University of Pittsburgh

ECE 1150: Computer Networks

Physical Layer & Communications Basics: Signals

Mai Abdelhakim, PhD

ECE Department

Swanson School of Engineering

University of Pittsburgh

In the Previous Unit

- Transmission medium
  - Twisted pair
  - Coaxial cable
  - Optical fiber
  - Wireless

Objectives of This Unit

- Describe what is signal
- Time and frequency representations
- Spectrum and Bandwidth

Context

Anyone — Application

Tell — Transport

No — Network

Do — Data Link

Please — Physical

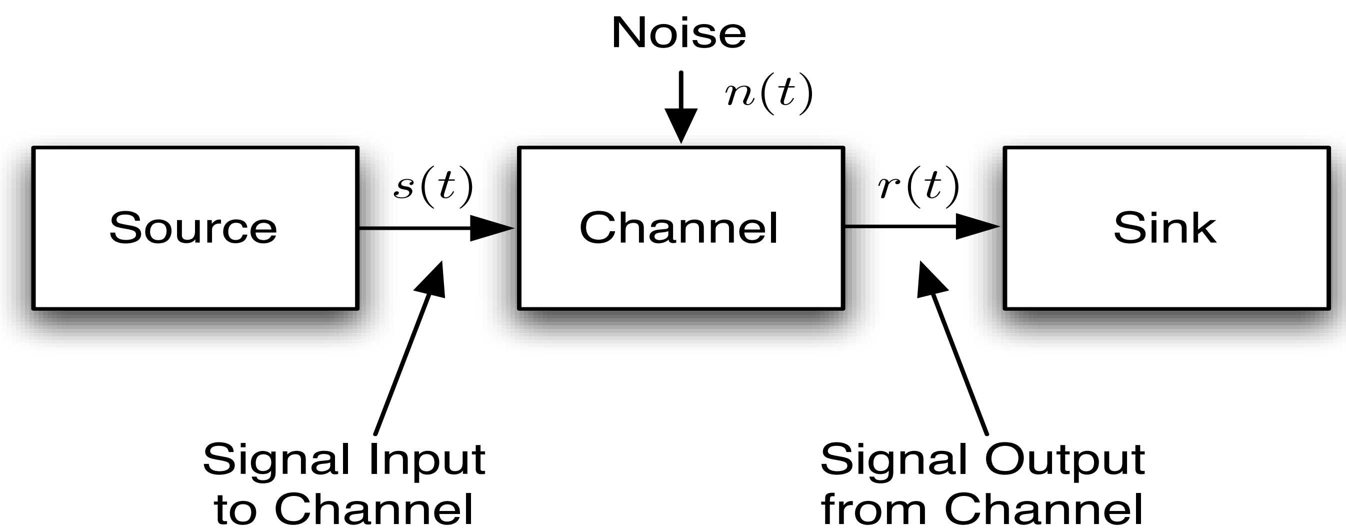
We are here
(Layer 1)

Signals

- Communication systems
  - At transmitter
    - Convert data to signal
    - Signal transmission
  - At receiver
    - Signal reception
    - Convert signal to data

Simple Communications Model

- The transmitter produces a signal in time – $s(t)$
- The link (medium) is the **channel** that carries the signal to the receiver (sink)
  - Analogy: Air carries audio to ear
- Noise – $n(t)$ – is a signal that distorts $s(t)$



Signals and Their Properties

- Good signals can provide
  - Easy detection by receiver (simply tune in)
  - Immunity from noise (compare FM vs. AM)
  - Efficient use of resources (bandwidth)
  - Ability to multiplex

Advances in the Physical Layer

- Easy reception
  - Easy reception allows cell phone to get smaller in size
    - Old phones need large batteries to transmit detectable signals

Advances in the Physical Layer

- Noise resistance affects the quality of the signal
  - FM (Frequency modulation) has much better noise resistance than AM (Amplitude modulation)
    - High quality music transmission is possible over FM radio

(Modulation will be discussed later)

Advances in the Physical Layer

- Efficient utilization of bandwidth & multiplexing
  - Data compression and improved signaling allow **eight hi-definition TV channels** to be transmitted using the same bandwidth as **one traditional analog TV channel** (e.g. 8MHz)

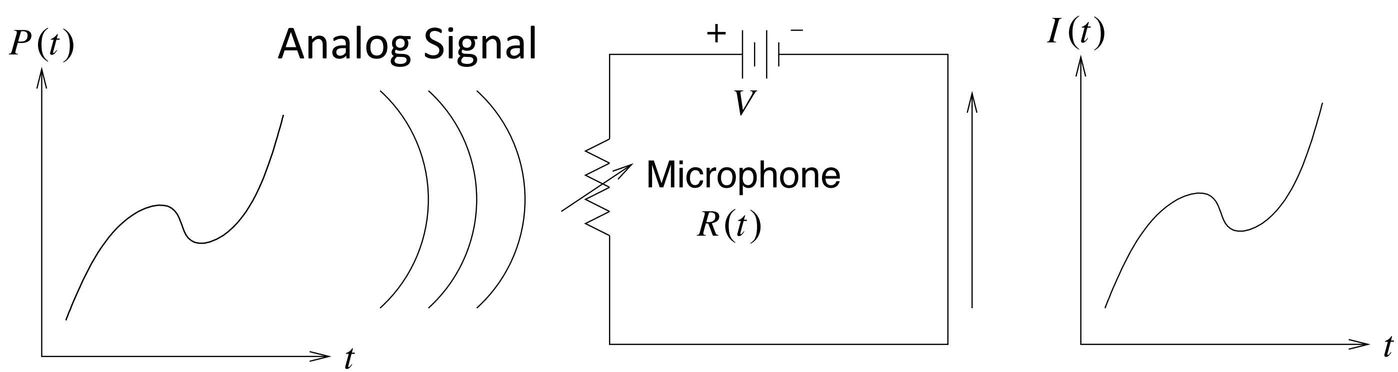
Characteristics of Signals

- Have amplitude and power
- Occupy a range of frequencies (i.e., bandwidth)
- Can be distorted by
  - Cable attenuation
  - Noise & dispersion …

Transmitting Signals

- Involve creating **change** at the sending end that can be **detected** at the receiving end

- Categories of signal
  - **Digital signal**
  - **Analog signal**

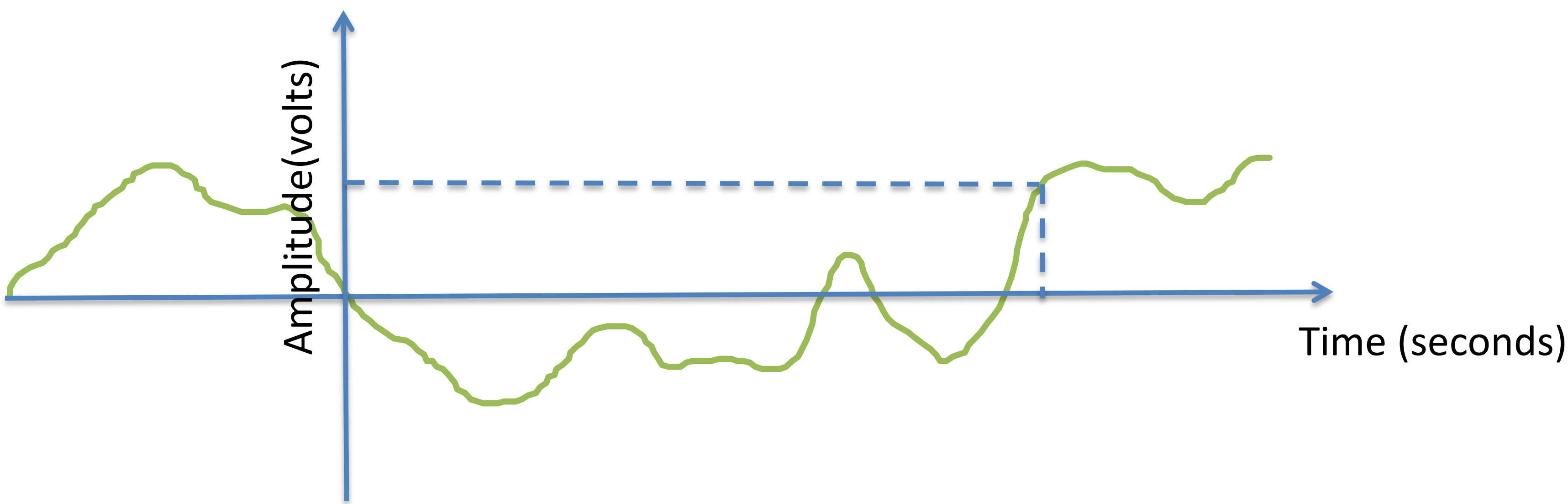


When we speak into a microphone, the analog audio vibrations are converted into an electrical signal

Analog Signals

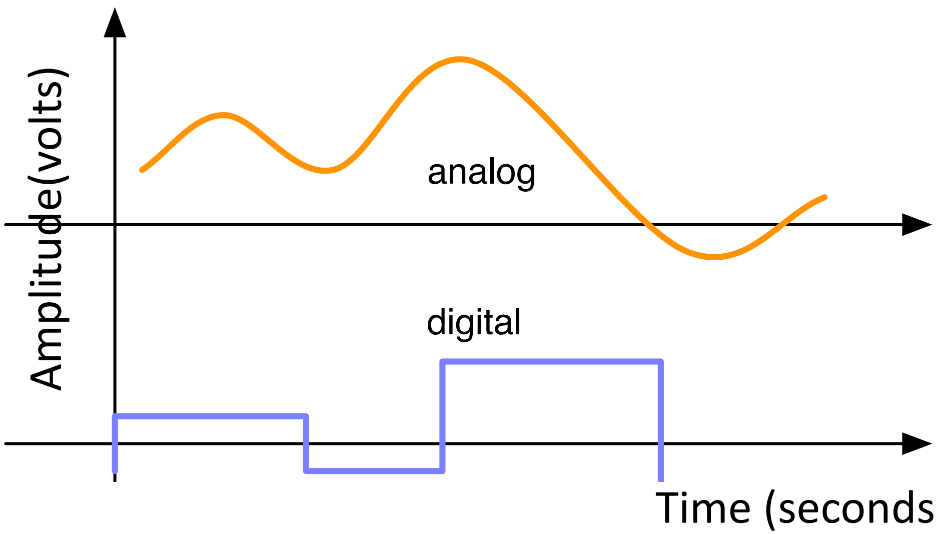
- Signal level (amplitude) can take **any value**
  – Information can be contained in each absolute signal level at each point in time

- Continuous time: Continuous variation in time



Digital signals

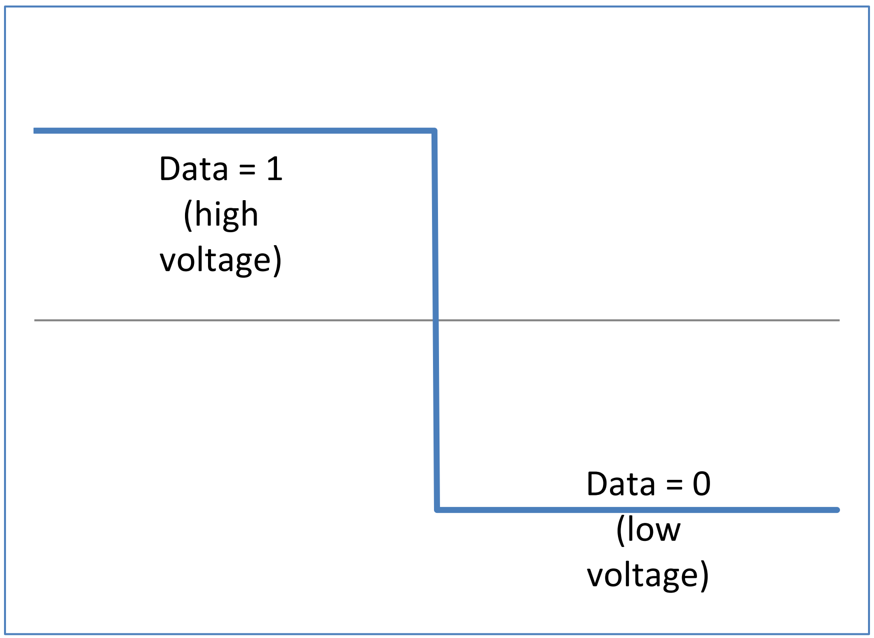
- The amplitude has **finite set of possible values**
  - Two-levels => binary
    - E.g. turn a switch on/off depending upon whether data is ‘0’ or ‘1’
  - Multiple levels
    - M-Ary for M levels
      - Covered later
    - Still carry bits!

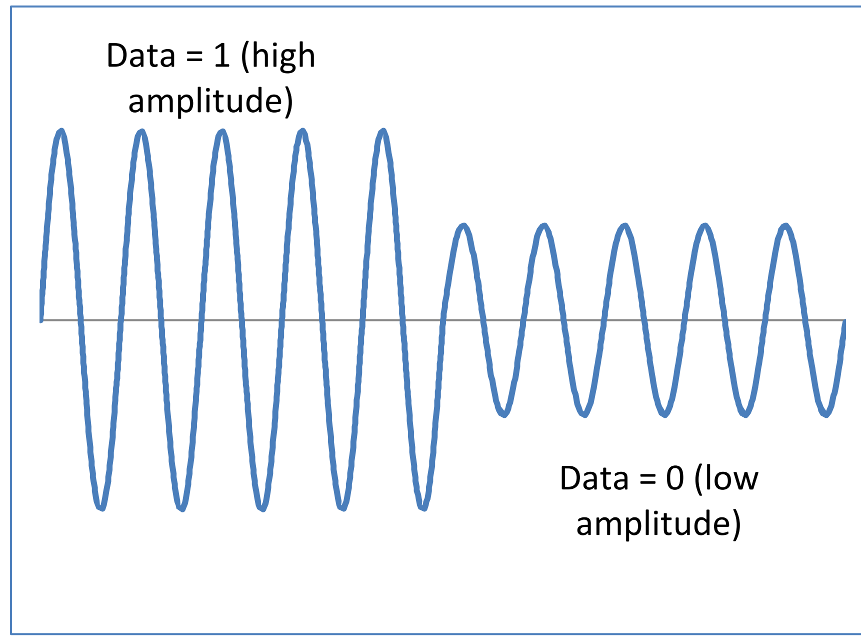


Digital vs Analog Signals

Digital signal – signals in which information is represented in discrete steps

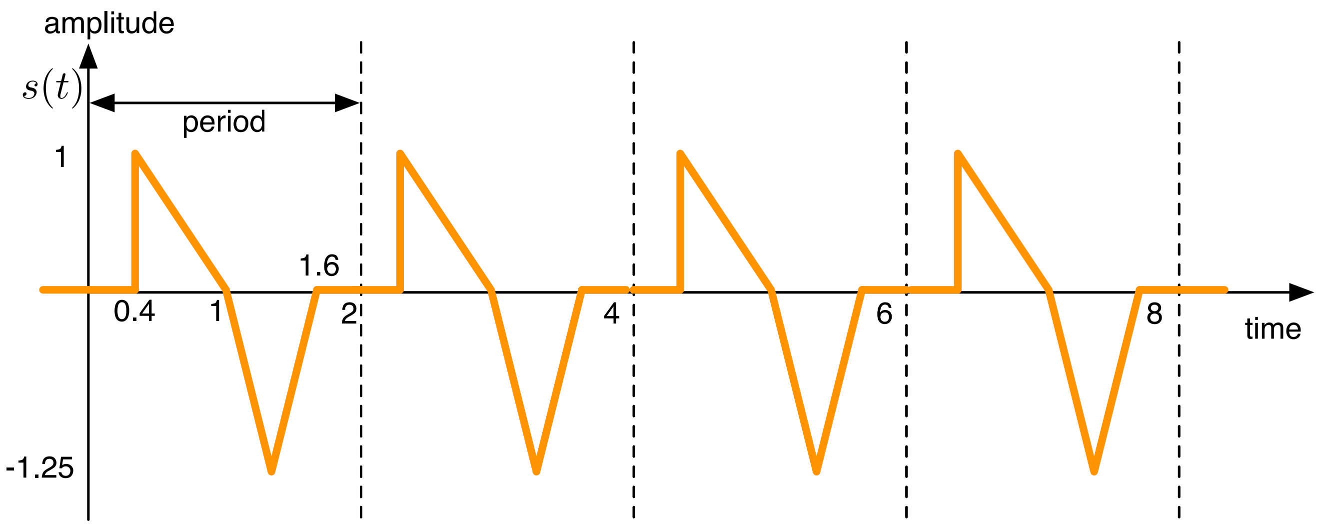
Analog signal – signals that have a continuous nature in amplitude



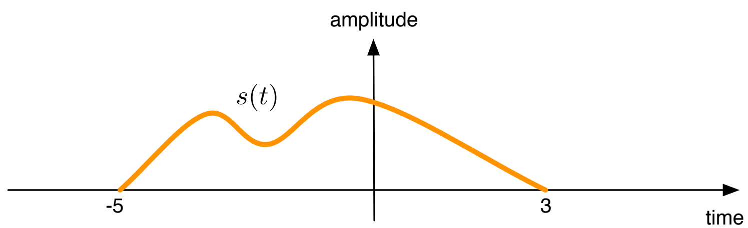


Periodic and Aperiodic Signals

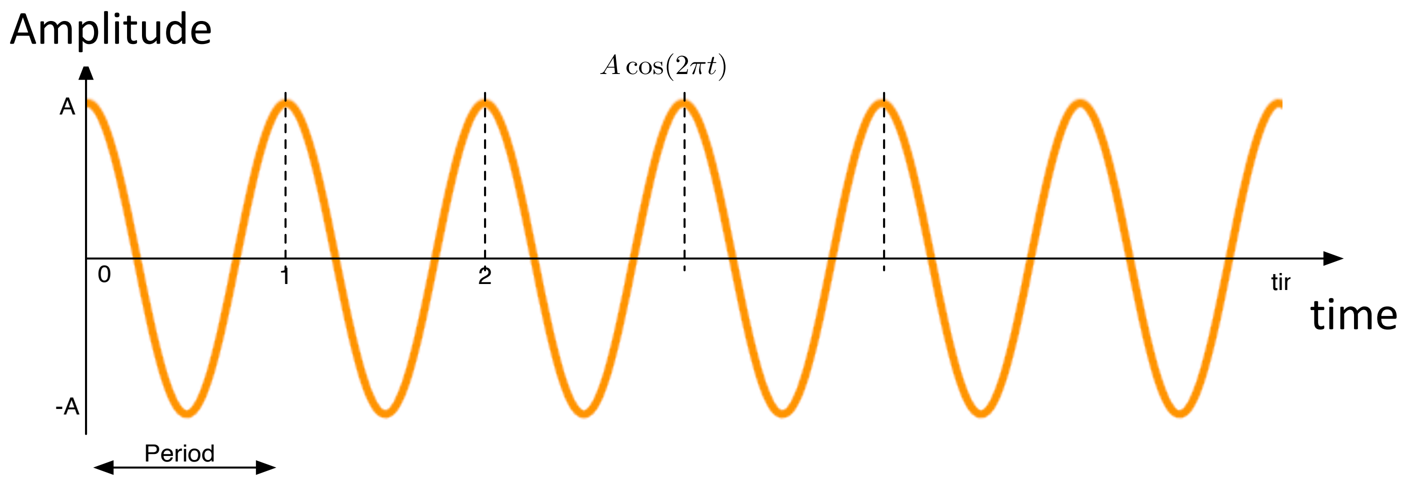
- Periodic: pattern repeated over time



- Aperiodic: no repeated pattern to the signal



Sinusoids



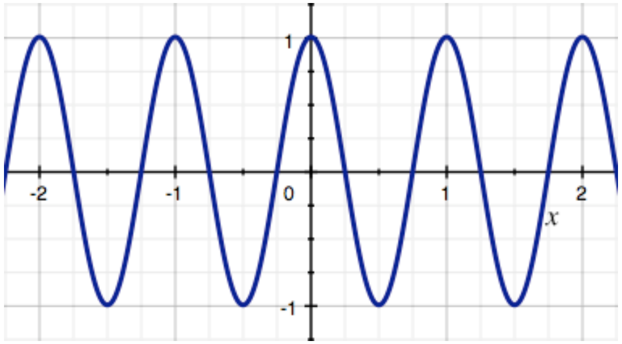
- Typical form: $s(t) = A \cos(2\pi f_c t + \varphi)$
  - *The maximum amplitude of the signal is A*
  - *Frequency of the signal is f_c*
  - *Phase of the signal is φ*
- The power of S(t) is $A^2/2$

Sinusoids

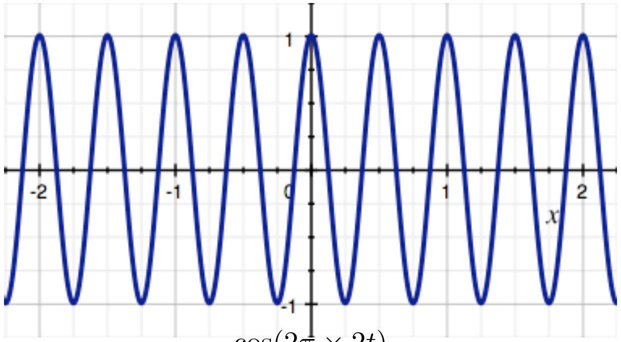
- ***Frequency*** **(f_c)**
  - Number of repetitions per second (unit is Hertz)
  - E.g. 5 KHz → 5000 times per second
- ***Period*** (T) - amount of *time* it takes for one repetition of the signal

  $T = 1/frequency = 1/f$, $5KHz \rightarrow T = .2\ ms$
- ***Phase*** (ϕ) - measure of the relative position in time within a single period of the signal
- ***Wavelength*** (λ) - distance occupied by a single cycle of the signal
  - For electromagnetic waves in air $\lambda = c/f_c$ where c is the speed of light = 3×10^8 m/sec

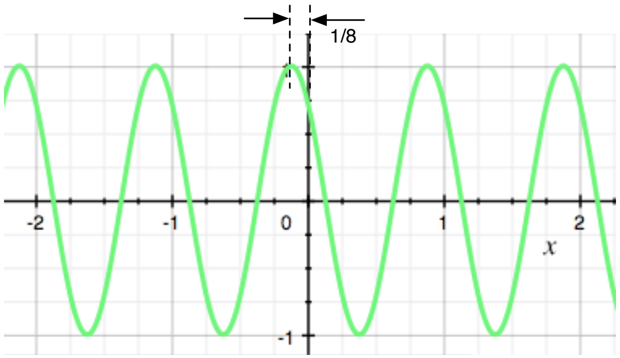
Some Sinusoids



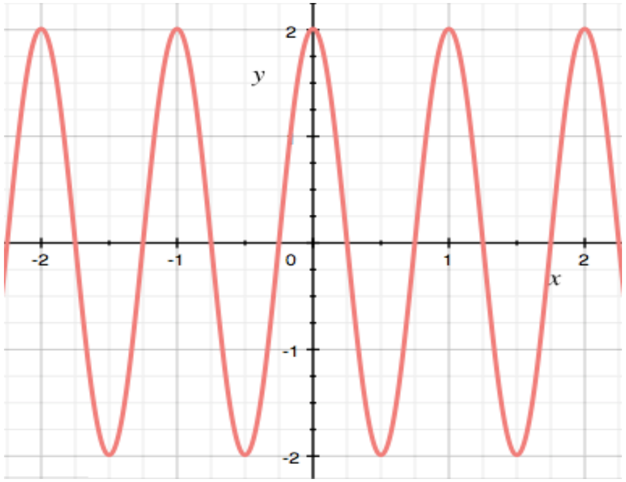
$\cos(2\pi t)$



$\cos(2\pi \times 2t)$



$\cos(2\pi t + \pi/4)$



$2 \times \cos(2\pi t)$

Tophat

Q_frequency Of signal

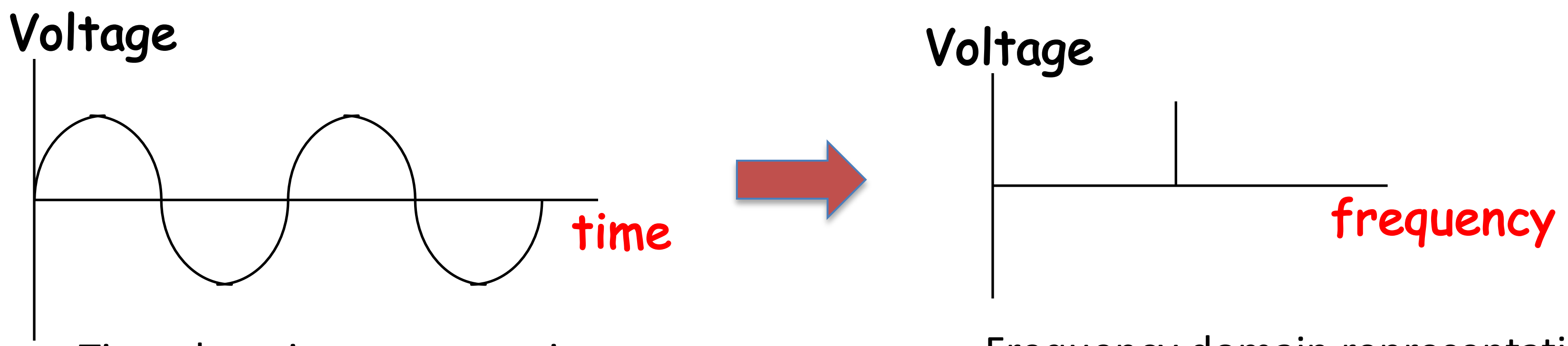
What is the frequency of signal $x(t) = \cos(200\pi t + \pi/2)$

A	frequency is 200π Hz
B	Frequency is 100 Hz
C	Frequency is 200 Hz

Frequency and Time

- Signal can be represented in frequency or in time
  - In the frequency domain, we call it the "**spectrum**" of the signal

- Signals can **"interfere" in time or in frequency**

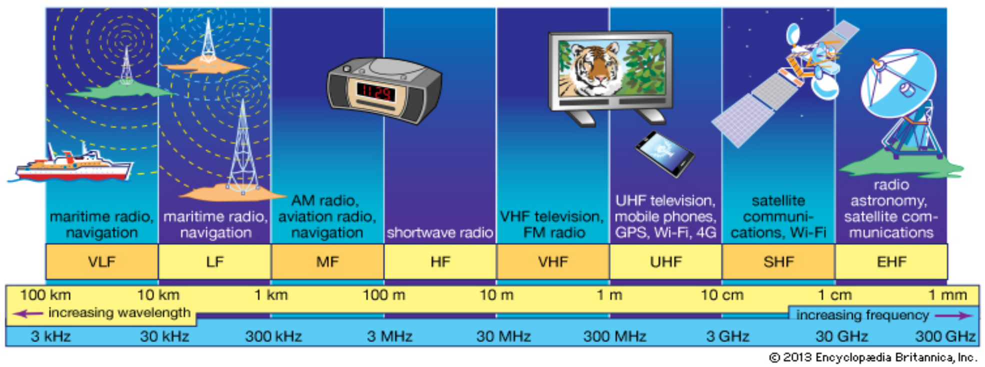


Time domain representation

Frequency domain representation

Frequency Domain

- Different applications are assigned different frequency bands
  - Avoid interfering with other signals



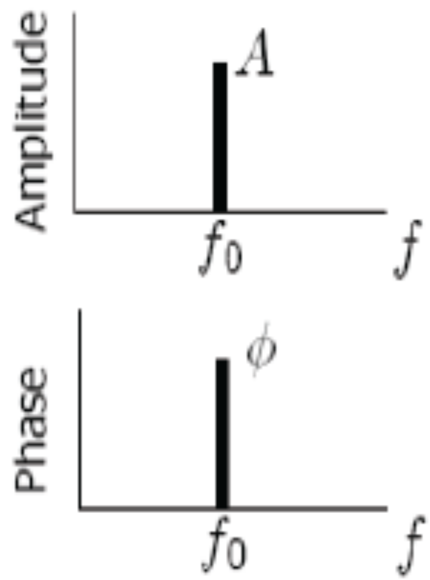
- **Impact** of medium on signal depend on **frequency**
  - Attenuation depends on frequency

Frequency Domain Representations

- Both periodic and aperiodic signals can be represented in frequency using **Fourier Series or Fourier Transform**

- Frequency plots
  - Amplitude
  - Phase

$A \cos(2\pi f_0 t + \varphi)$



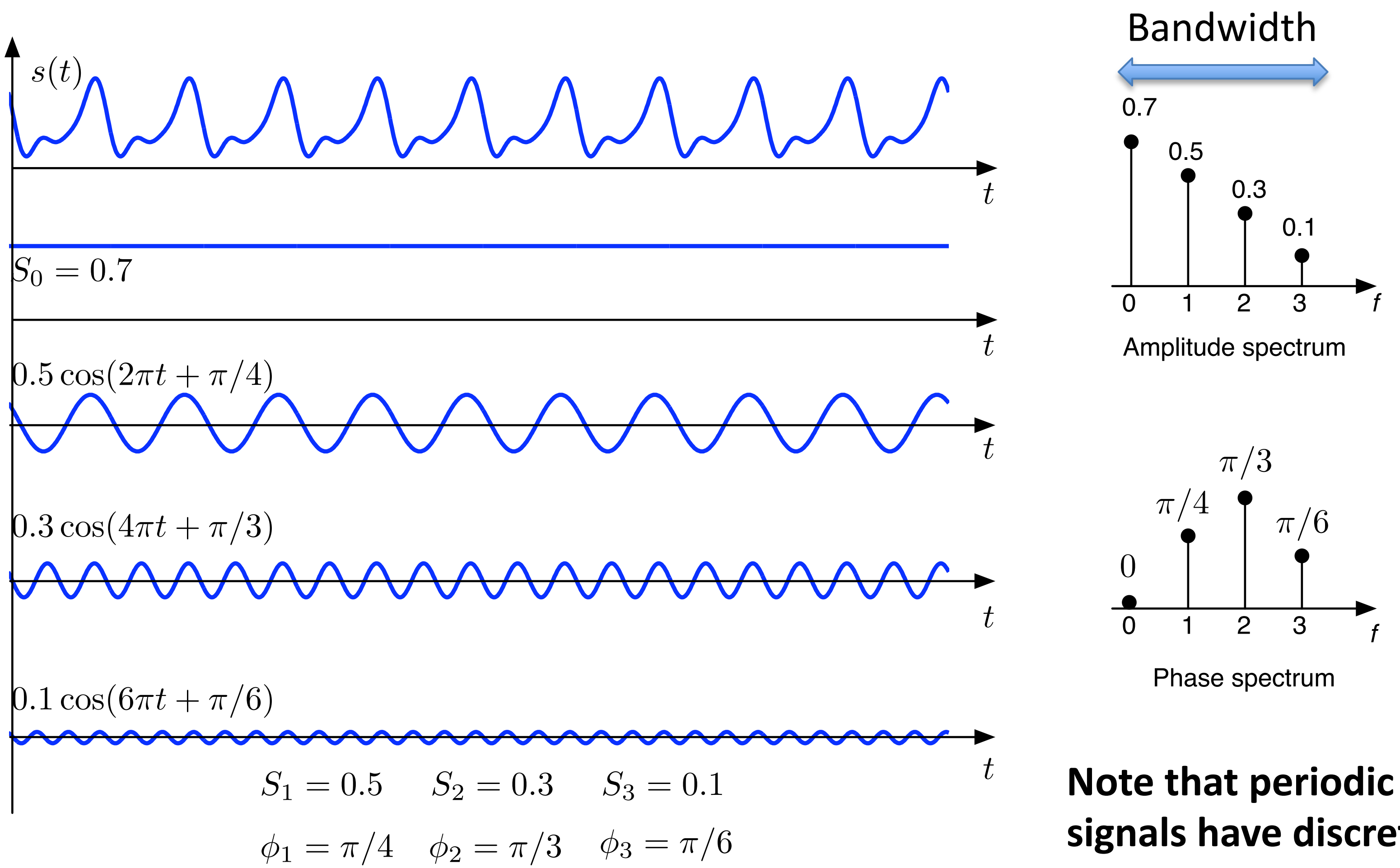
Why Sinusoids?

- Any **periodic** signal can be broken into a **sum** of **weighted sinusoids** using **Fourier Series**
  - Has a "fundamental" frequency f_0
  - Multiples of f_0 are called "harmonics"
    - Each frequency has a weight S_n
      - Think of the weights as "how much energy is there at that frequency"
- Fourier series of a signal y(t) is

$$y(t) = S_0 + \sum_{n=1}^{\infty} S_n \cos(2\pi n f_0 t + \varphi_n)$$

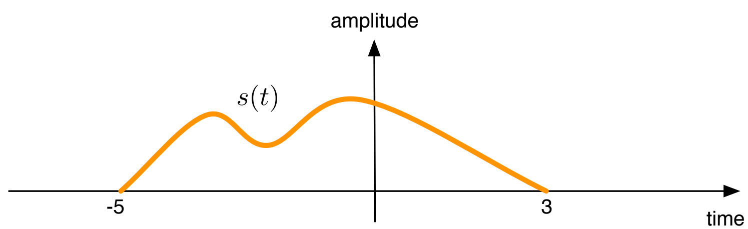
Bandwdith

Here, $s(t) = S_0 + 0.5\cos\left(2\pi t + \frac{\pi}{4}\right) + 0.3\cos(4\pi t + \frac{\pi}{3}) + 0.1\cos(6\pi t + \frac{\pi}{6})$

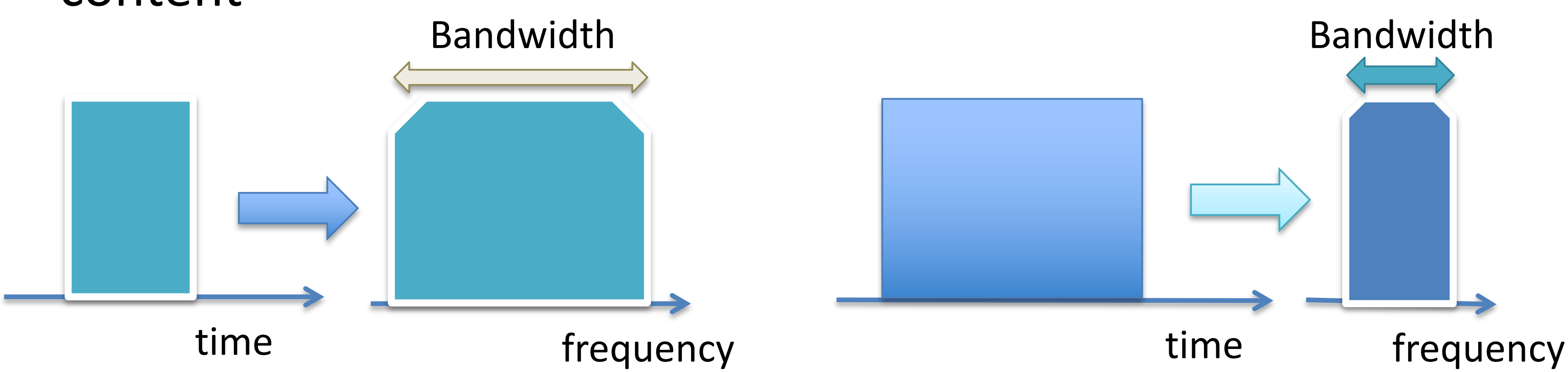


Note that periodic signals have discrete frequency components

Bandwidth: Aperiodic Signals

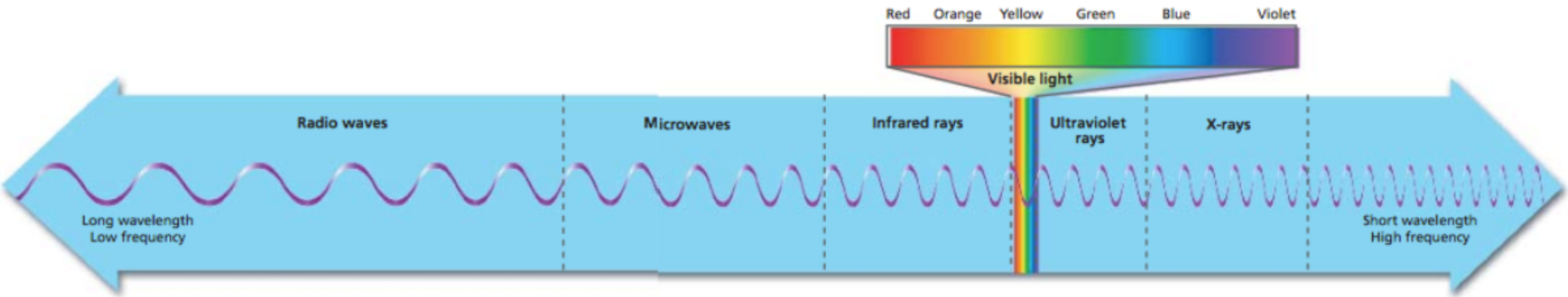


- They have a *continuous range* of frequencies in them
- A wide (in time) signal has a smaller range of frequency content
- A thin (short in time) signal has a larger range of frequency content



Spectrum and Bandwidth

- **Electromagnetic Spectrum – a range of frequencies**
  –All types of radiation

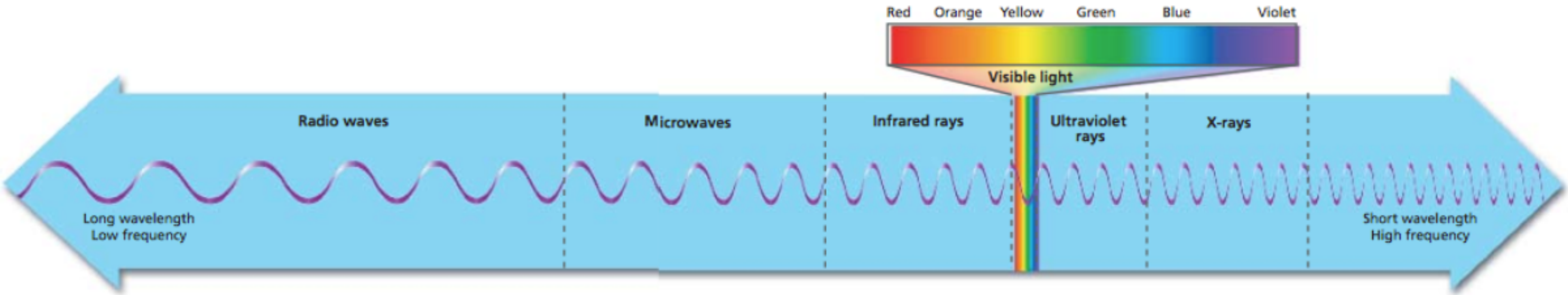


Wavelength x Frequency = speed of light

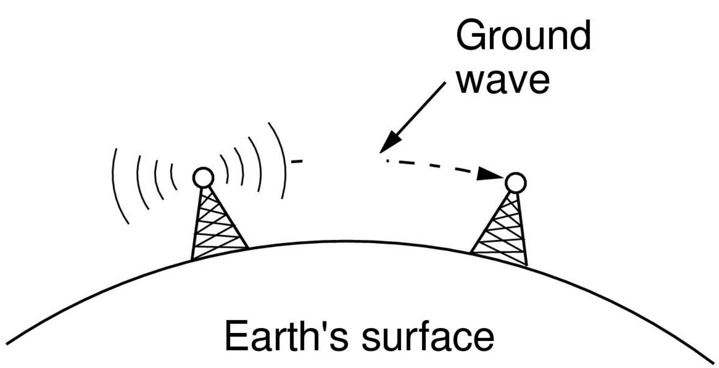
  – Radio waves: 3kHz –300MHz, Microwaves: up to 300 GHz
  – Visible Spectrum: 400 – 790 THz
  – Human audible frequencies: 20-20 kHz

Hear different tones: http://onlinetonegenerator.com/
Try:1000, 2000, 5000,..

- **Band – a small slice of the spectrum**
  – USA AM Radio band 530-1710 kHz



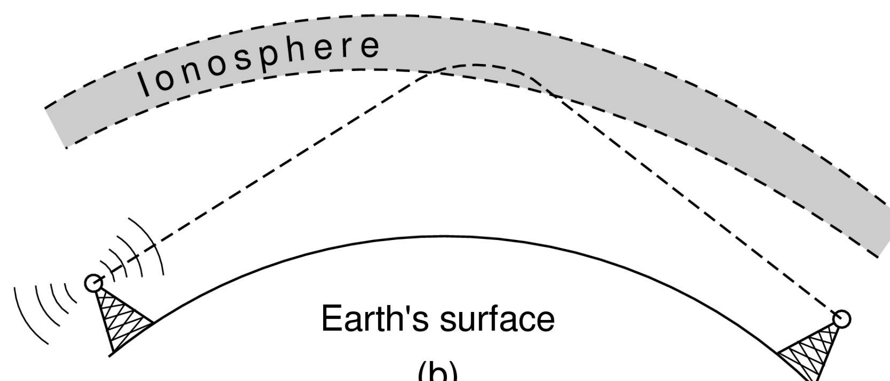
- Radio waves: below 300MHz
  - Penetrate buildings well
  - Propagate for long distances with path loss



(a)

In the VLF, LF, and MF bands, radio waves follow the curvature of the earth

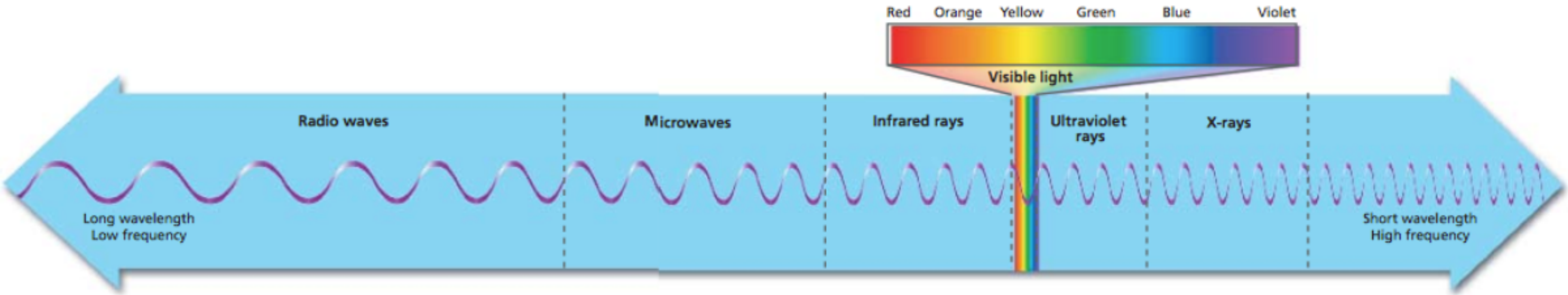
3–30 kHz Very low frequency VLF
300 kHz – 3 MHz Medium frequency MF



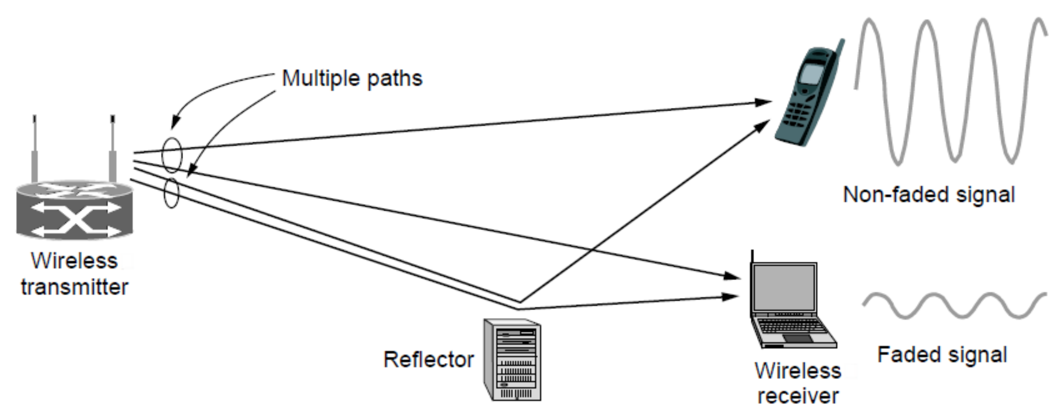
(b)

In the HF band, radio waves bounce off the ionosphere.

3–30 MHz High frequency HF
30–300 MHz Very high frequency VHF



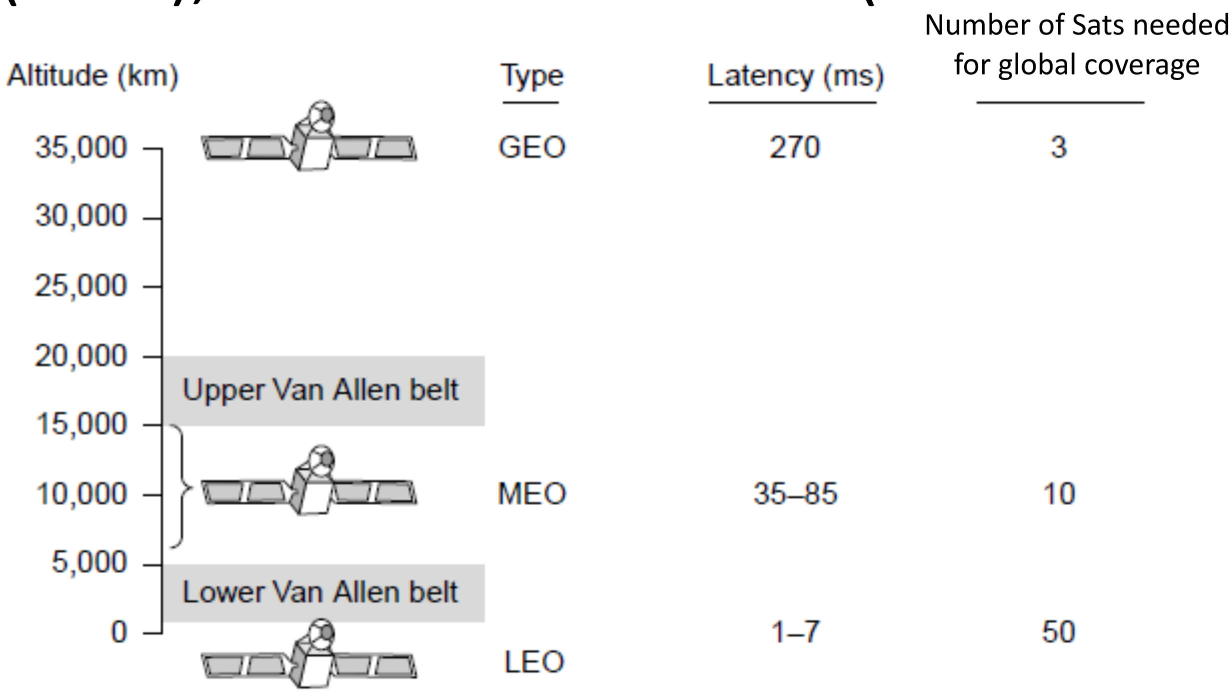
- Microwave:
  - Don’t pass well through buildings
  - Widely used indoors (WiFi) and outdoors (cellular, satellites)

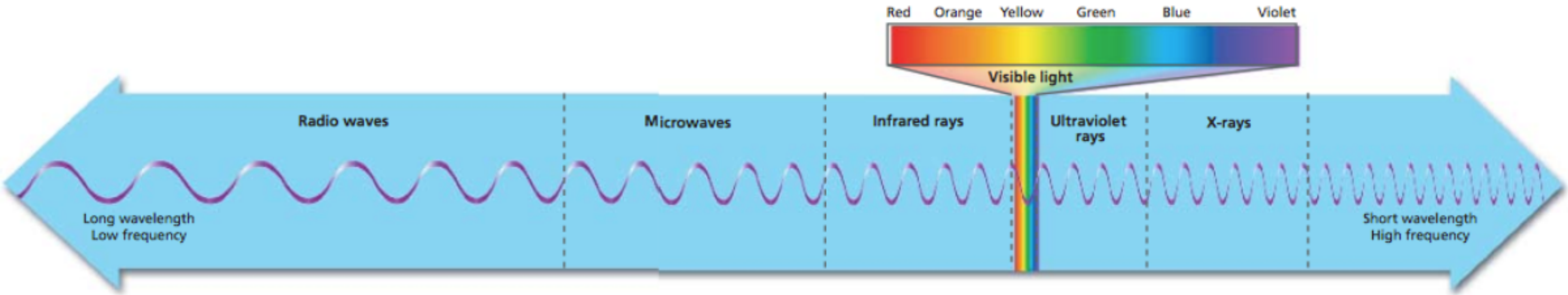


Kinds of Satellites

Satellites and their properties vary by altitude:

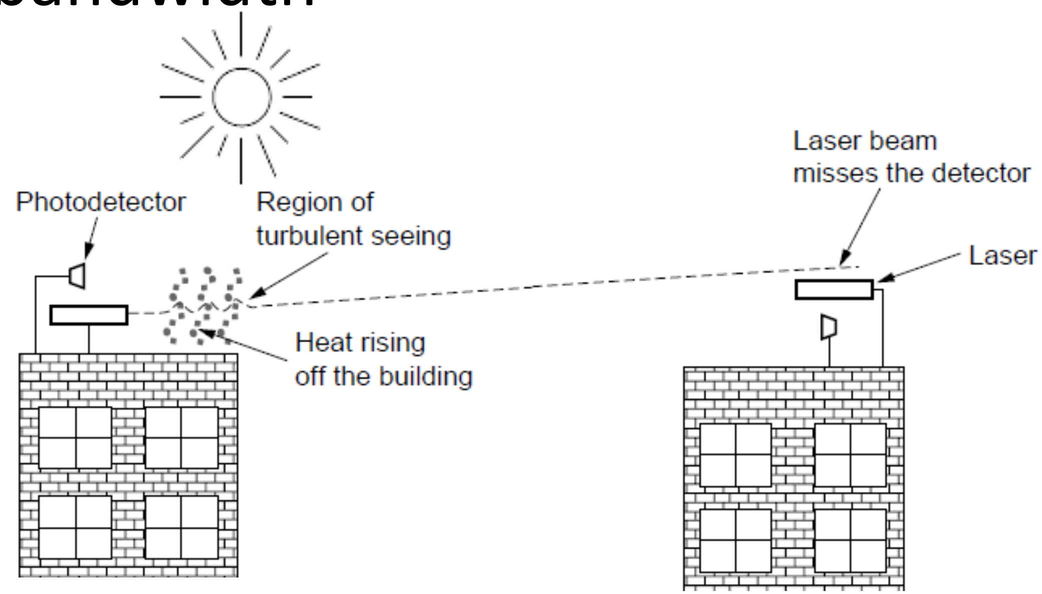
- Geostationary (GEO), Medium-Earth Orbit (MEO), and Low-Earth Orbit (LEO)



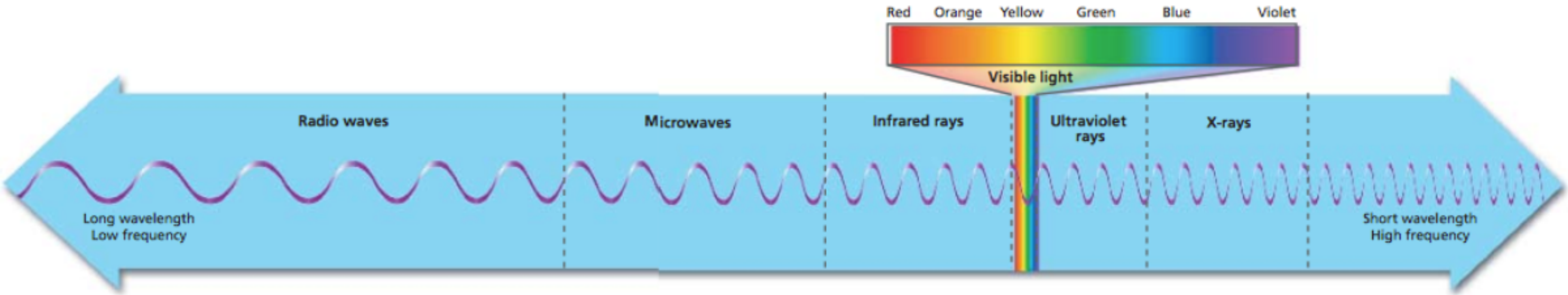


- Light communications

  - Line-of-sight light, Light is highly directional, has much bandwidth



Connect LAN in two buildings



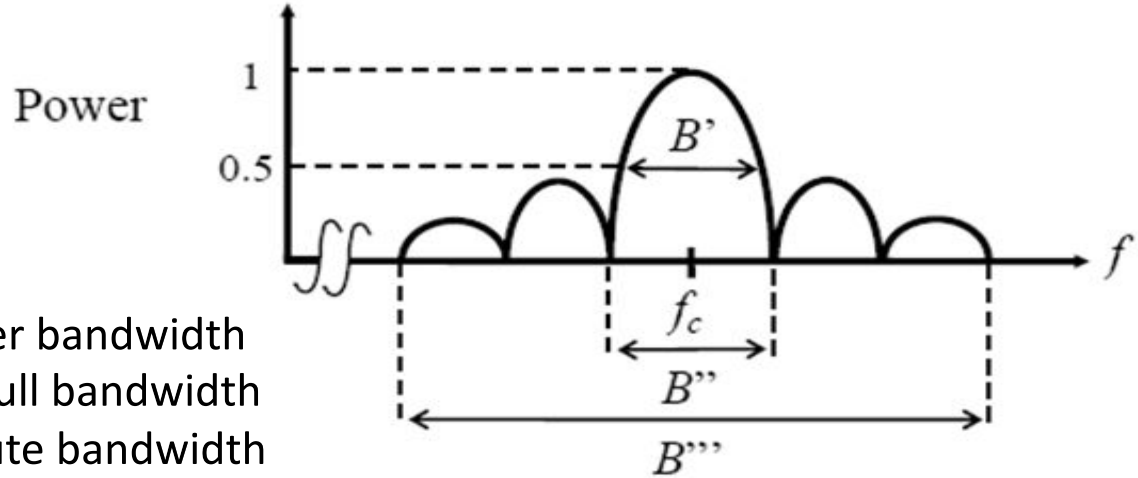
Higher frequencies

Ultraviolet, x-rays and Gamma rays

- Hard to produce and modulate
- Don’t propagate well through obstacles
- Not safe

Signal Bandwidth

- **Absolute bandwidth** - width of the spectrum of a signal
- **Effective bandwidth** - Band of frequencies that contains most of the signal's energy
  - Example: human voice – absolute bandwidth 0-20 kHz, effective bandwidth 50 – 3400 Hz
    - Bandwidth of a voice channel is 4000Hz



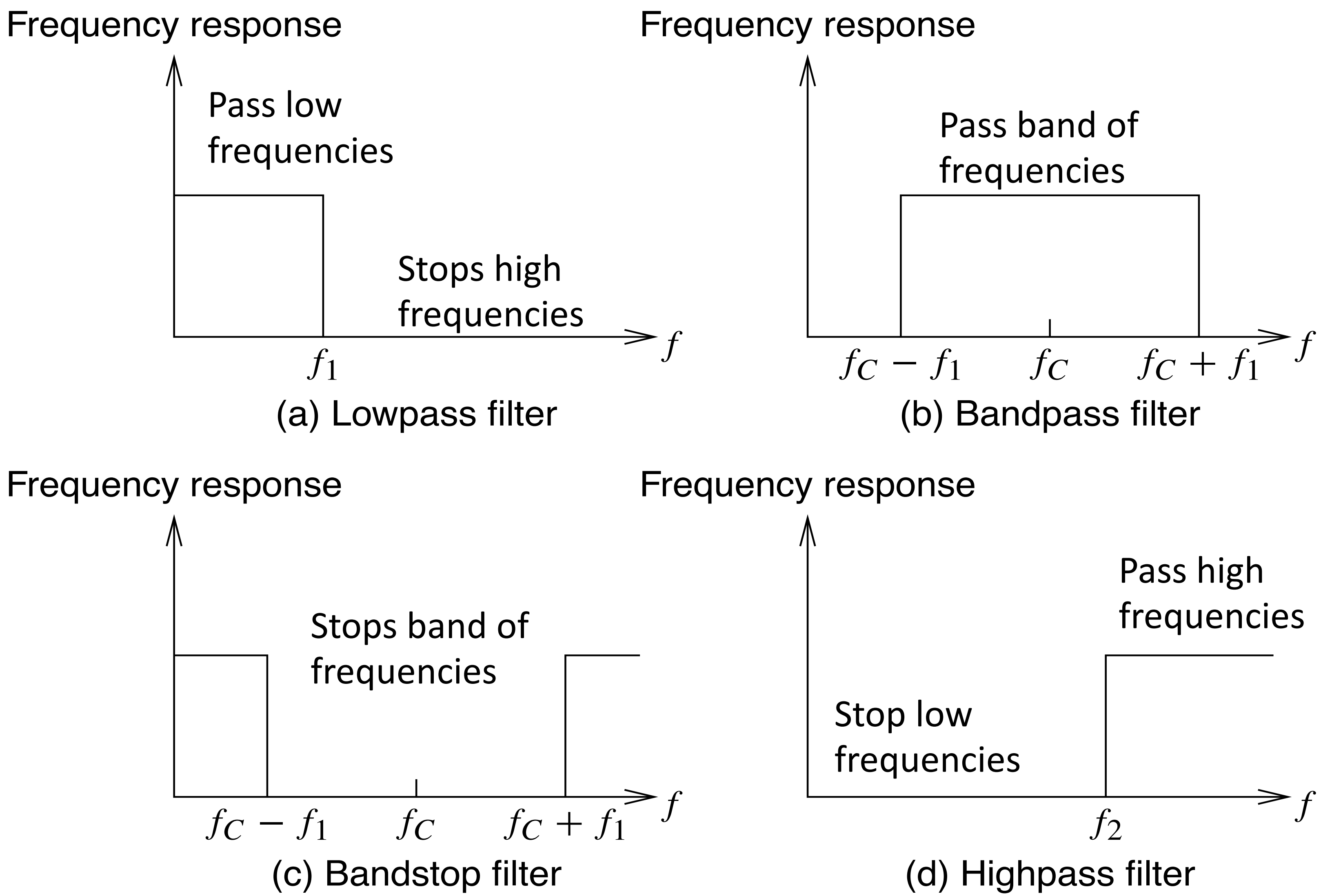
B' half-power bandwidth
B'' null-to-null bandwidth
B''' is absolute bandwidth

Filters

- Filters allow certain frequencies to go through and stop other frequencies
  - Useful for **separating** multiplexed signals

- Receivers use filters to receive signals from particular bands

Types of Ideal Filters



Takeaways

- Signals, analog vs digital, periodic vs aperiodic
- Signals can be represented in time or frequency
- The frequency domain representation helps us understand **bandwidth** more precisely
  - Regulate applications
  - Impact of medium on signal depends on the frequency