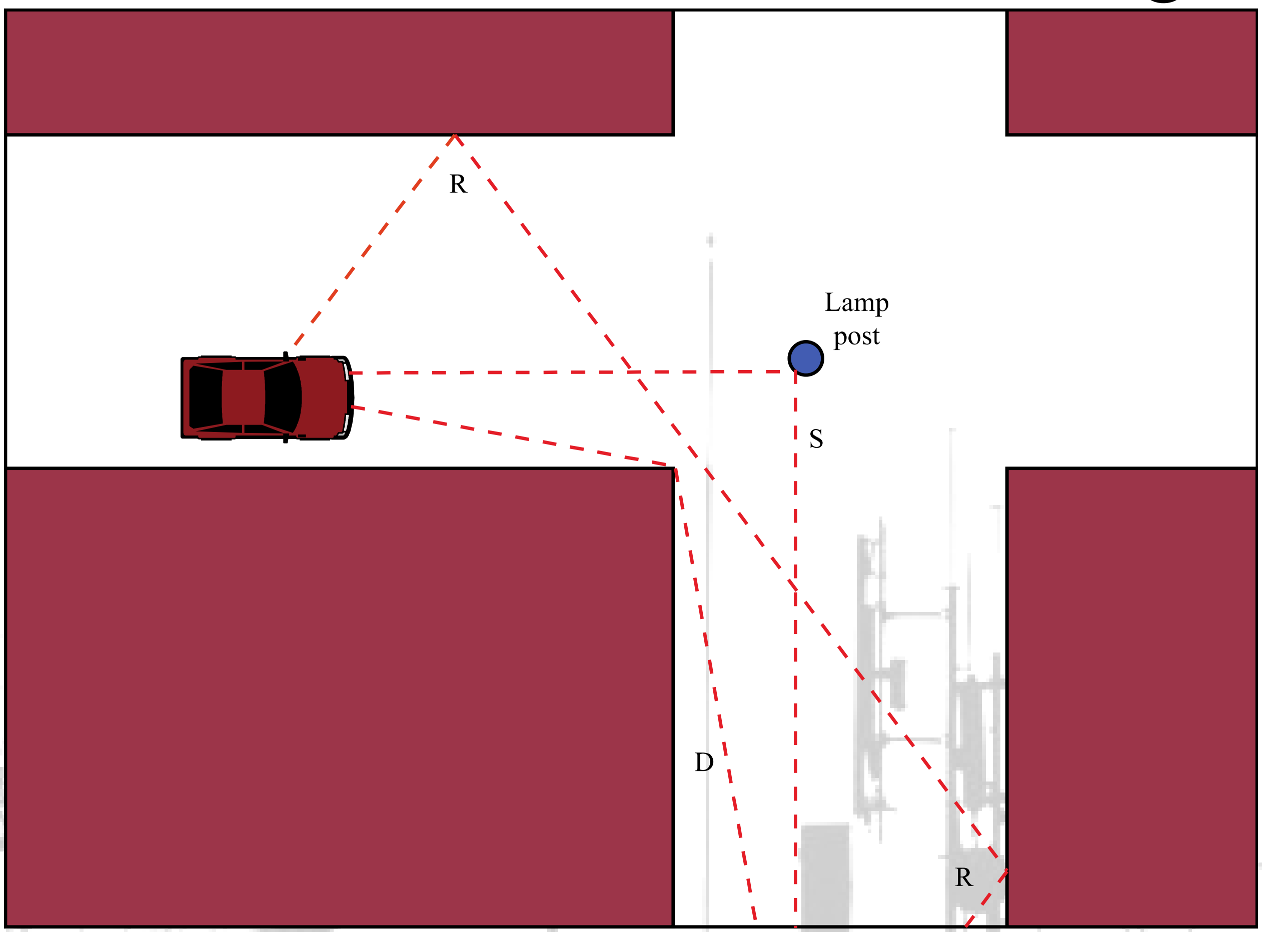
- The bit error rate (i.e., bit error probability) for digital data is a function of E_b/N_0
  - Given a value for E_b/N_0 to achieve a desired error rate, parameters of this formula can be selected
  - As bit rate R increases, transmitted signal power must increase to maintain required E_b/N_0

OTHER IMPAIRMENTS

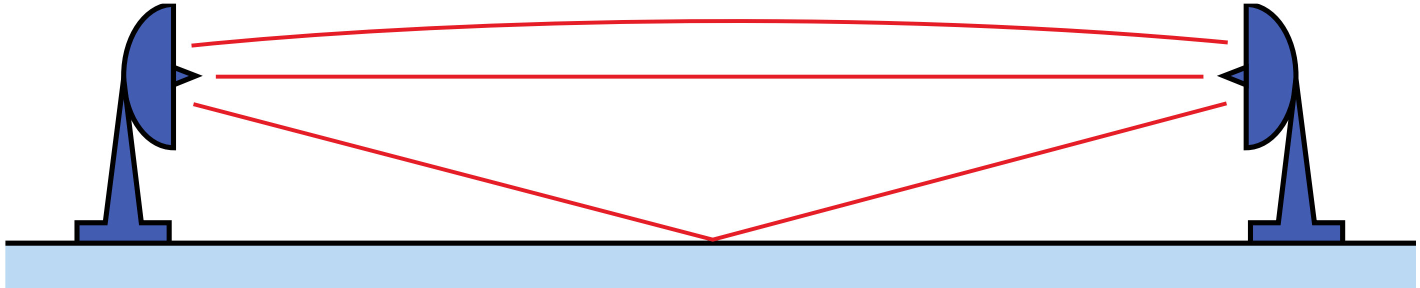
- Refraction – bending of radio waves as they propagate through the atmosphere
- Multipath – obstacles reflect signals so that multiple copies with varying delays are received

THE EFFECTS OF MULTIPATH PROPAGATION

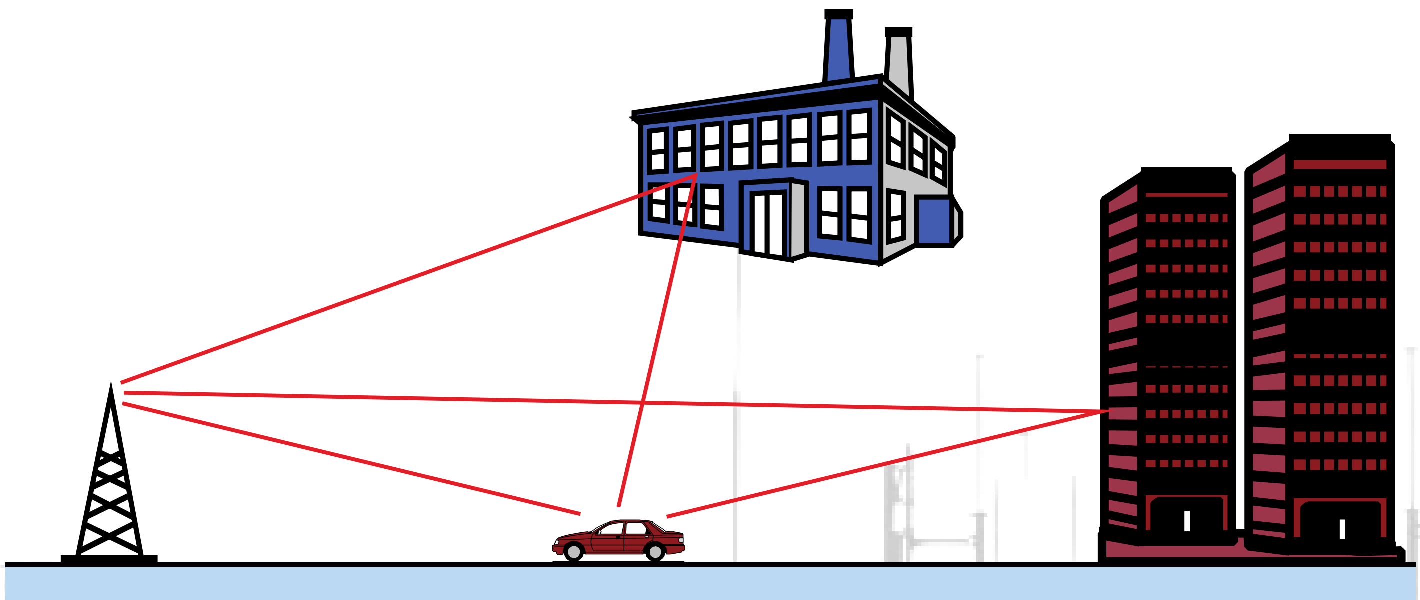
- Reflection, diffraction, and scattering



6.11 SKETCH OF THREE IMPORTANT PROPAGATION MECHANISMS

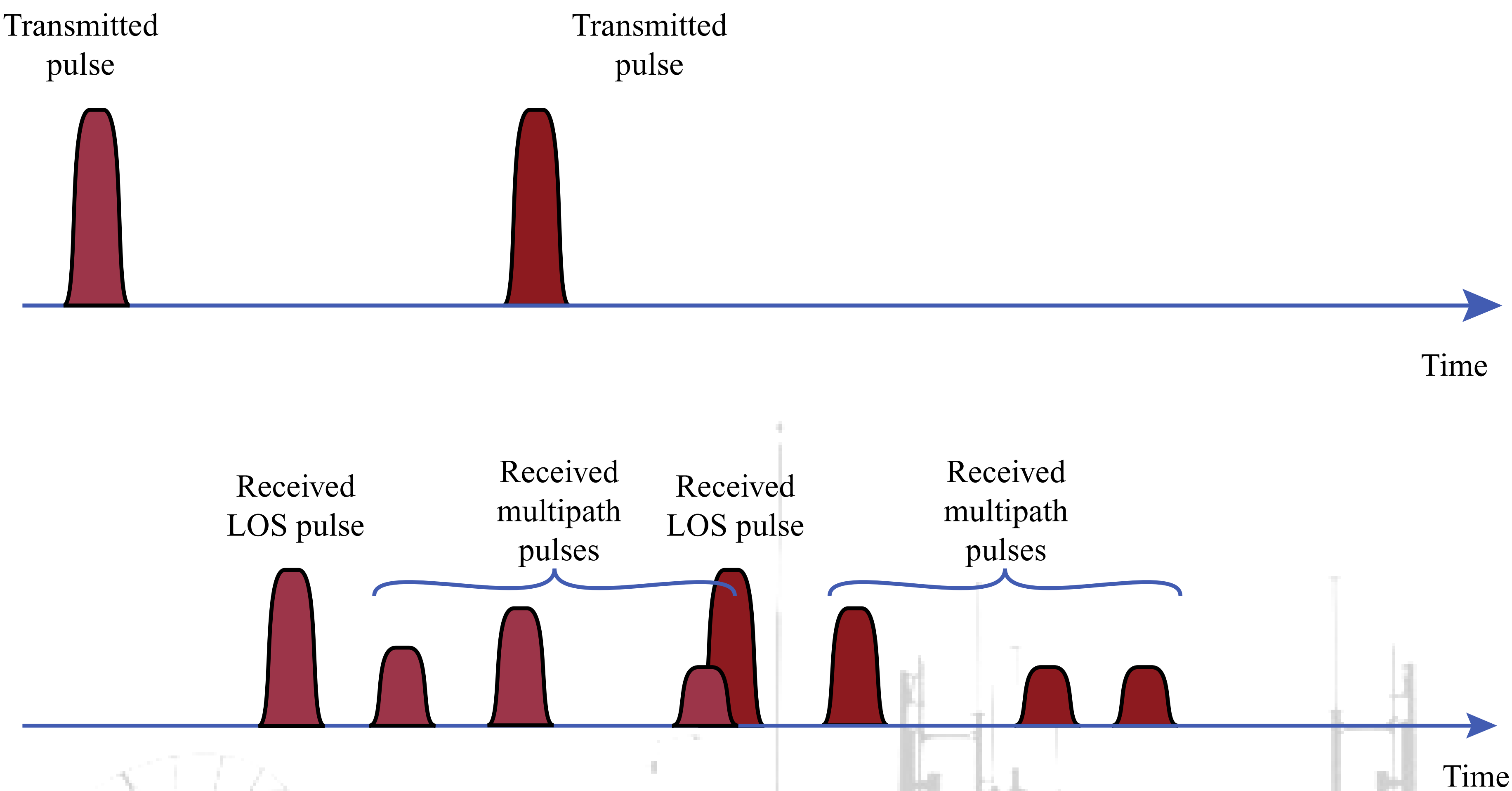


(a) Microwave line of sight



(b) Mobile radio

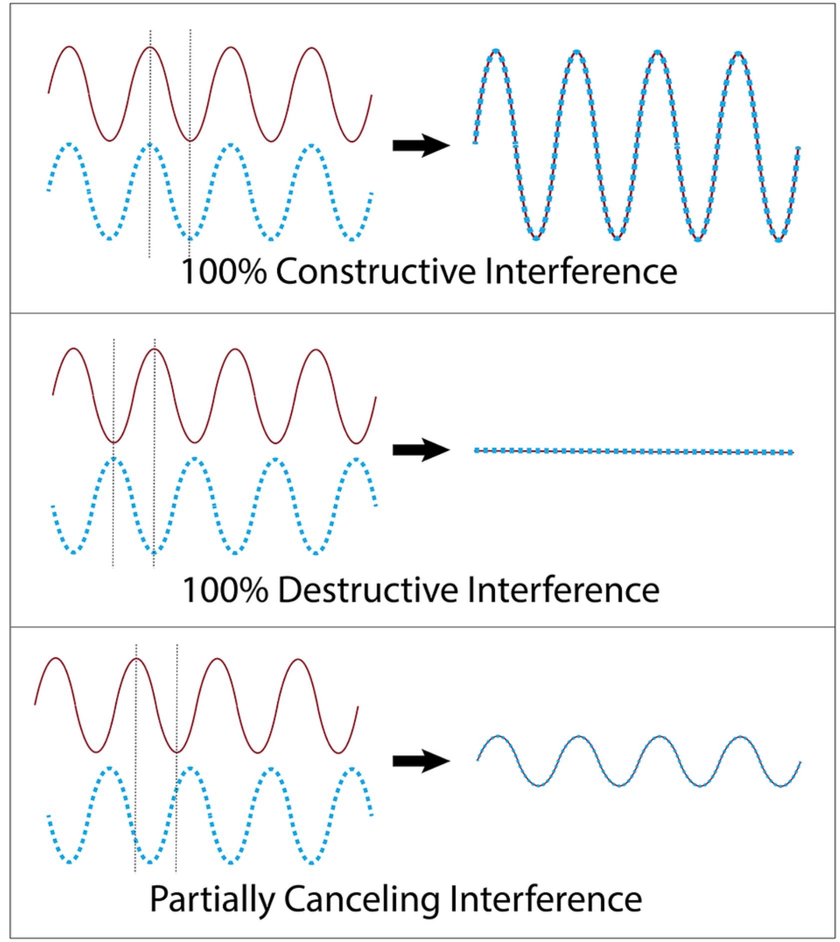
6.10 EXAMPLES OF MULTIPATH INTERFERENCE



6.12 TWO PULSES IN TIME-VARIANT MULTIPATH

THE EFFECTS OF MULTIPATH PROPAGATION

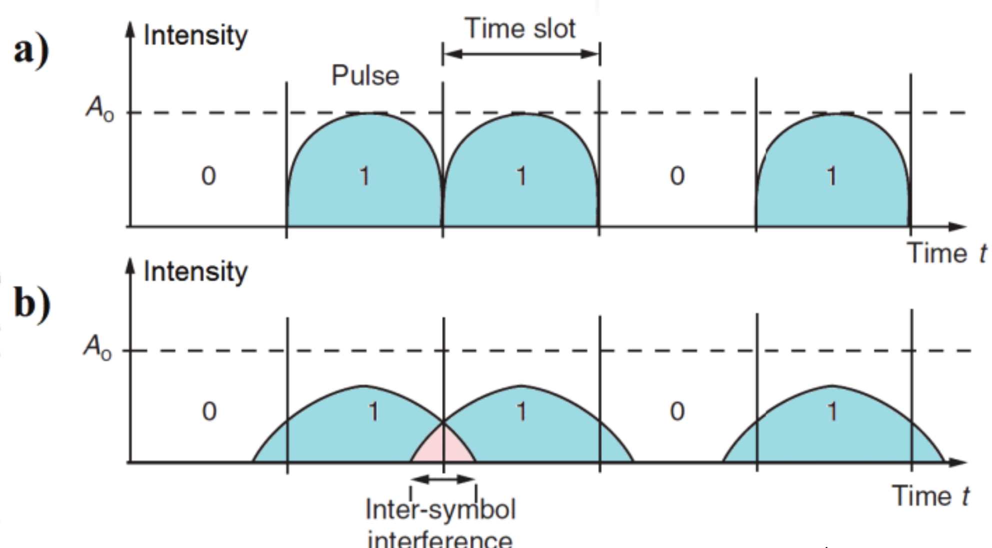
- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult



https://www.hamradioschool.com/post/vhf-multipath-more-than-one-signal-path

THE EFFECTS OF MULTIPATH PROPAGATION

- Intersymbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit



•DOI: 10.5755/j01.eee.113.7.622

FADING

Fading is the **variation (or fluctuation) in received signal strength** over time, frequency, or space due to changes in the transmission environment.

Causes of Fading

- **Multipath propagation**
  - The signal takes **multiple paths** (reflections, diffraction, scattering) to reach the receiver.
- **Mobility**
  - As the transmitter, receiver, or objects move, the **path lengths change**, causing rapid variations in phase and amplitude.
- **Environmental factors**
  - Buildings, vehicles, trees, and even weather can alter signal paths or absorption levels.

TYPES OF FADING

- Slow Fading (Large-Scale)

or

Fast Fading (Small-Scale)

- Flat Fading

or

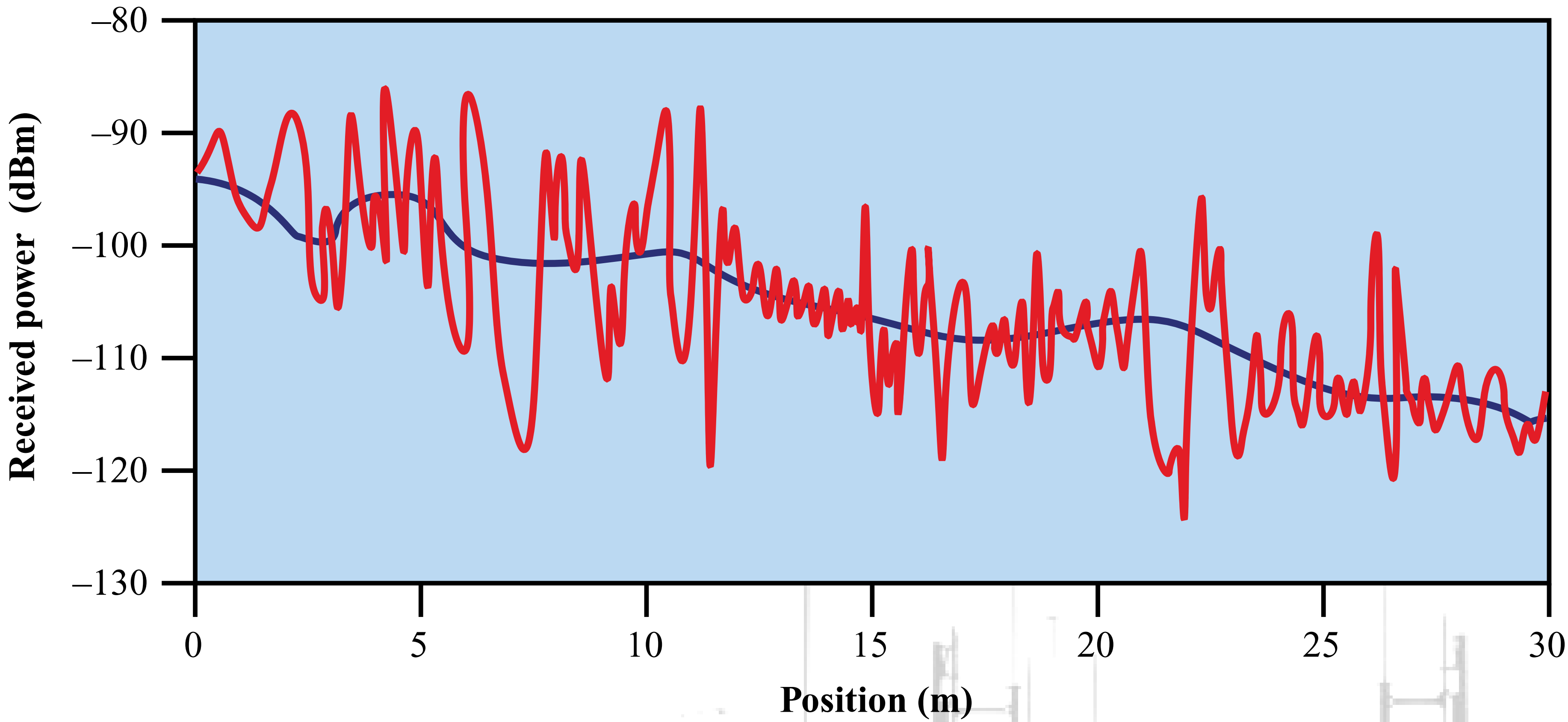
Frequency Selective Fading

TYPES OF FADING

Slow Fading (Large-Scale)

or

Fast Fading (Small-Scale)



6.13 TYPICAL LARGE-SCALE AND SMALL-SCALE FADING IN AN URBAN MOBILE ENVIRONMENT

TYPES OF FADING

- Slow Fading (Large-Scale)
  - Signal variations occur **slowly over time** (over large distances)
  - Shadowing (caused by large obstacles)
  - **Easily modeled using statistical distributions** (Rayleigh and Rician)

- Fast Fading (Small-Scale)
  - Rapid fluctuations in signal amplitude and frequency caused by relative **motion between the transmitter, receiver, or surrounding objects**.

TYPES OF FADING

Coherence time T_c characterizes Doppler shift

- How long a channel remains the same

– Coherence time $T_c >> T_b$ bit time → *slow fading*

- The channel does not change during the bit time

– Otherwise, *fast fading*

DISCUSSION TIME II

You are given the following parameters for a wireless link:

$T_c = 70$ ms

and bit rate r_b = 100 kbs. What type of fading does our channel experience? What does it mean? Think about the channel characteristics (amplitude, phase) over time, the received signal at the receiver, and errors.

DISCUSSION TIME II

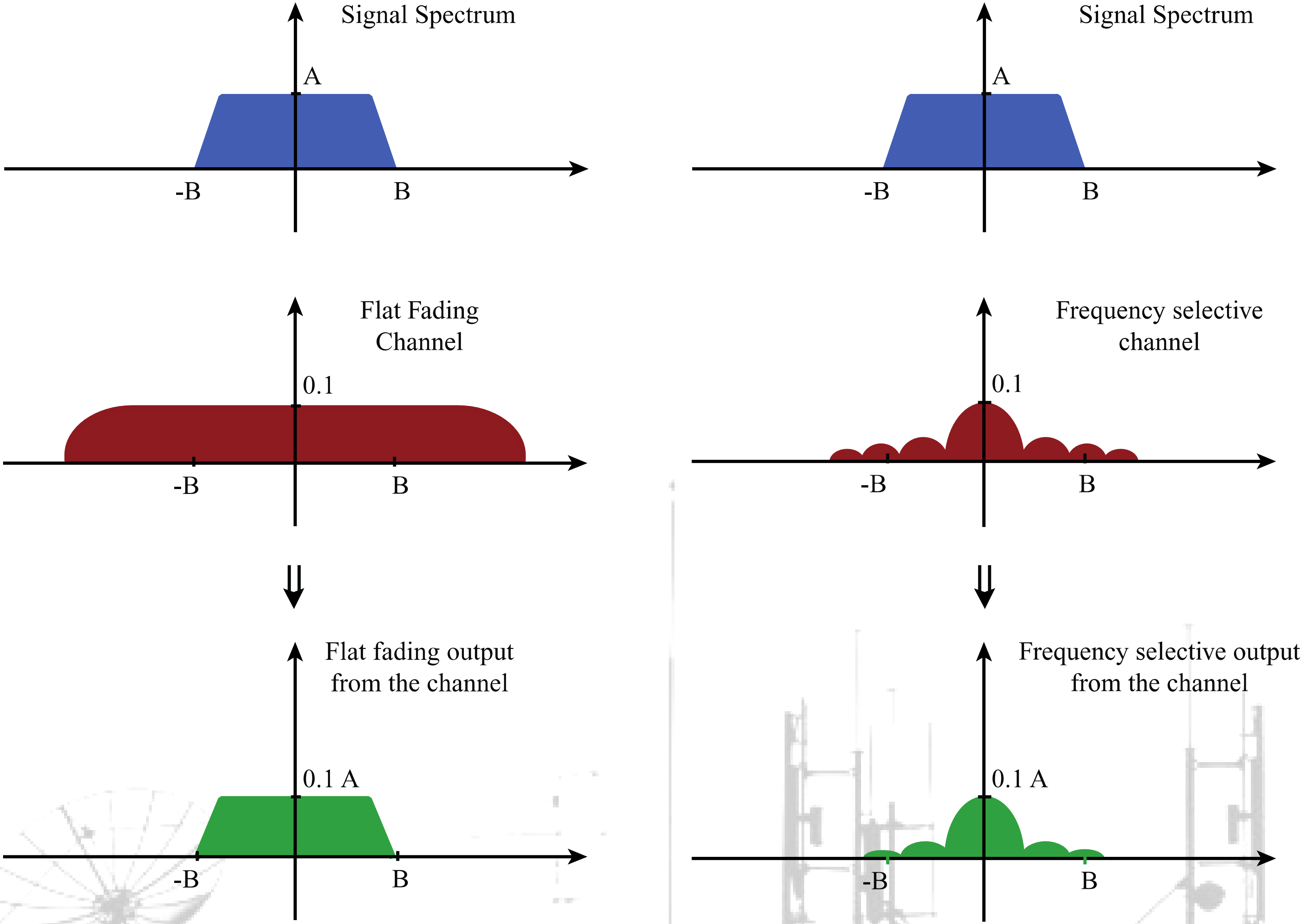
- Bit time $T_b = 1/100 \times 10^3 = 10\ \mu s$
- $T_c \gg T_b$? 70 ms >> 10 μs
- True, so *slow fading*
  - The channel characteristics (amplitude, phase) remain nearly constant over many bits or symbols.
  - The receiver experiences long-term variations due to shadowing, rather than rapid fluctuations.
  - Errors tend to occur in bursts when the signal level drops (deep fades).

TYPES OF FADING

Flat Fading

vs

Frequency Selective Fading



6.14 FLAT AND FREQUENCY SELECTIVE FADING

TYPES OF FADING

Flat Fading vs Frequency Selective Fading

- **Coherence bandwidth** B_c characterizes multipath
  - **Bandwidth over which the channel response remains relatively constant**
  - Related to delay spread, the spread in time of the arrivals of multipath signals
- Signal bandwidth B_s is proportional to the bit rate
- If $B_c >> B_s$, then *flat fading*
  - The signal bandwidth fits well within the channel bandwidth
- Otherwise, *frequency selective fading*

DISCUSSION TIME II

You are given the following parameters for a wireless link: B_c = 150 kHz, bit rate r_b = 10 kbs. What type of fading does our channel experience? What does it mean? Think about the channel spectrum, received signal, and ISI.

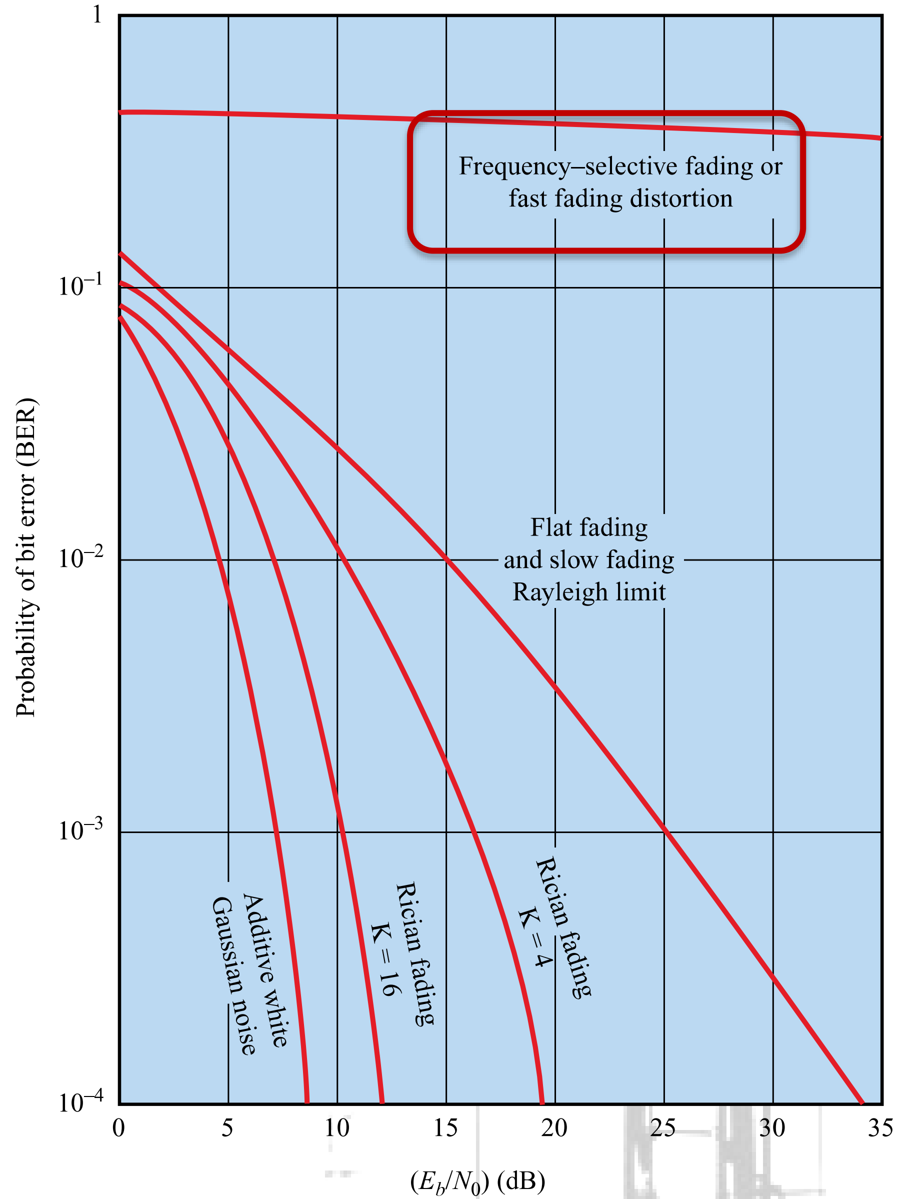
DISCUSSION TIME II

- Assume signal bandwidth $B_s \approx r_b$, $B_s = 10\ kHz$
- $B_c >> B_s$? 150 kHz >> 10 kHz?
- Using a factor of 10 for “>>”, 150 kHz is more than 10 ×10 kHz
- False, so *flat fading*

▪ The channel affects all frequency components of the signal in the same way — there is no significant frequency selectivity.

▪ The signal experiences attenuation and phase shift, but no inter-symbol interference (ISI) occurs.

▪ The channel can be modeled as a single complex gain (amplitude + phase) that varies over time.



6.15 THEORETICAL BIT ERROR RATE FOR VARIOUS FADING CONDITIONS

CHANNEL CORRECTION MECHANISMS

- Forward error correction (Lecture 11)
- Adaptive equalization
- Adaptive modulation and coding
- Diversity techniques and MIMO (Lecture 12)
- OFDM (Lecture 8)
- Spread sprectrum (Lecture 10)
- Ect.

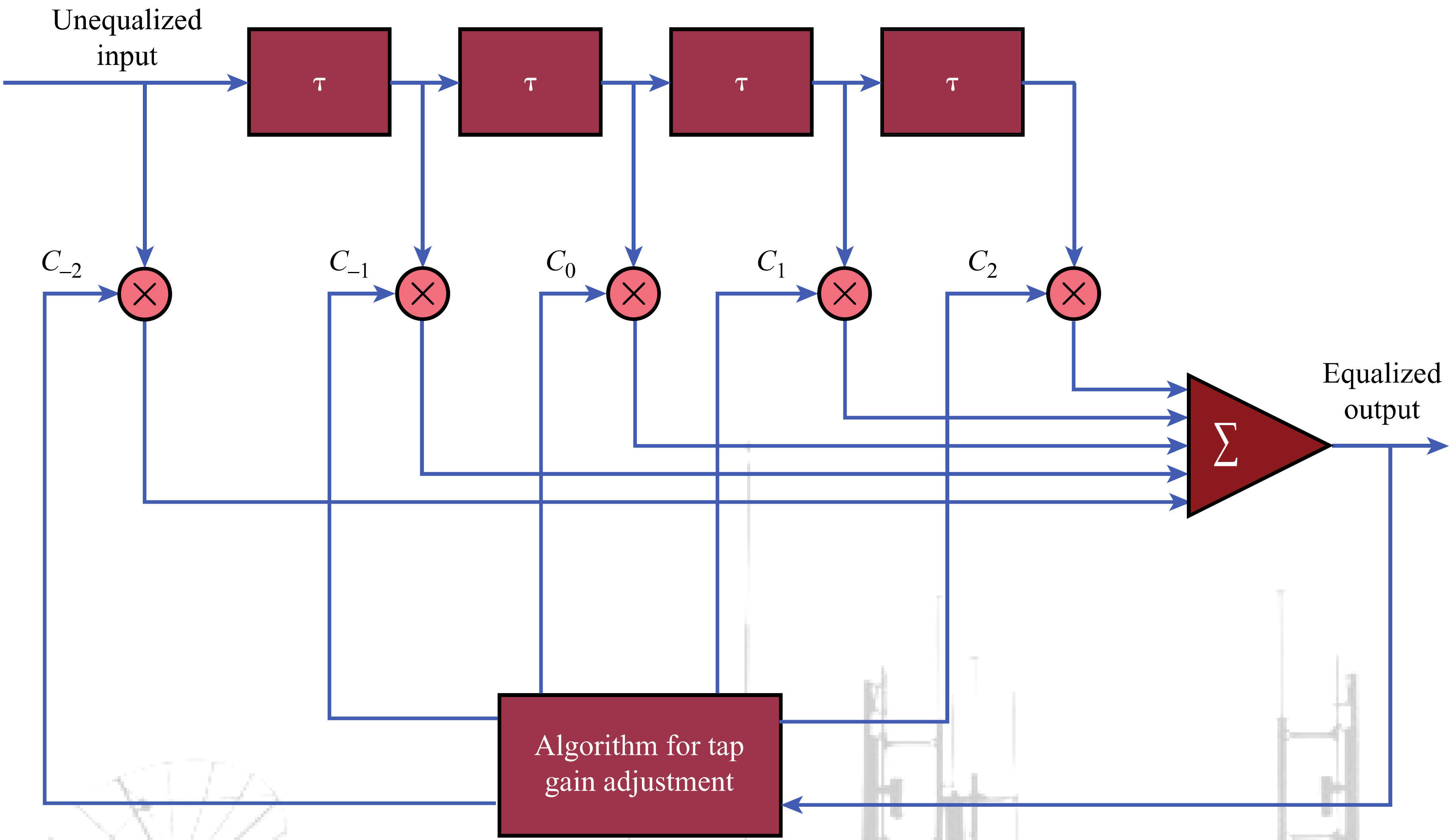
ADAPTIVE EQUALIZATION

An **equalizer** is a filter (usually digital) at the receive:

- **Shapes** the received signal to **reverse** the channel's distortion
- **Restores** the original transmitted symbols as accurately as possible

Essentially, it **learns** the channel and **cancels out** its effects.

An **adaptive equalizer** automatically **updates its filter coefficients** to keep track of the changing channel.



6.16 LINEAR EQUALIZER CIRCUIT

QUESTIONS?