Lecture 2. Wireless Channels (06/28)

1. Introduction	
2. Review of Modulation Techniques	a. Principles of SS modulations b. General model of DSSS modulation c. Code orthogonality d. DSSS E Spread spectrum in CDMA
3. Mobile Radio Propagation	a. Propagation theory b. Free space propagation c. Wireless link power budget analysis
4. Basics of Antenna Theory	
5. MAC in Wireless 802.11b LAN5	a. Difference with wired Ethernet
6. Random Access Protocols	
7. Motivation for a specialized MAC	a. WACA
8. MAC 802.11 Sub-layer Protocol	a. 802.11 bottom layers protocol stack b. 802.11 characteristics

1.Introduction

The Electromagnetic Spectrum

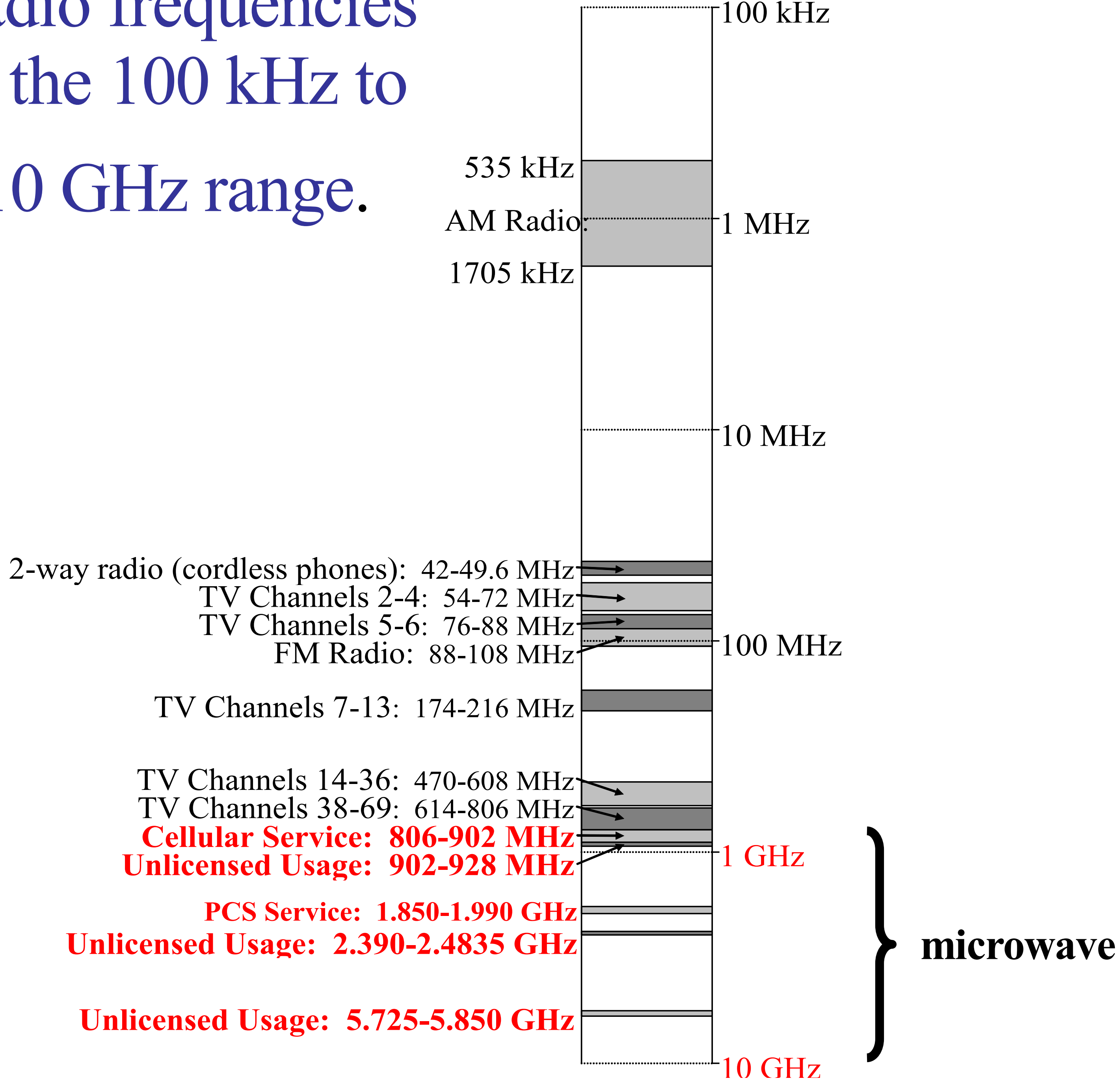
- Radio Transmission
- Microwave Transmission
- Infrared and Millimeter Waves
- Lightwave Transmission

In vacuum, all electromagnetic waves travel at the same speed, no matter what their frequency. This speed is the speed of light-c, is about 1 foot (30cm)/ns. In copper or fiber the speed slows to about 2/3 of this value and is slightly frequency dependent.

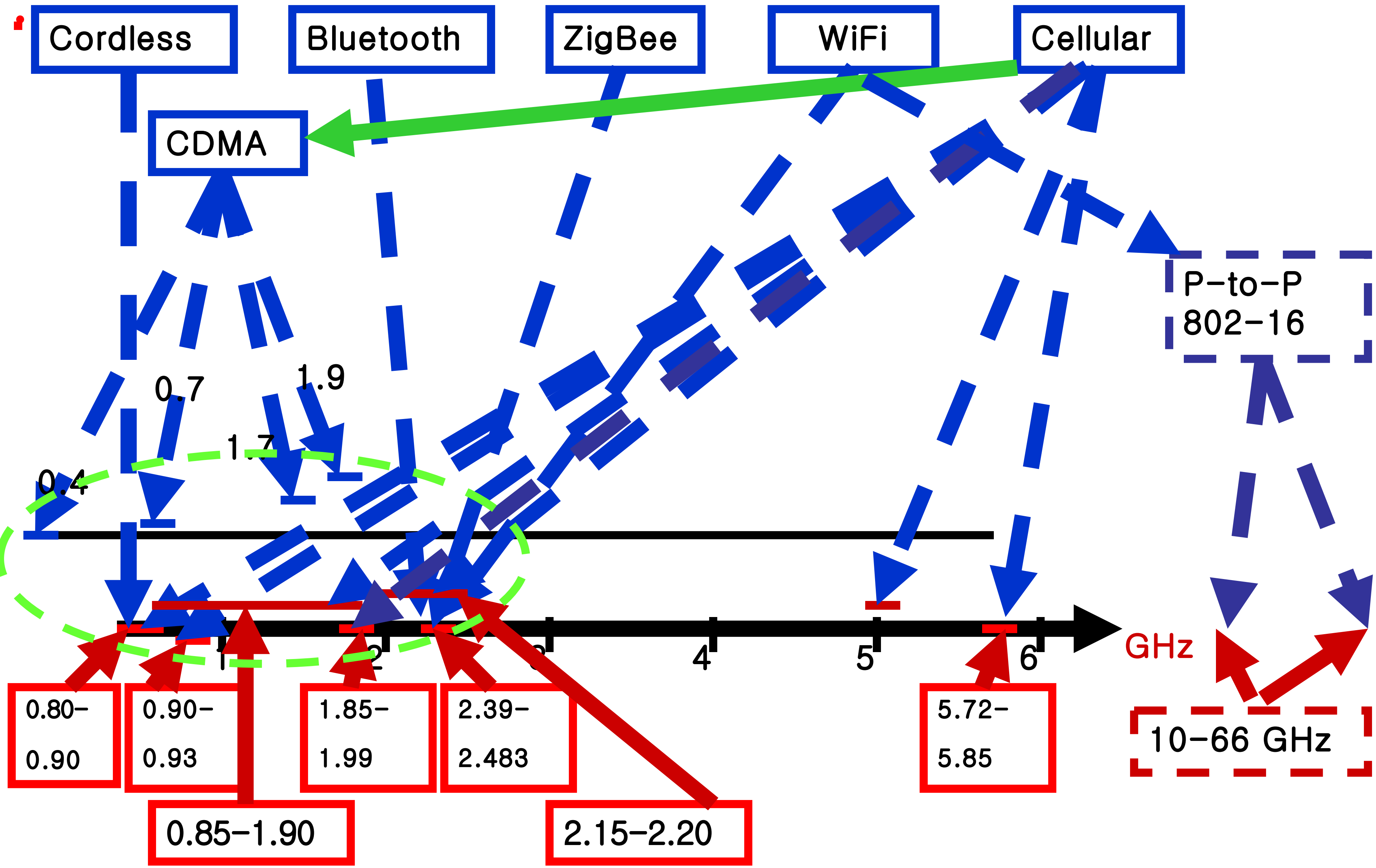
- The relation between frequency f , wavelength λ , and speed –c is $\boxed{f\lambda = c}$.
- As a rule of thumb, when λ is in meters and f is in MHz-
  .

$$\boxed{f\lambda = [300]}$$

Radio frequencies in the 100 kHz to 10 GHz range.



Wireless Services



Absorption

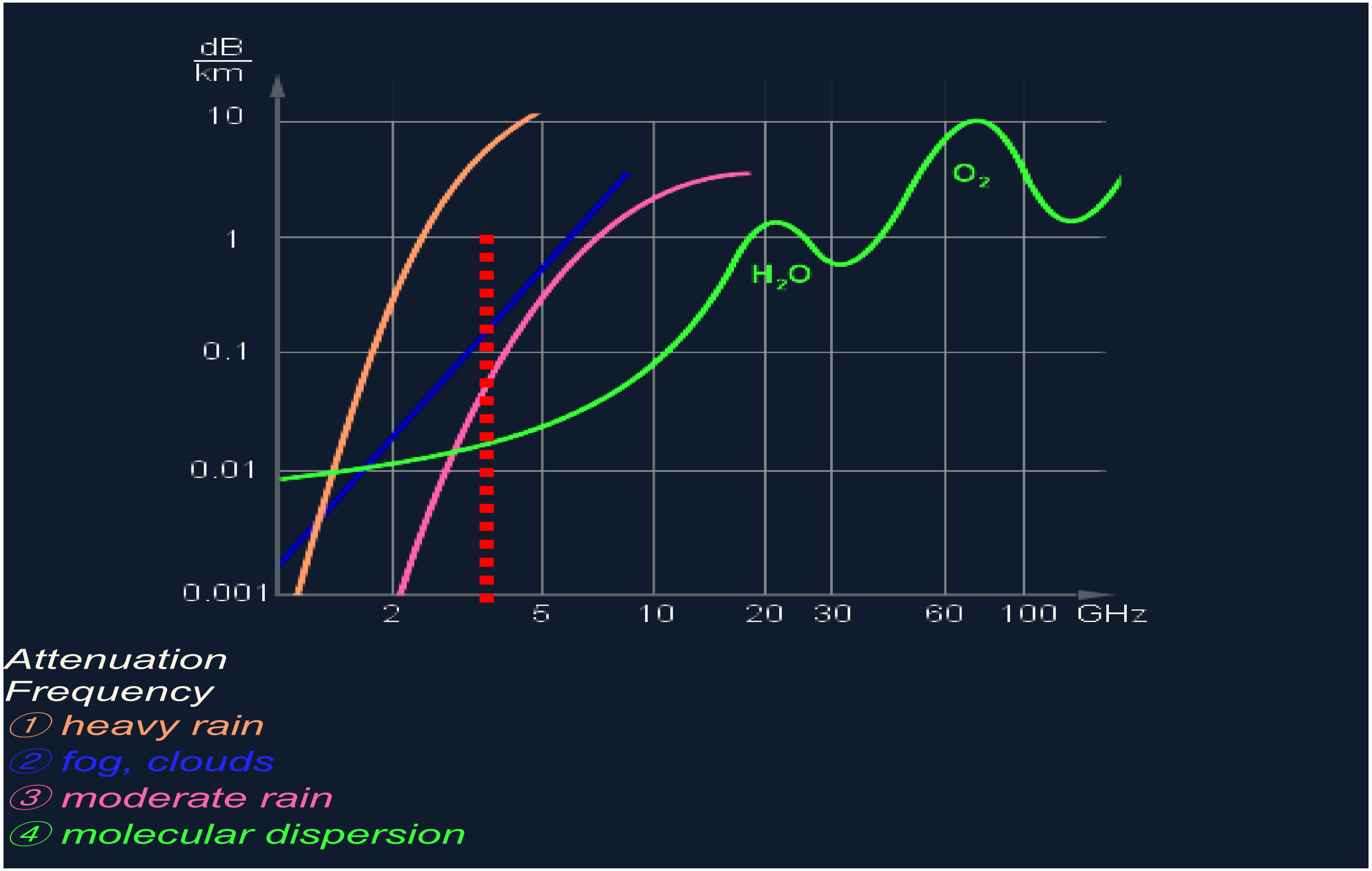


Figure 1: Electromagnetic absorption of the earth's atmosphere

The electromagnetic wave may be partially or totally absorbed by an absorbing medium due to atomic and molecular

The absorption of electromagnetic radiation is insignificant at low frequencies less than 3 Gigahertzes (or a wavelength longer than ten centimeters

2. Review of Modulation Techniques

1. Microwave voice/data transmissions: No AM.

2. Data-modulate the carrier wave using: PSK, FSK, and **SS modulation** techniques.

2a. Links (channels) are separated with: FDMA.

3. Voice data-to encode signal digitally use: PCM

3a. Several voice signals in one channel are separated by: TDMA

Shannon's law shows the relationship between analog Channel bandwidth and digital channel capacity:

$$\boxed{C = W \cdot \log_2\left[1+\frac{S}{N}\right]}$$

When the SNR < below 1 (wireless channel is noisy channel), less than 1 bit can be transferred by each sample.
If the SNR ratio = 3, and the C=<2B.

Transmission Rate R is provided $\boxed{R \le C}$

Equality is achieved only when SNR is infinity

In practice: impossible to create an encoding scheme that allows accurate transmissions near to the Shannon limit.
SS modulation allows to more closely approach the Shannon's limit, by transmitting at a low SNR.

a. Principles of SS modulation

- The most important parameter in any SS system is the processing gain G_p:

$$\boxed{G_p = \frac{W}{C}}$$

$$\boxed{C = W \cdot \log_2\left[1 + \frac{S}{N}\right]}$$

This value measures the ratio of Transmitted RF bandwidth W to the narrowband information rate C.

A system with a low signal-to-noise ratio must have a high processing gain Gp in order to recover the original signal.

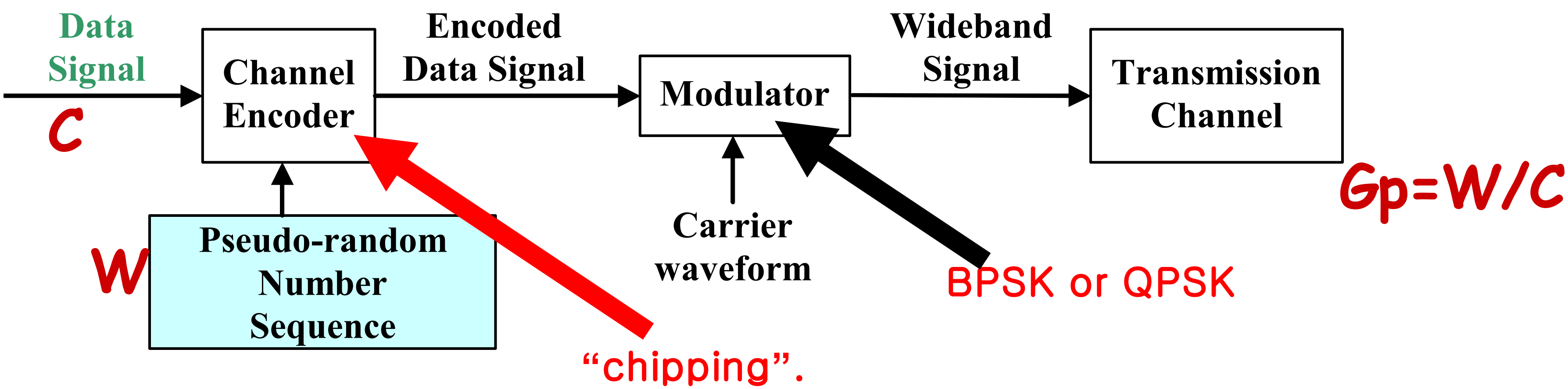
Types of Spread Spectrum Modulation:

- **Direct Sequence Spread Spectrum (DSSS)**
- **Frequency Hopping Spread Spectrum (FHSS)**

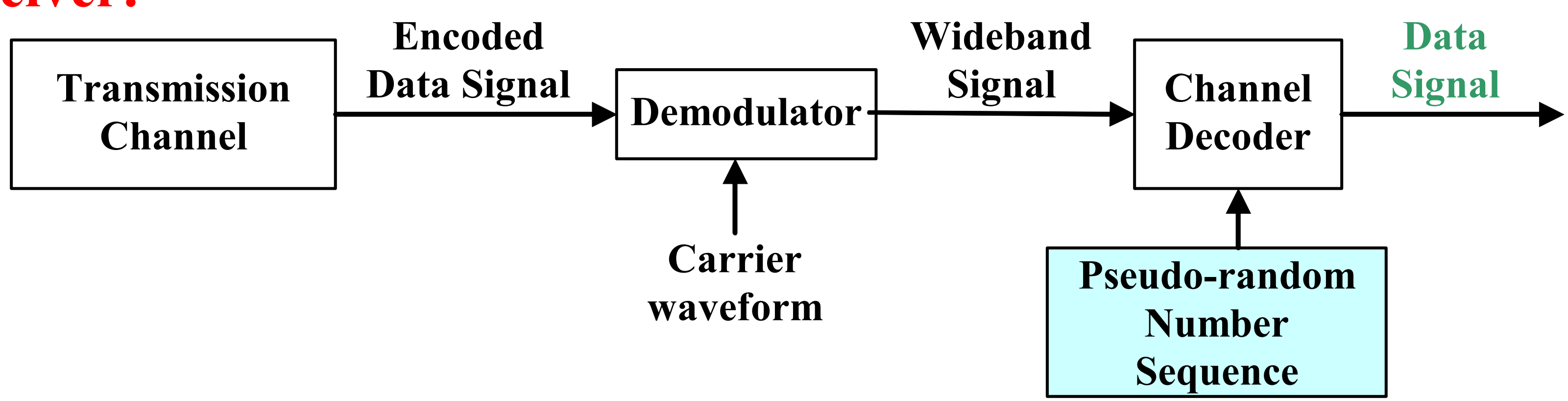
b. General model of DSSS modulations

CDMA

Transmitter:



Receiver:



c. Code orthogonality

DSSS

Two vectors called orthogonal if their inner product is 0

(Orthogonal in code space has the same meaning as in standard space).

Two vectors (2,5,0) and (0,0,17); (2,5,0)*(0,0,17)=0+0+0=0; The vectors (1,2,3) and (4,2,-6) are not (inner product -10); (1,2,3) and (4,2,-3) are "almost" orthogonal (-1 which is close to zero).

Code for a certain user should be orthogonal to other codes, and should have a good autocorrelation.

Barker code (+1,-1,+1,+1,-1,+1,+1+1,-1,-1,-1), has good autocorrelation, (inner product with itself is large 11). But if this Barker code is shifted 1 chip, the correlation drops to a value of 1. It stays at this low until the code matches itself again perfectly. This he lps to synchronize a receiver with the data stream. The matching process helps the receiver, to reconstruct the original data.

A and **B**, want to send data, CDMA assigns the following unique and **orthogonal key sequences**: **Key for sender A**, $\boxed{A_k = 010011}$

Key for sender B $\boxed{B_k = 110101}$; **A** wants to send the bit $\boxed{A_d = 1}$, sender **B** sends $\boxed{B_d = 0}$. To illustrate this example, let us assume that we code a binary 0 as -1, and binary 1 as +1. We can then apply the standard addition and multiplication rules. Both senders spread their signal using their key as chipping sequence (the term "spreading" here refers to the multiplication on the data bit with the whole chipping sequence).

$$\boxed{A_s = A_d * A_k = +1 * (-1,+1,-1,-1,+1,+1) = (-1,+1,-1,-1,+1,+1).}$$

$$\boxed{B_s = B_d * B_k = -1 * (+1,+1,-1,+1,-1,+1) = (-1,-1,+1,-1,+1,-1).}$$

Both signals are then transmitted at the same time using the same frequency, the signals superimpose in space. (No interference, no noise from this simple example), If the signals have the same strength at the receiver, the following signal C is received at a receiver

$$\boxed{C = A_S + B_S = (-2, 0, 0, -2 + 2, 0).}$$

DSSS

Receiver now wants to receive data from sender **A** and, therefore, tunes in to the code of **A**, i.e., applies **A's** code for dispreading:

$$\boxed{C * A_K = (-2,0,0,-2,+2,0) * (-1,+1,-1,-1,+1,+1) = 2+0+0+2+2+0 = 6.}$$

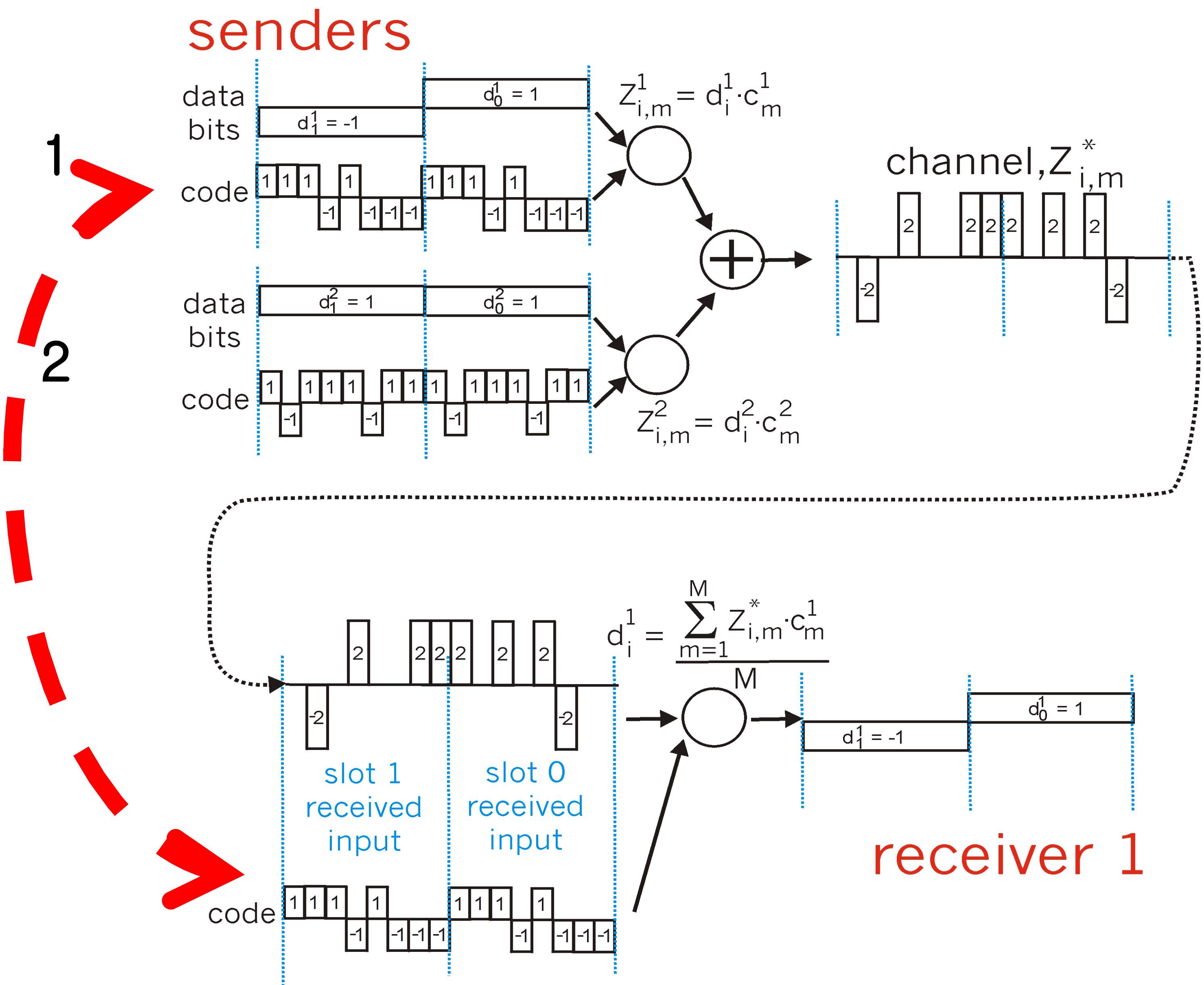
It is much larger than 0, the receiver detects a binary **1** (**A has sent 1**).

Tuning in to sender **B**, i.e., applying **B's** code gives

$$\boxed{C * B_K = (-2,0,0,-2,+2,0) * (+1,+1,-1,+1,-1,+1) = -2+0+0-2-2+0 = -6.}$$

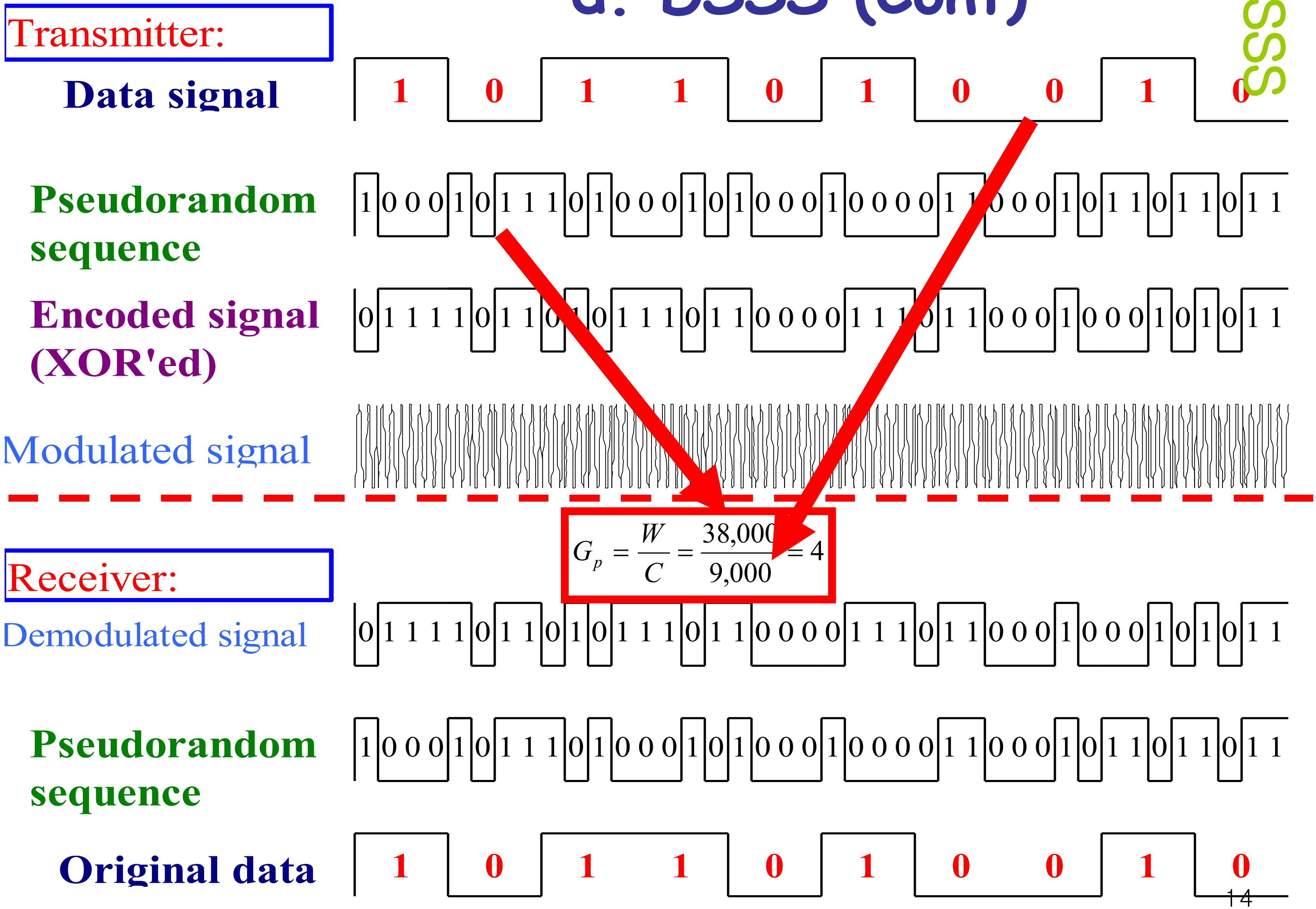
The result is negative, so a **0** has been detected (**B has sent bit 0**).

CDMA: two-sender interference



d. DSSS (Cont)

DSSS

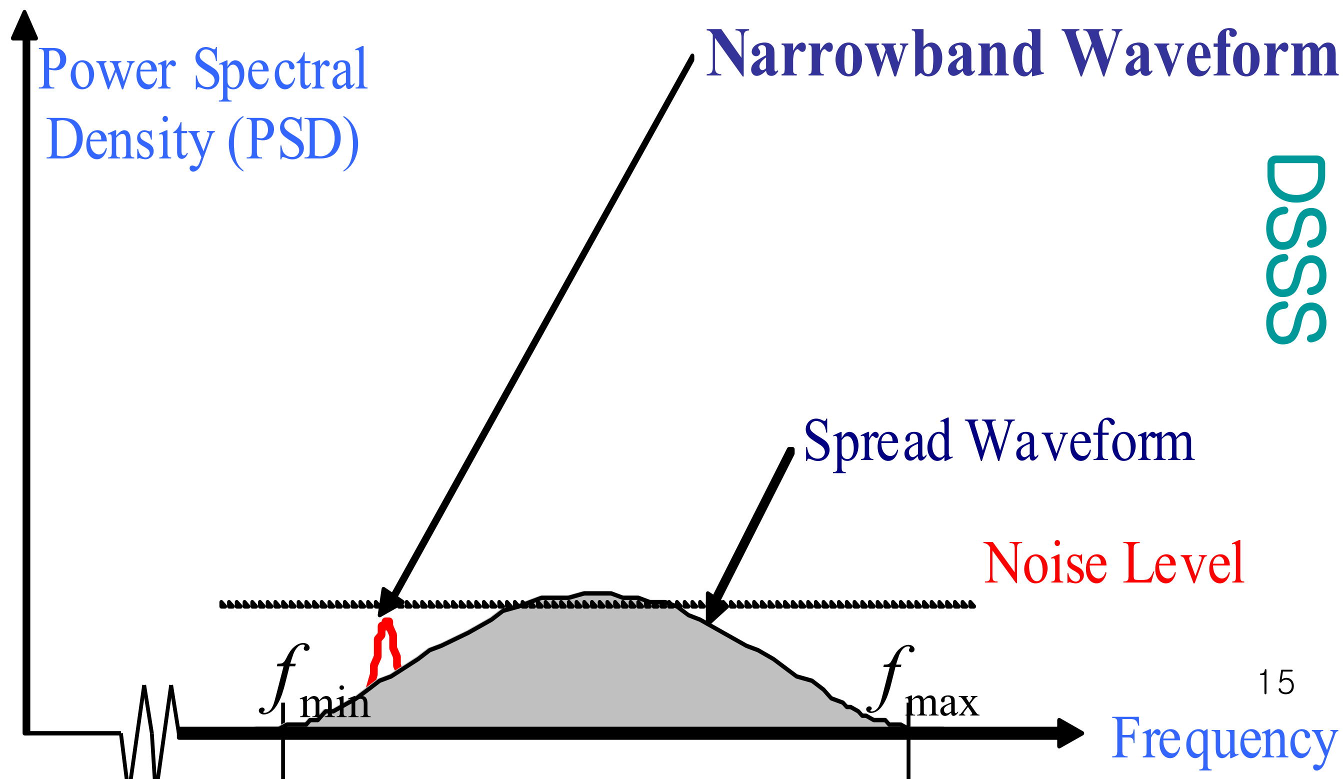


DSSS (Cont)

Gp **is determined from: PN sequence bit rate / the data signal information rate.**

For example: **If the information signal is transmitted at 9600 bps. The PN sequence has a bit rate of 38,400 bps. The resulting, transmitted bit rate is 38,400 bps, so**

$$\boxed{G_p = \frac{W}{C} = \frac{38,000}{9,000} = 4}$$



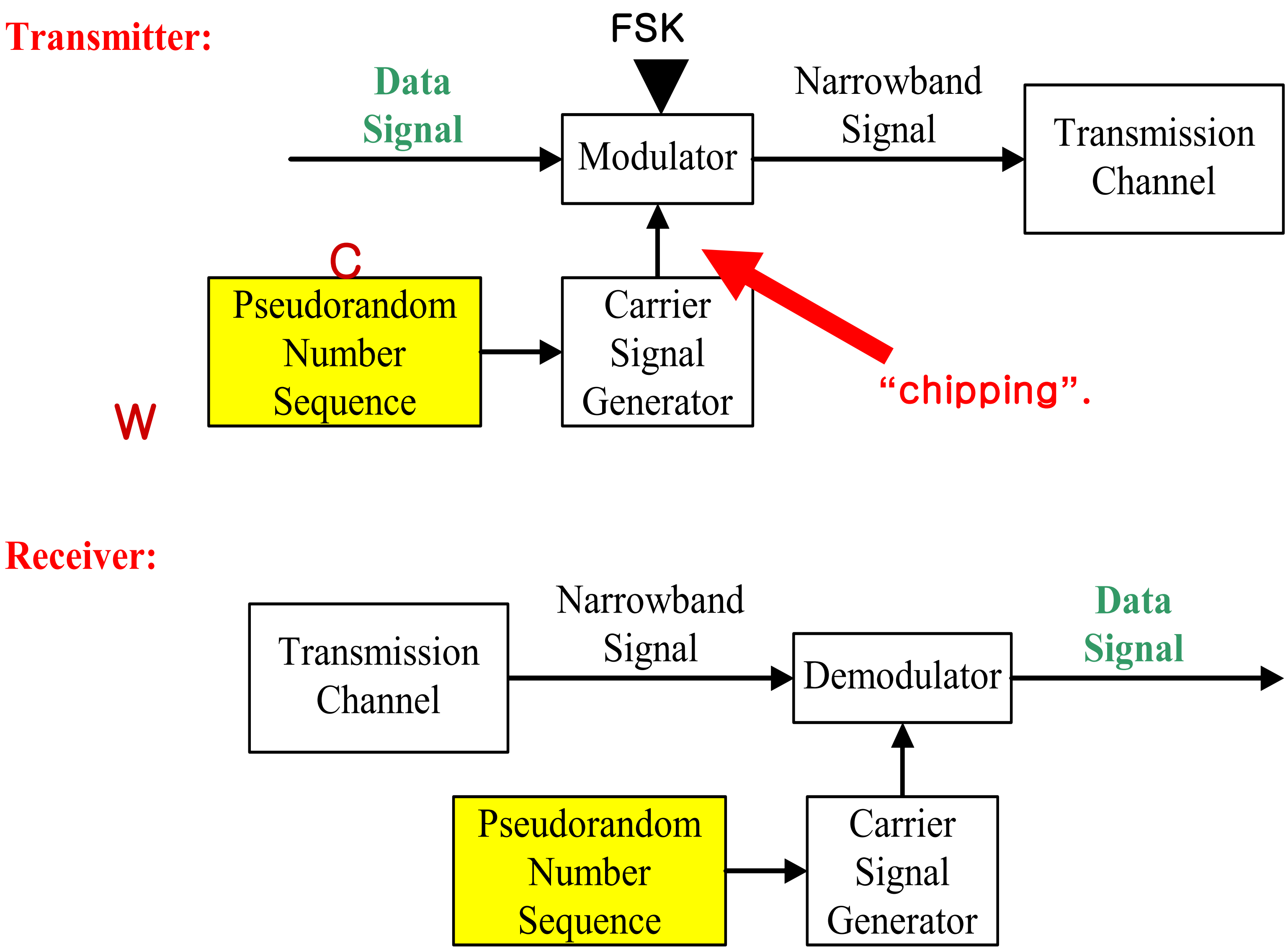
DSSS

e. Spread Spectrum in CDMA

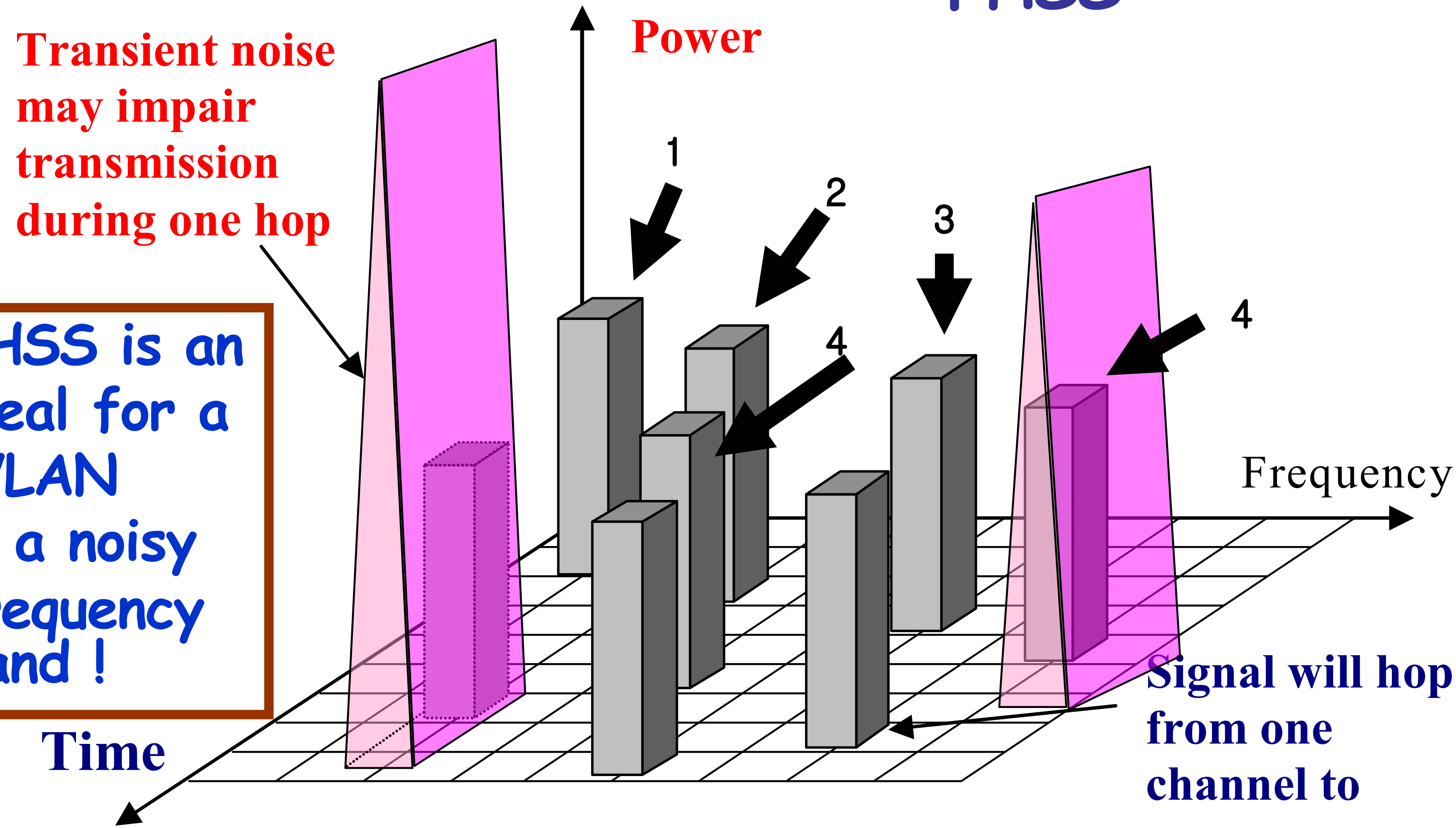
- **CDMA**: uses SS (DSSS or FHSS) encoding scheme
- Unique **code** assigned to each user (**code set** partitioning) Used in **wireless** broadcast channels (cell., satellite)
- All users in the same channel share the **same frequency**, but each user has **own "chipping" sequence** (i.e., code)
- Chipping sequence used to **encode** the signal
- **Encoded signal** =(**original signal**) X (**chipping sequence**)
- To make CDMA work, chipping sequences must be chosen **orthogonal** to each other.

Global System Mobile (GSM) uses FM and TDMA

3. General model of FHSS modulation



FHSS



FHSS is an ideal for a WLAN in a noisy frequency band !

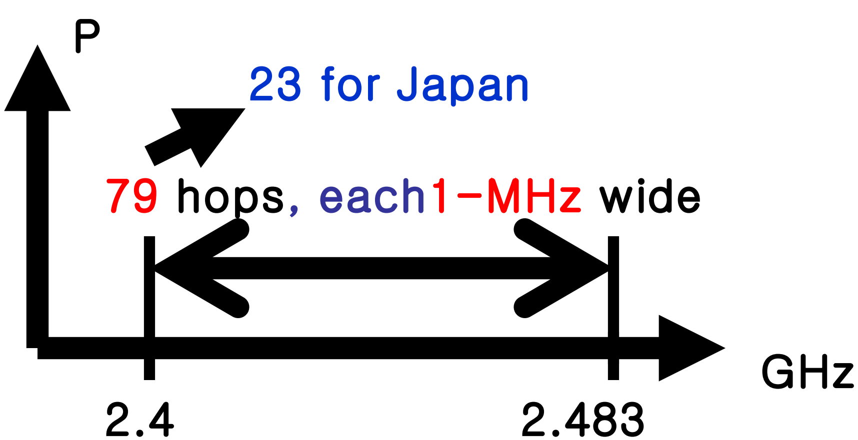
During any one hop, the signal is vulnerable to noise in that frequency band, but it will soon move to another frequency with hopefully less noise. This new band will be sufficiently removed from the previous noisy band

FHSS-hops carrier frequency

If stations use the same PN number, they stay synchronized in time.

They will hop to the same frequencies simultaneously

FHSS provides a security since an station, who does not know the hopping sequence or dwell time cannot overhear on transmissions.



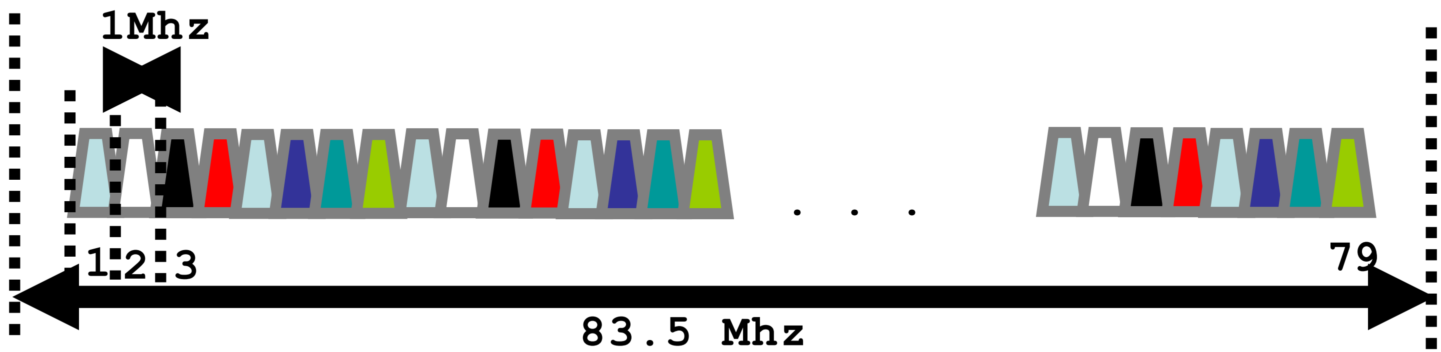
Dwell time, is an adjustable parameter, but must less than 400 msec.

FHSS advantages for WLAN

- WLAN systems can overlap without interference
- Immunity from noise and interference
- Resistance to radio reflections **(multipath transmission)**
- High data transfer capacity
- Low price for Tr and Rec

FHSS offers good resistance to multipath fading

4. Example: Bluetooth Frequency Hopping



- frequency hopping spread spectrum
  - 2.402 GHz + k MHz, k=0, …, 78
  - 1,600 hops per second
- GFSK modulation
  - 1 Mb/s symbol rate
- transmit power
  - 0 dBm (up to 20 dBm with power control)

5. Medium Access with CSMA/CA-WLAN

When many users are located in the same area, and use the same wireless Network at the same time, two different MAC methods are defined for signal multiplexing:

1. Distributed Coordination Function (DCF) (no control)

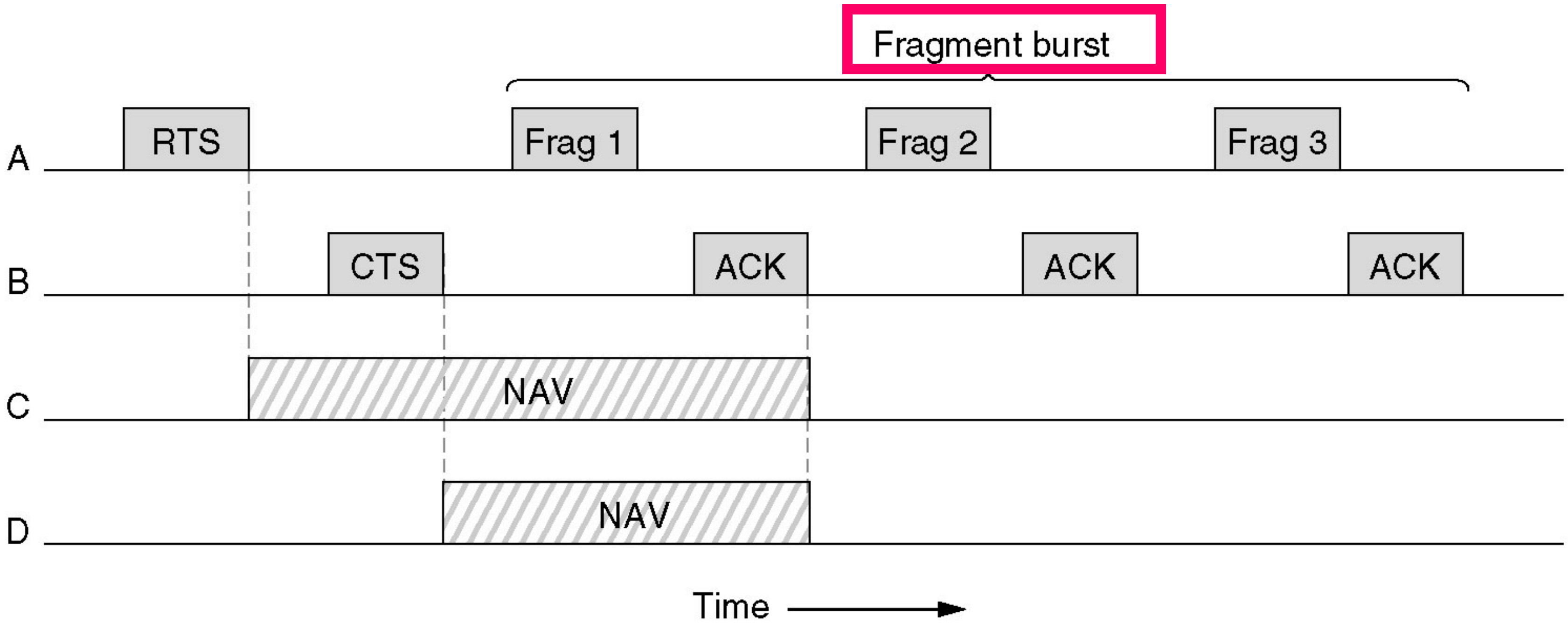
2. Point Coordination Function (PCF) (BS controls cell)

The basic access mechanism, called the **DCF**, Each unit senses the medium before it starts to transmit. If the medium **is free** for several microseconds, the unit can transmit for a **limited time**. If the medium **is busy**, the unit will **back-off** for a random time before it senses again.

It does not sense the channel while transmitting,

The 802.11 MAC Protocol (Cont) : fragments

DCF-The use of virtual channel sensing using CSMA/CA.



stop-and-wait protocol

6. Mobile Radio Propagation

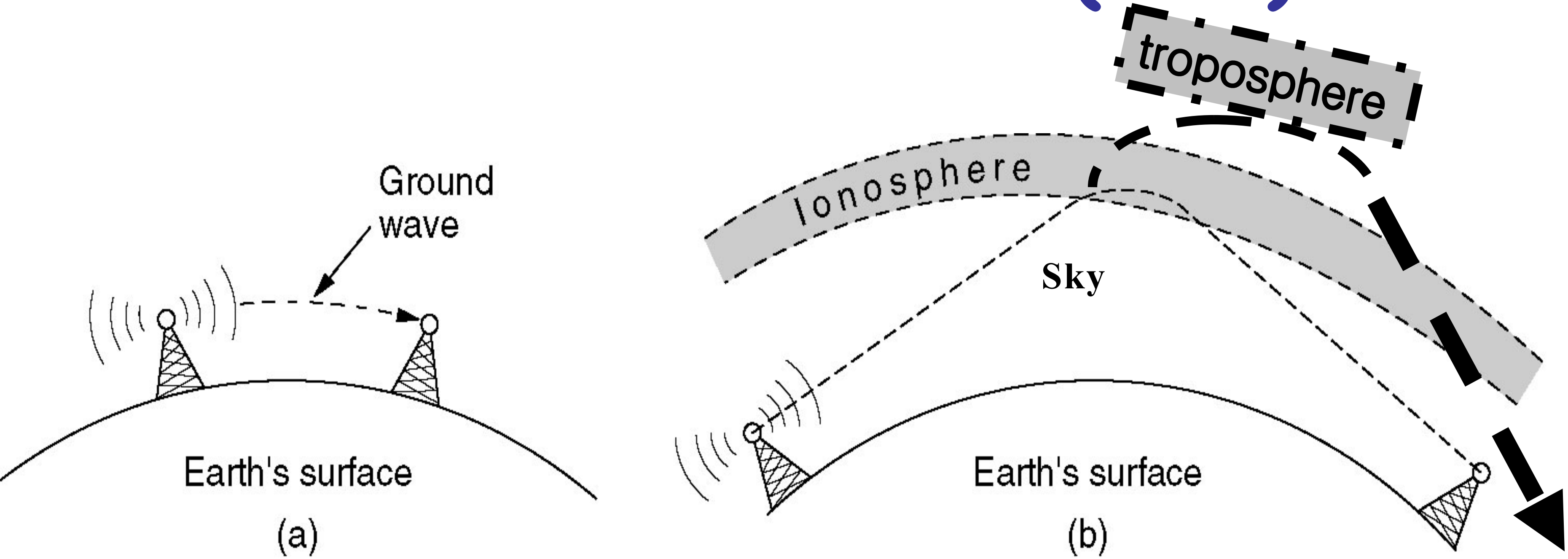
- Free space loss
- Two ray model
- Slow fading
- Fast fading
- Delay spread

Ground, Space, Sky, and Satellite waves

a. Propagation mechanisms

- **Reflection:** wave reflected by object larger than wavelength results **Large-scale fading.**
- **Scattering:** wave hits loose objects smaller than wavelength; signal scattered in bunch of outgoing weaker signals are result **Small-scale fading.**
- **Diffraction:** wave obstructed by surface with sharp, irregular edges.

Radio Transmission (cont)



(a) In the **LF** (10^5 hertz), and **MF** (10^6 hertz) bands, radio waves follow the curvature of the earth (ground).

(b) In the **HF** (10^7 hertz) band, they bounce off the ionosphere (space).

Example 1 What is the period of the moon according to Kepler's law?

Solution The moon is located approximately 384,000 km above the earth. The radius of the earth is 6378 km. Applying the formula, we get

Period = $(1/100)\ (384{,}000 + 6378)^{1.5}$ = 2,439,090 s = 1 month

Example 2 According to Kepler's law, what is the period of a satellite that is located at an orbit approximately 35,786 km above the earth?

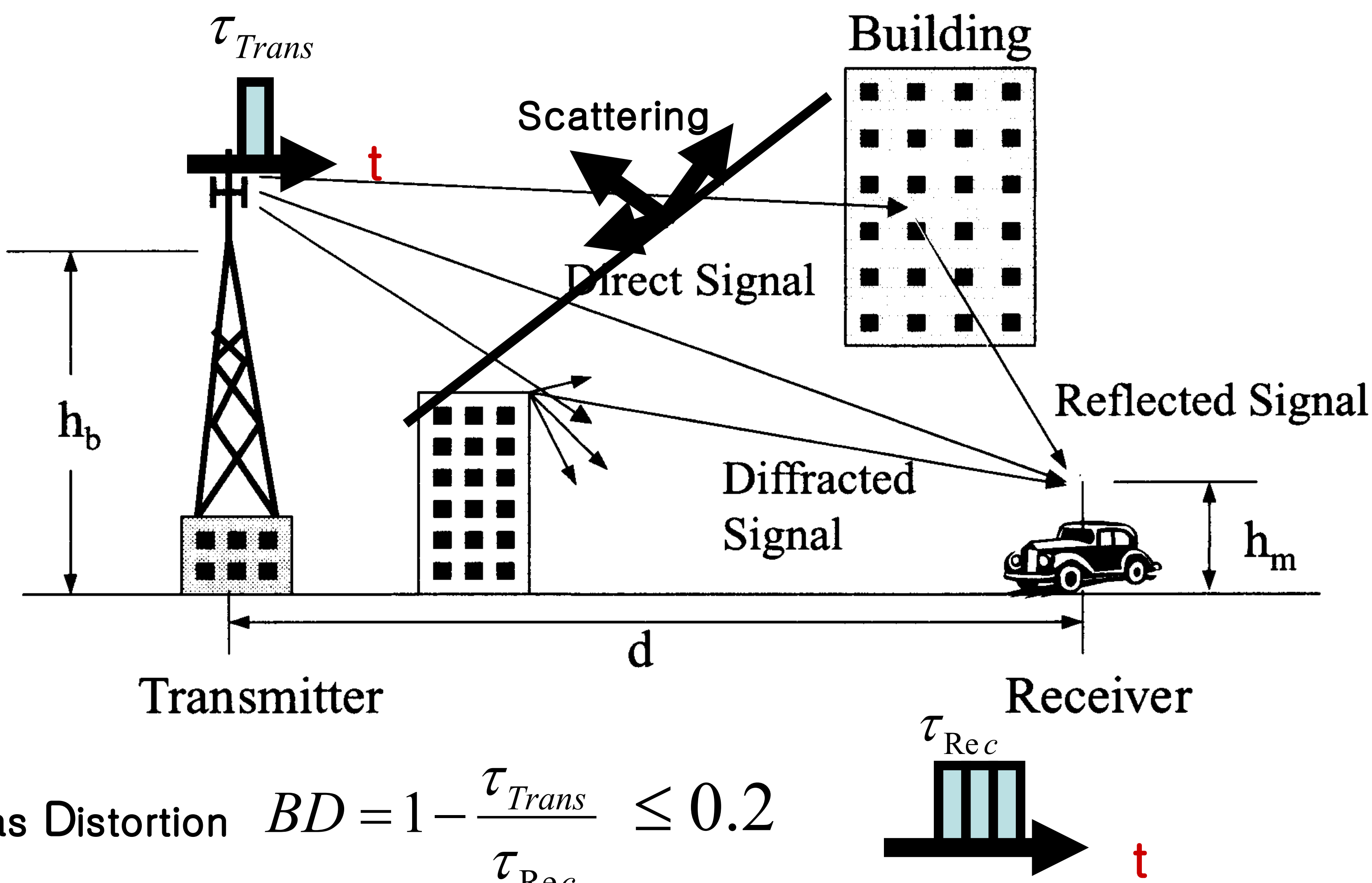
Solution Applying the formula, we get

Period = $(1/100)\ (35{,}786 + 6378)^{1.5}$ = 86,579 s = 24 h

A satellite like this is said to be stationary to the earth.

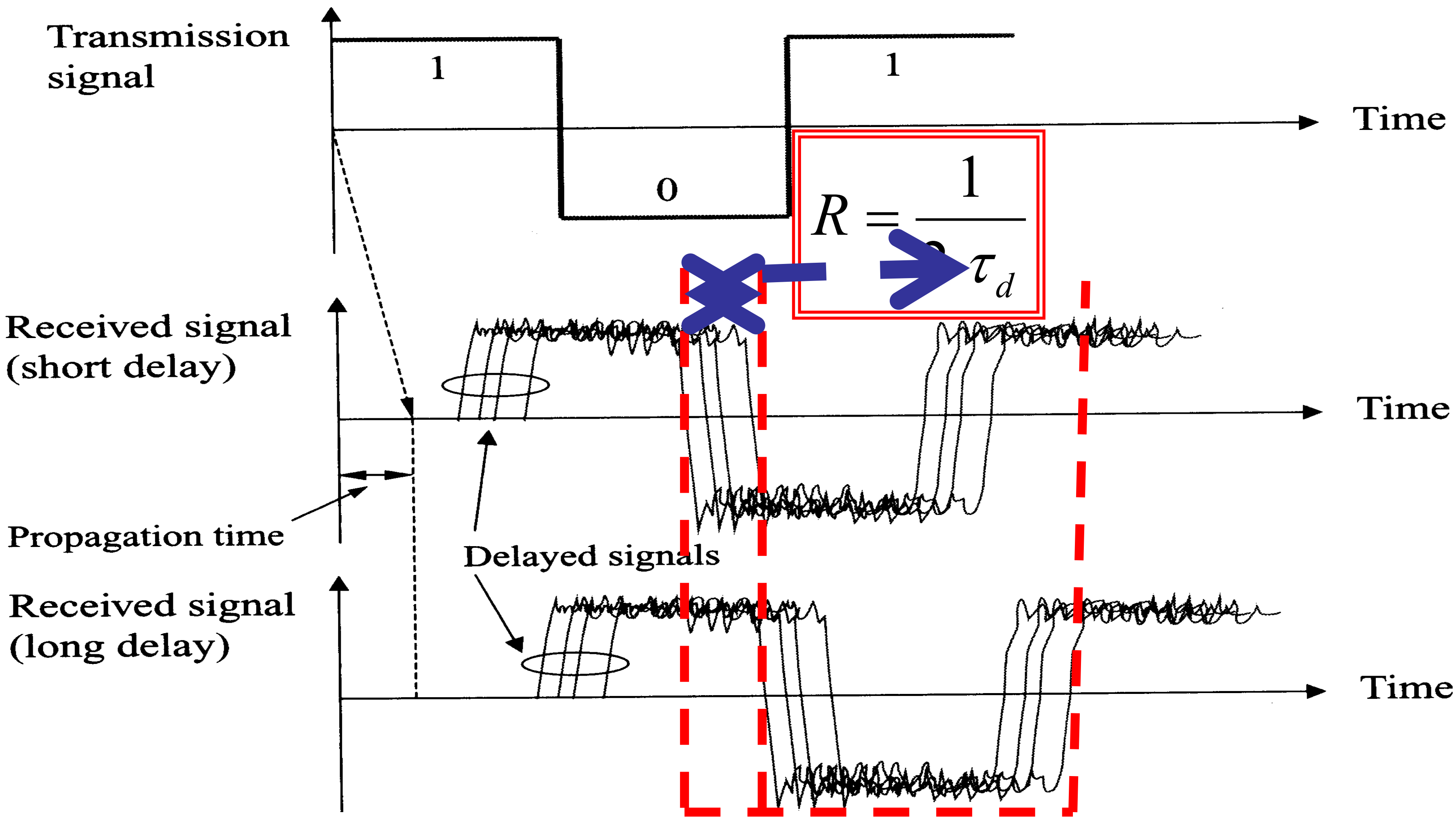
The orbit, as we will see, is called a **geosynchronous orbit.**

Scattering, Reflection and diffraction of radio signals



Bias Distortion $BD = 1 - \frac{\tau_{Trans}}{\tau_{Rec}} \leq 0.2$

multipath signals, Intersymbol interference



In a time-dispersive medium the transmission rate R for a digital transmission is limited by the delay spread

b. Free space propagation

- Consider an isotropic radiation point source with power **P_t**. At distance **d** the radiated power is uniformly distributed over surface of a sphere.
- Thus, received power **P_r** at distance **d**:
- **A_e** = receiver antenna effective area
- **G_t** = transmitter antenna antenna gain

$$\boxed{\mathrm{Pr} = \frac{AeG_t P_t}{4\pi d^2}}$$

Free Space Path loss (Lp)

Free space losses could be calculated by:

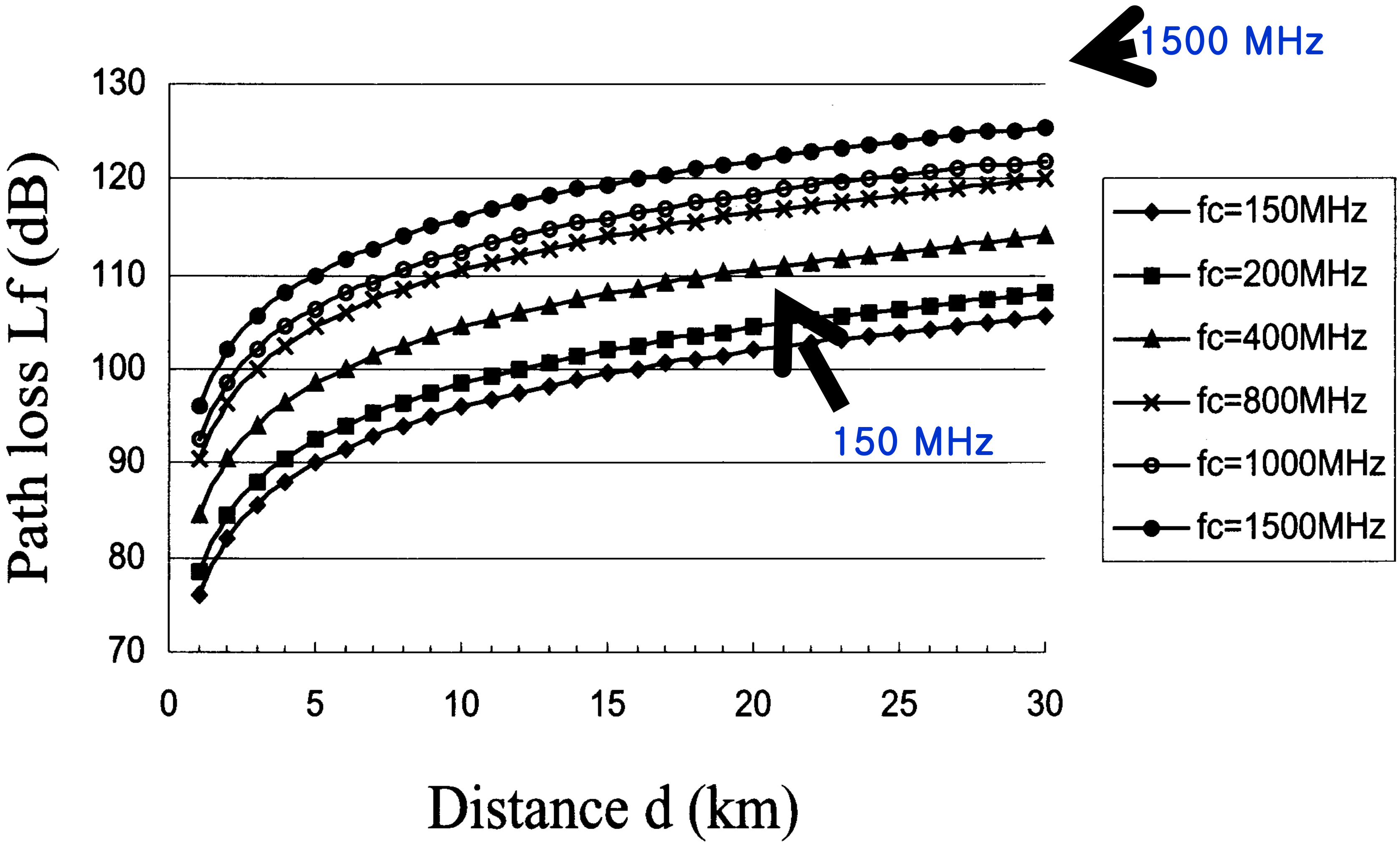
$$\boxed{L_f = 32.45 + 20\log_{10} f_c(MHz) + 20\log_{10} d(km)}$$

Note: loss increases with carrier frequency.

Lp = path loss (average propagation loss over wide area):
Determined by **distance**, **carrier frequency**, **land profile**

Free-space path loss (Cont)

$$L_f = 32.45 + 20\log_{10} f_c(MHz) + 20\log_{10} d(km)$$



c. Wireless Link Power Budget Analysis

When operating at 3 Mbps, a WLAN system has transmission power of 15 dBm, and the receiver power must be at least –72 dBm. The communication power budget is therefore:

$$\begin{aligned} Power\ budget\ (dB) &= P_{trans}(dBm) - P_{receiver}(dBm) \\ &= 15\ dBm - \left(-72\ dBm\right) = 87\ dB \end{aligned}$$

To find how transmission distance and frequency affect the power budget, we can calculate the free space isotropic loss. This is the path loss incurred by an electromagnetic wave as it propagates in a straight line through a vacuum from one isotropic antenna to another. At any point around the antenna, the power density is:

$$\rho_{ISO}\left(r\right) = \frac{P_{total}}{4\pi r^2}$$

Signal Loss Chart

Obstruction	Additional Loss (dB)	Effective Range	Approximate Range
Open Space	0	100 %	300 m
Window (non-metallic)	3	70 %	215 m
Window (metallic tint)	5-8	50 %	150 m
Wall (dry wall)	5-8	50 %	150 m
Wall (wood)	10	30 %	100 m

THANK YOU!

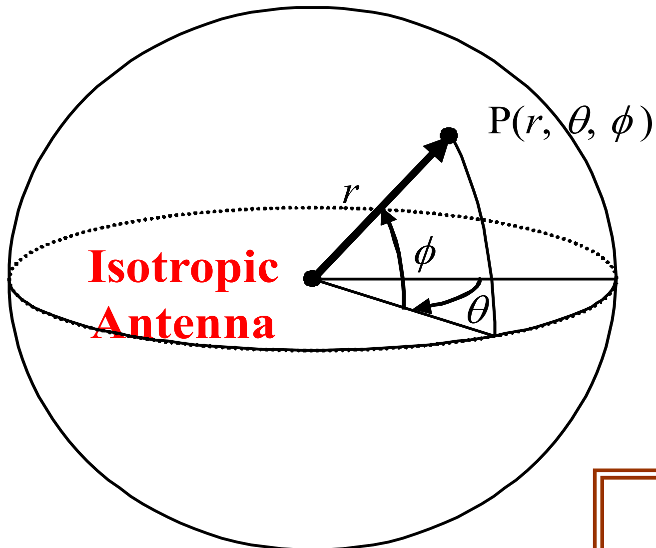
7. Appendix

Basics of Antenna Theory

- **Antenna reciprocity** -A transmitting antenna will transfer energy to the atmosphere with the same efficiency with which it transfers energy from the atmosphere to its terminals, **Antenna reciprocity**.
- **Isotropic** -If an antenna is a point source that radiates power equally in all directions.
- **Power density** at any point of sphere would be total radiated power, divided by the area of this sphere:

$$\boxed{w_{ISO}(r) = \frac{W_{total}}{4\pi r^2}}$$

An isotropic antenna would radiate equally in all directions



Power density at any point is dependent only on radius

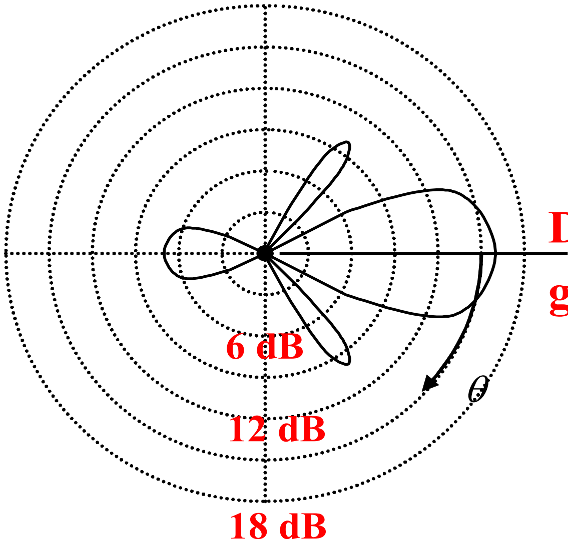
For transmission antenna, the **directivity** of the antenna is the ratio of max power to isotropic power density. This ratio is usually expressed in decibels:

$$D_{directivity} = \frac{w_{\max}(r)}{w_{ISO}(r)}$$

$$\text{decibels}: \quad D = 10 \cdot \log\left(\frac{w_{\max}(r)}{w_{ISO}(r)}\right) dB$$

The power density is always dependent on the orientation of the receiver, which is measured in polar coordinates. The direction of maximum power density is assigned to $\theta = 0$, $\phi = 0$. This point is also called the **foresight** of the antenna.

Transmission antenna (cont)



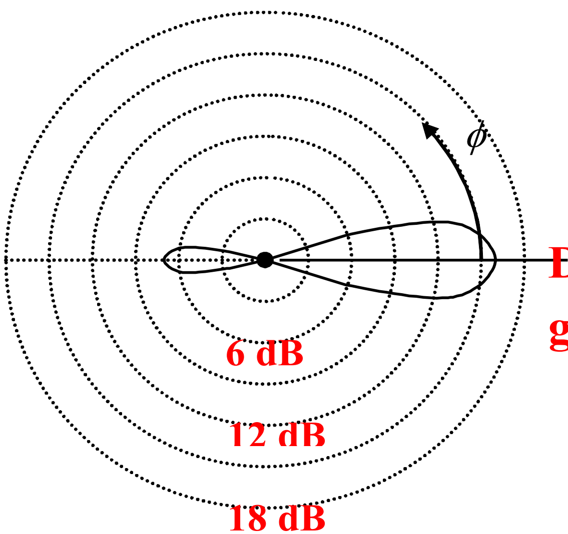
Direction of maximum gain ($\theta = 0$, $\phi = 0$)

Foresight

Radiation diagram for horizontal plane ($\phi = 0°$)

$$G(\theta,\phi) = \frac{w(r,\theta,\phi)}{w_{ISO}(r)} \, gain$$

$$\text{decibels}: \quad G(\theta,\phi) = 10 \cdot \log\left(\frac{w(r,\theta,\phi)}{w_{ISO}(r)}\right)$$



Direction of maximum gain ($\theta = 0°$, $\phi = 0°$)

Foresight

Radiation diagram for vertical plane ($\theta = 0°, 180°$)

A radiation diagram describes the ratio of the antenna's power density at any orientation around the antenna to the isotropic power density: or **gain** of the antenna in this direction.

Receiving antenna (cont)

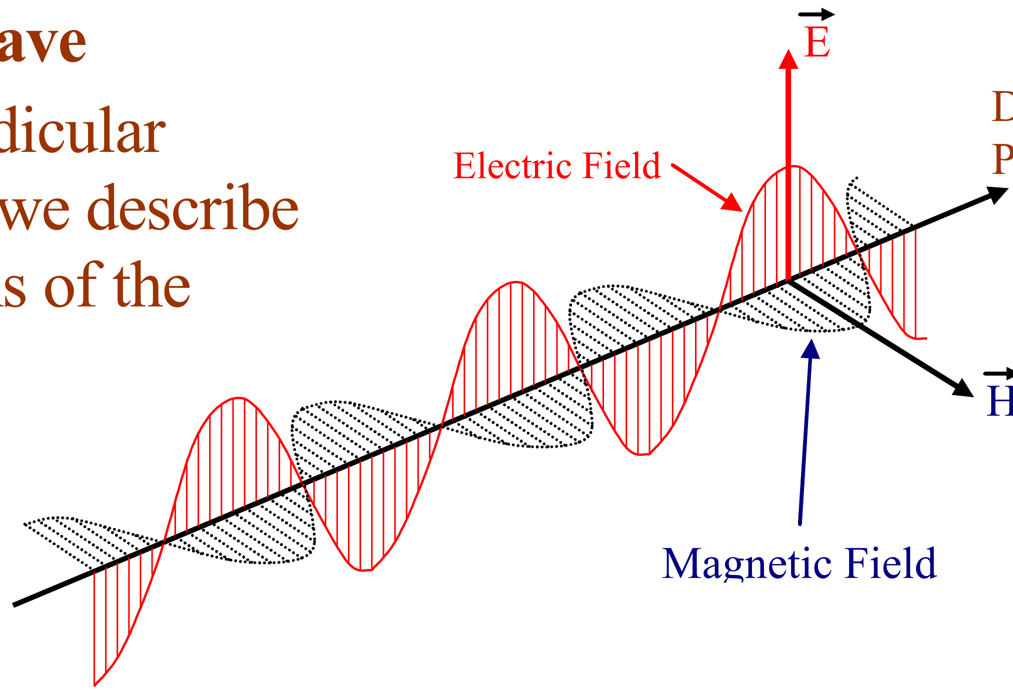
- **Effective area** of the antenna measures **how well the antenna captures power**, and is simply the ratio of the power received by the antenna **to** the power density at the point where the antenna is located.
- **The effective area** of the antenna can be much larger than the antenna geometric area. Because of the principle of reciprocity, the effective area of an antenna is related to the antenna gain by the following formula:

$$\boxed{A_{eff}(\theta,\phi) = G(\theta,\phi)\cdot\frac{\lambda^2}{4\pi} = \frac{w(r,\theta,\phi)}{w_{ISO}(r)}\times\frac{\lambda^2}{4\pi}}$$

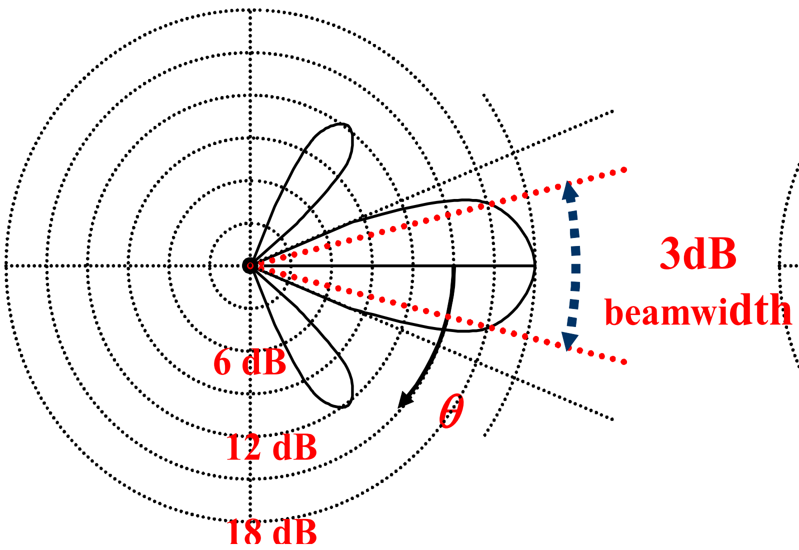
The polarization of the electromagnetic wave

Polarization describes the direction of the electrical field of the electromagnetic wave

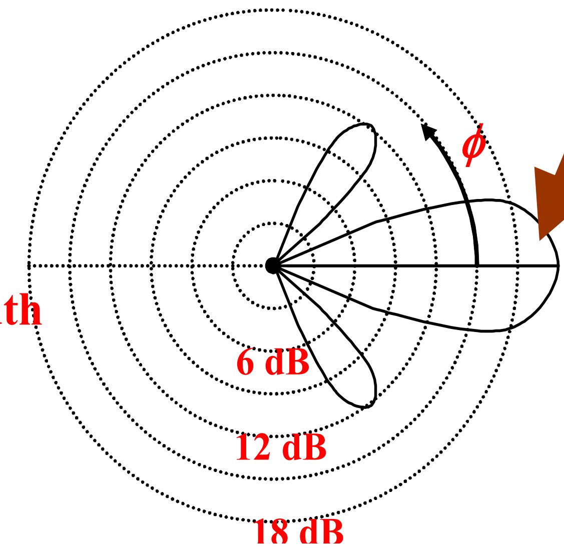
There is also a perpendicular magnetic field, but we describe polarization in terms of the electric field.



An antenna generally has a preferred polarization direction, and it is important that the polarization of the transmitting antenna **matches** the polarization of the receiving antenna.



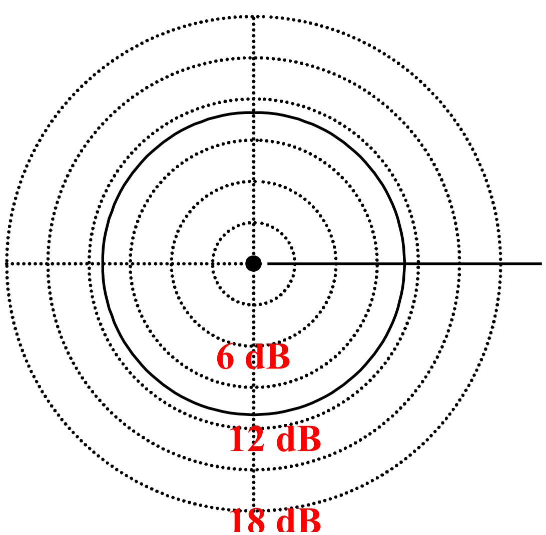
Horizontal plane ($\phi = 0°$)



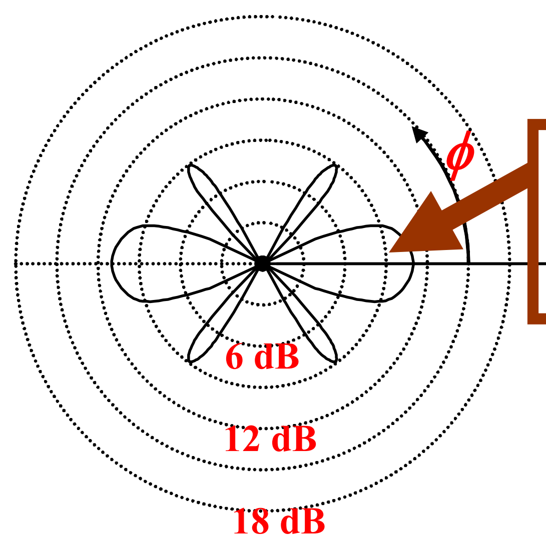
Vertical plane ($\theta = 0°$),

Directional antenna radiation pattern.

3 dB beamwidth, the angle between points that are 3dB below the max power output.



Horizontal plane ($\phi = 0°$)



Vertical plane ($\theta = 0°$),

Omnidirectional antenna radiation pattern