Transmission Fundamentals

Slides made by Yu-Chee Tseng

Electromagnetic Signal

- is a function of time
- can also be expressed as a function of frequency
  - Signal consists of components of different frequencies

Time-Domain Concepts

- Analog signal - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
- Digital signal - signal intensity maintains a constant level for some period of time and then changes to another constant level
- Periodic signal - analog or digital signal pattern that repeats over time

  $$s(t+T) = s(t) \quad -\infty < t < +\infty$$

  where T is the period of the signal
- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time

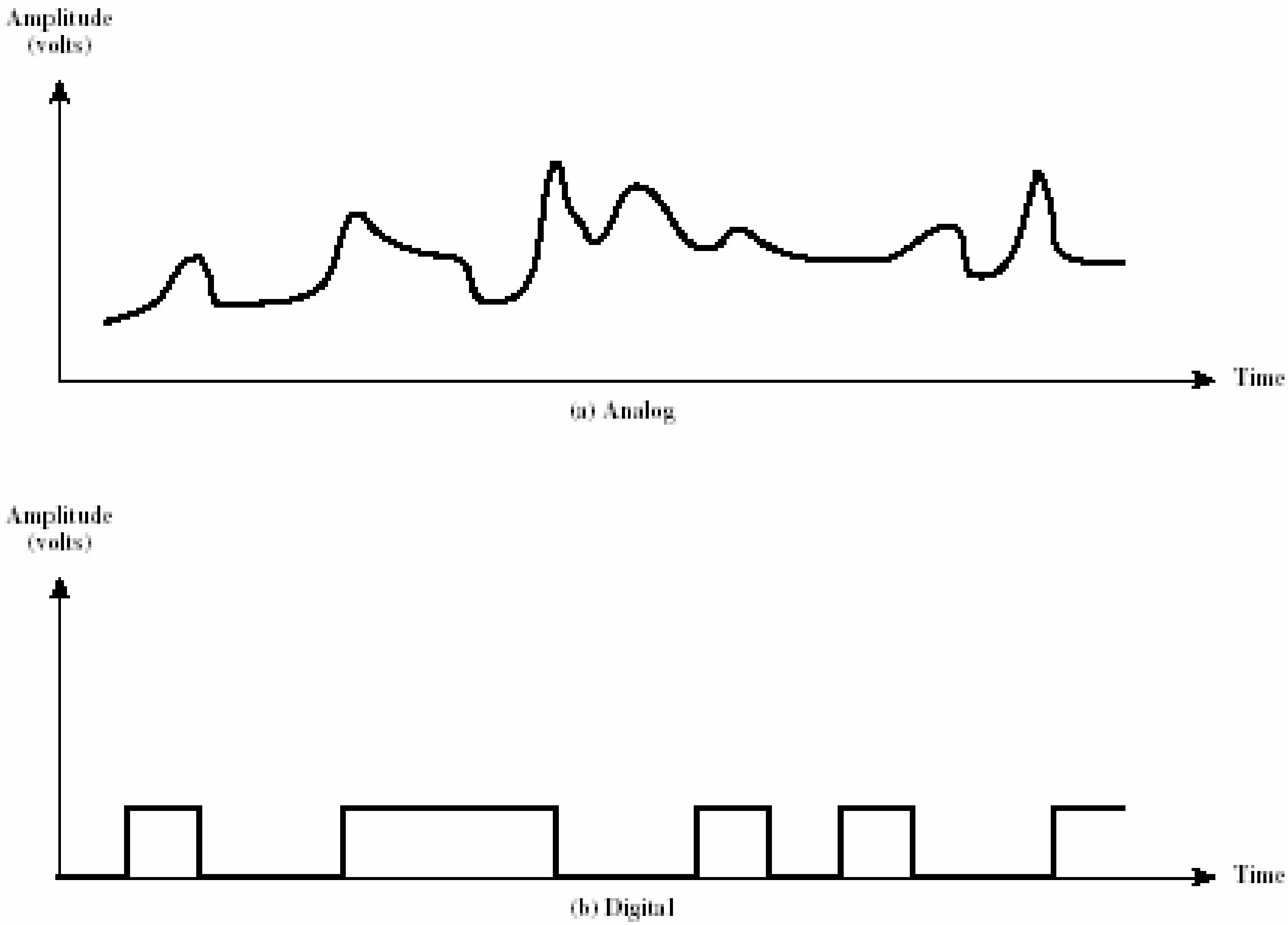


Figure 2.1 Analog and Digital Waveforms

Time-Domain Concepts (cont.)

- Peak amplitude (*A*)
  - maximum value or strength of the signal over time
  - typically measured in volts.
- Frequency (*f*)
  - Rate, in cycles per second, or Hertz (Hz), at which the signal repeats.

Time-Domain Concepts (cont.)

- Period (T)
  - amount of time it takes for one repetition of the signal
  - $T = 1/f$
- Phase (ϕ) - measure of the relative position in time within a single period of a signal
- Wavelength (λ) - distance occupied by a single cycle of the signal
  - Ex: Speed of light is $v = 3 \times 10^8$ m/s. Then the wavelength is $\lambda f = v$ (or $\lambda = vT$).

Sine Wave Parameters

- General sine wave
  - $s(t) = A \sin(2\pi ft + \phi)$
  - note: 2π radians = 360° = 1 period
- Figure 2.3 shows the effect of varying each of the three parameters
  - (a) $A = 1$, $f = 1$ Hz, $\phi = 0$; thus $T = 1$s
  - (b) Reduced peak amplitude; A=0.5
  - (c) Increased frequency; $f = 2$, thus $T = ½$
  - (d) Phase shift; $\phi = \pi/4$ radians (45 degrees)

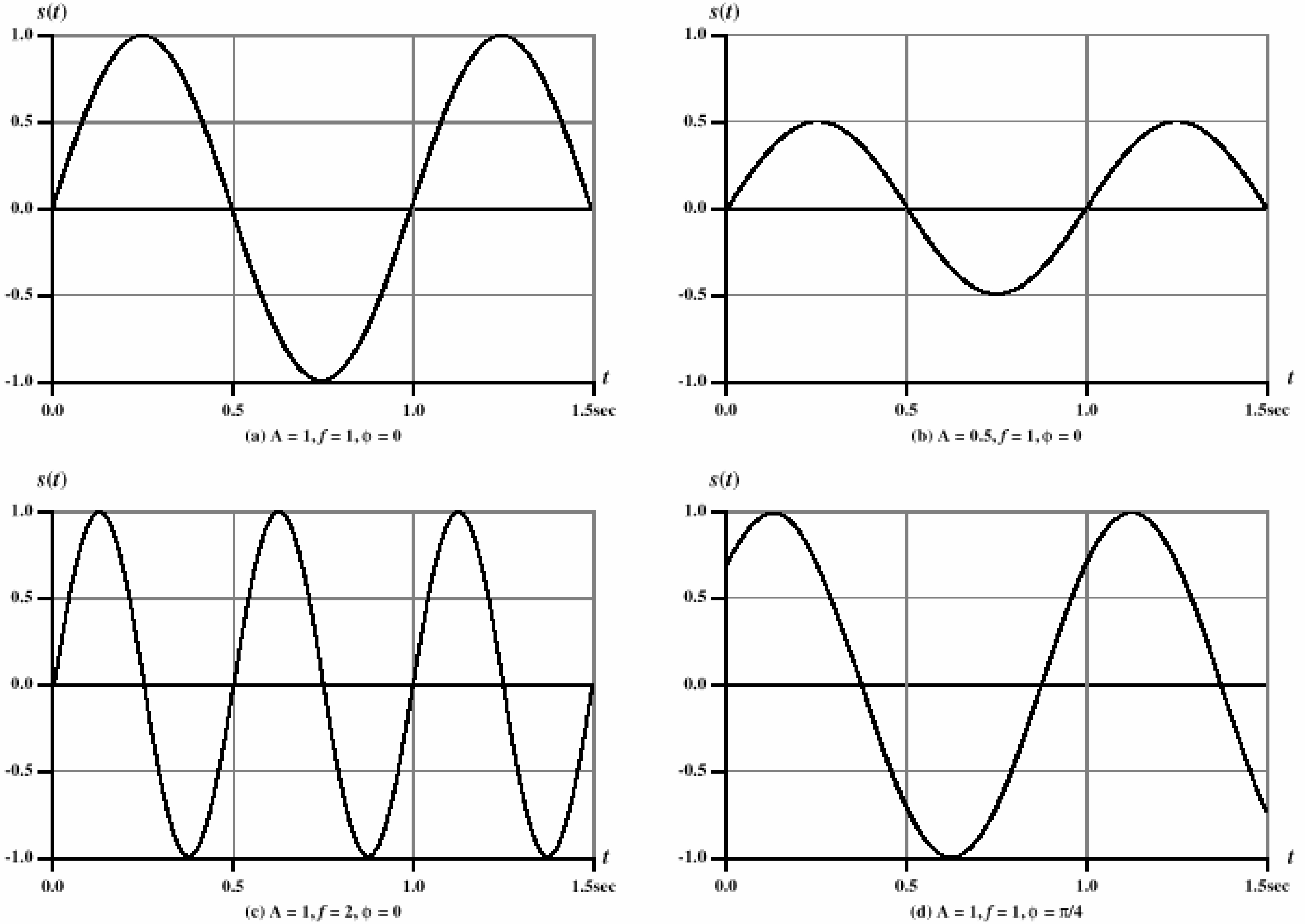
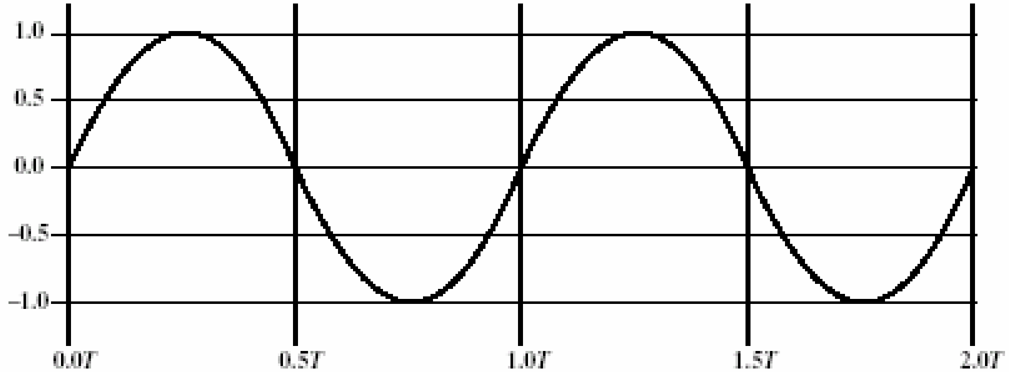


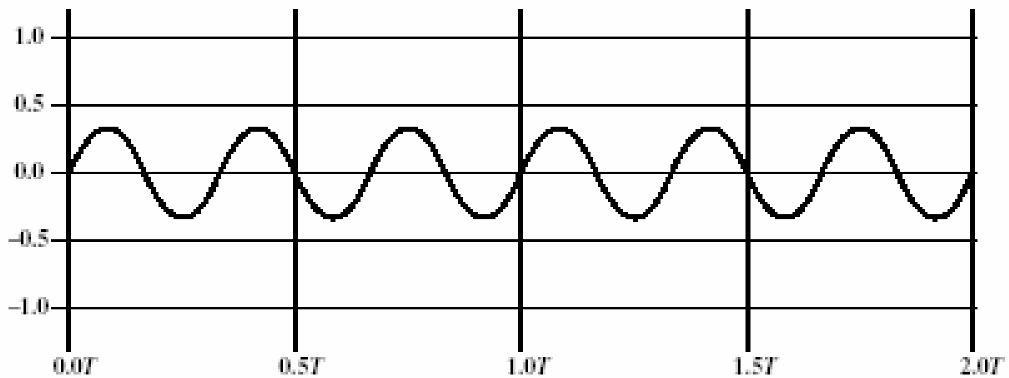
Figure 2.3 $s(t) = A \sin (2\ \ ft + \phi)$

Frequency-Domain Concepts

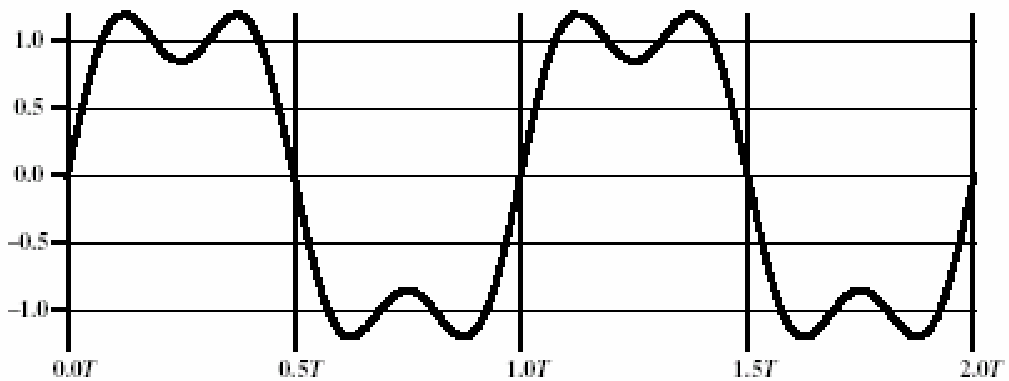
- An electromagnetic signal can be made up of many frequencies.
  - Example: $s(t) = (4/\pi) \cdot (\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t))$
    - Fig. 2.4(a) + Fig. 2.4(b) = Fig. 2.4(c)
    - There are two component frequencies: f and 3f.



(a) sin (2 ft)



(b) (1/3) sin (2 (3f)t)

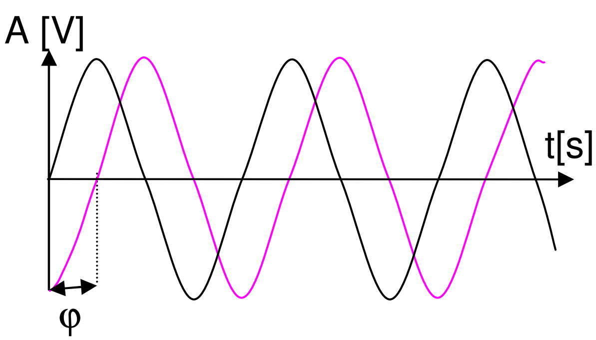


(c) (4/) [sin (2 ft) + (1/3) sin (2 (3f)t)]

Figure 2.4 Addition of Frequency Components ($T = 1/f$)

Time-Domain v.s. Frequency-Domain

- Based on Fourier analysis, any signal is made up of components at various frequencies,
  - in which each component is a sinusoid wave, at different amplitudes, frequencies, and phases.
- Frequency domain: we represent a signal by recording the amplitudes, frequencies, and phases of its components.
  - A signal can be represented either in the time domain, or in the frequency domain.

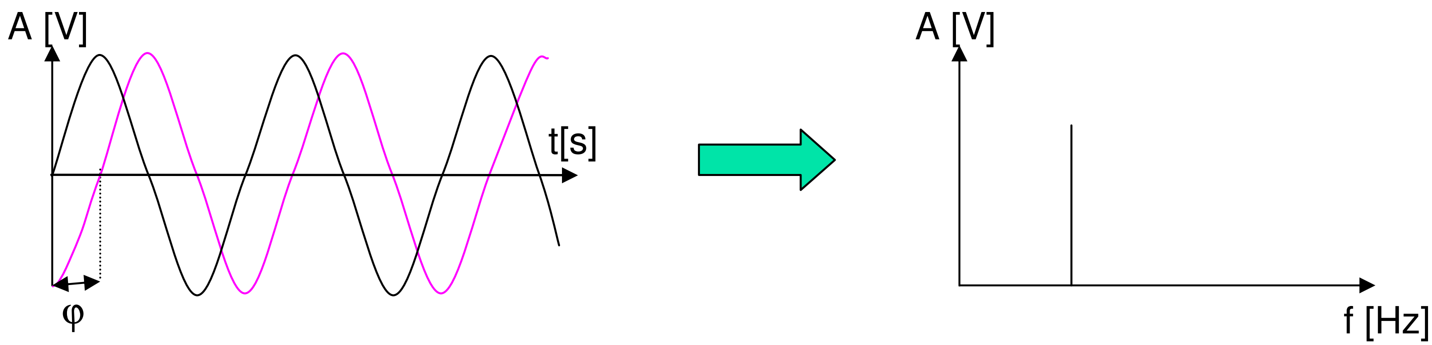


Frequency-Domain (cont.)

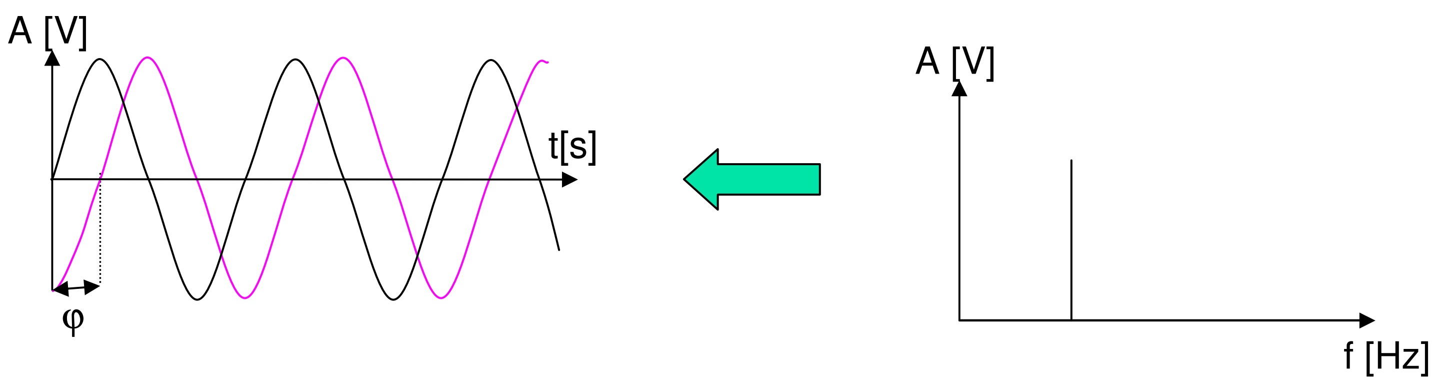
- Spectrum - range of frequencies that a signal contains
  - In Fig. 2.4(c), spectrum extends from f to 3f.
- Absolute bandwidth - width of the spectrum of a signal
  - In Fig. 2.4(c), it is 3f – f = 2f.
- Effective bandwidth –
  - A signal may contain many frequencies.
  - But most of the energy may <u>concentrate in a narrow band of frequencies</u>.
  - These frequencies are effective bandwidth.

Time-Domain v.s. Frequency-Domain

- Fourier transform



- Inverse Fourier transform

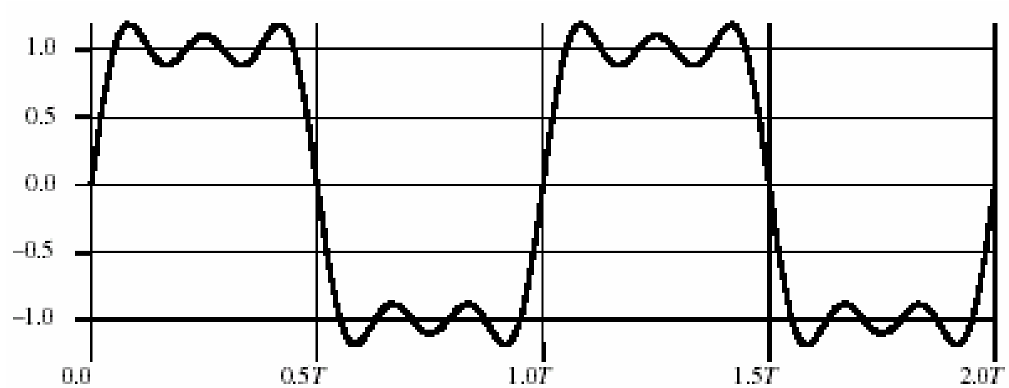


Data vs. Signal

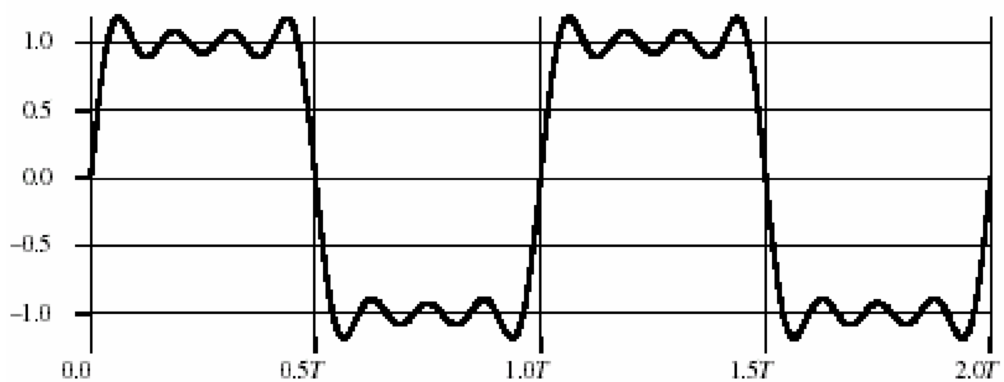
- Signals - electric or electromagnetic representations of data
- Data - entities that convey meanings or information
- Transmission - communication of data by the propagation and processing of signals

Approximating Square Wave by Signals

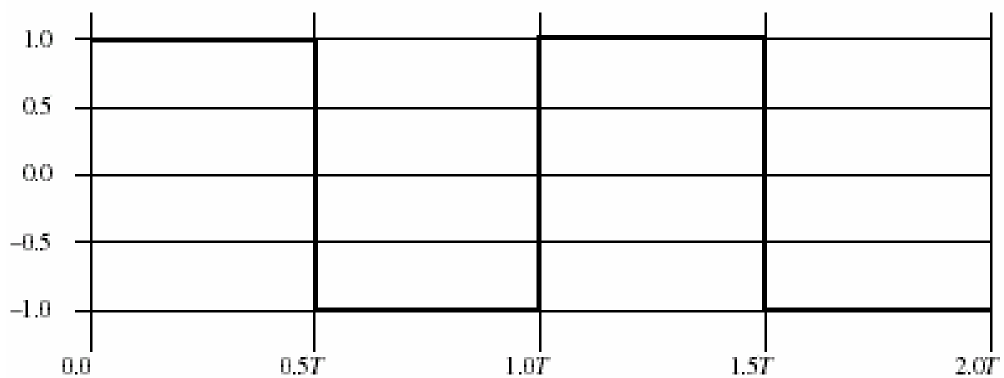
- adding a frequency of 5f to Fig. 2.4(c) ➔ Fig. 2.5(a)
- adding a frequency of 7f to Fig. 2.4(c) ➔ Fig. 2.5(b)
- adding all frequencies of 9f, 11f, 13f, ... ➔ Fig. 2.5(c), a square wave
  - This square wave has an infinite number of frequency components, and thus infinite bandwidth.



(a) (4/) [sin (2 ft) + (1/3) sin (2 (3f)t) + (1/5) sin (2 (5f)t)]



(b) (4/) [sin (2 ft) + (1/3) sin (2 (3f)t) + (1/5) sin (2 (5f)t) + (1/7) sin (2 (7f)t)]



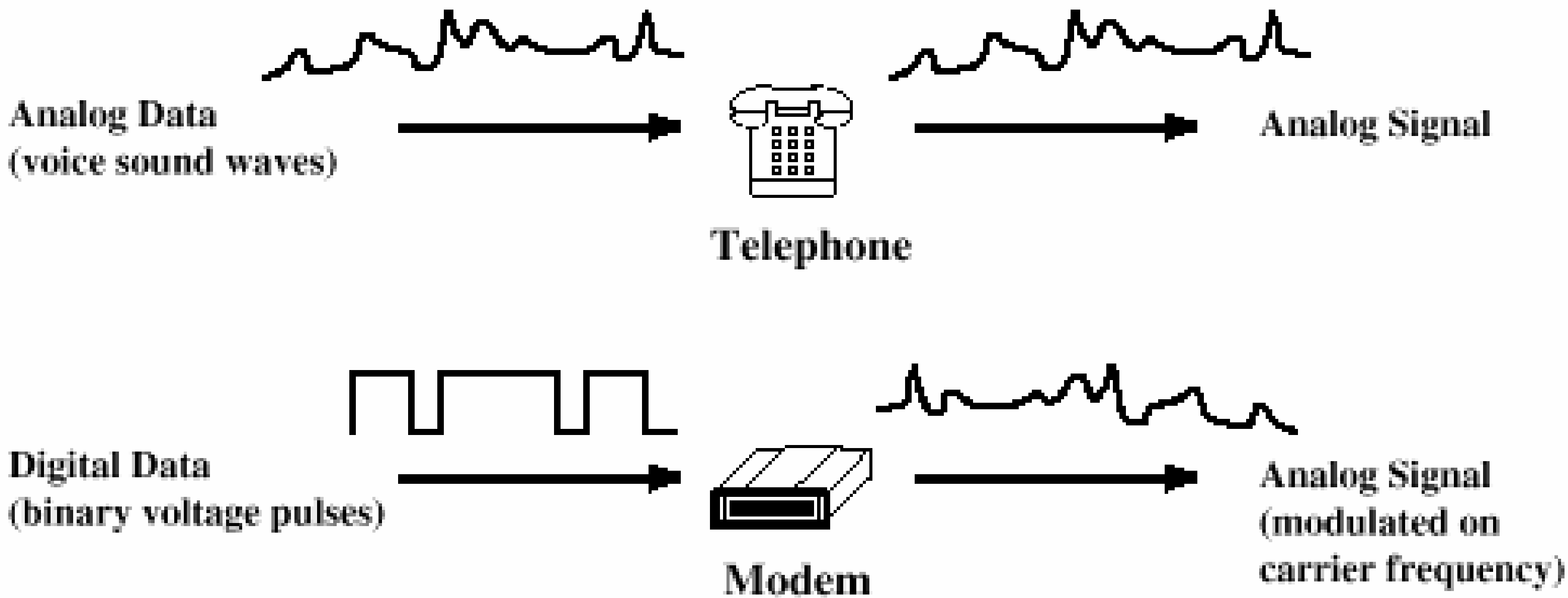
(c) (4/) ∑ (1/k) sin (2 (kf)t), for k odd

Figure 2.5 Frequency Components of Square Wave ($T = 1/f$)

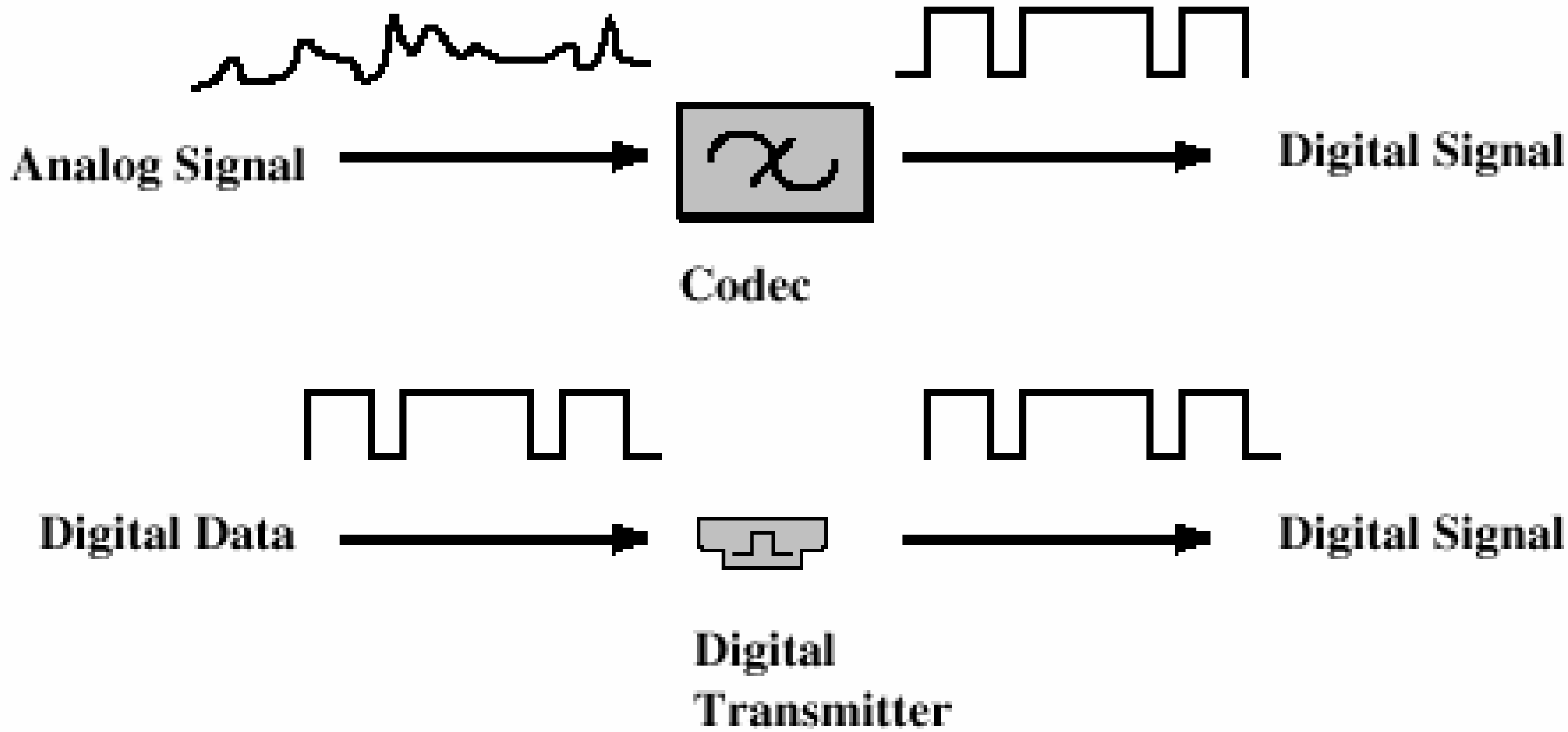
Examples of Analog and Digital Data

- Analog
  - Video
  - Audio
- Digital
  - Text
  - Integers

Analog Signals: Represent data with continuously varying electromagnetic wave



Digital Signals: Represent data with sequence of voltage pulses



Reasons for Choosing Data and Signal Combinations

- Digital data, digital signal
  - Equipment for encoding is less expensive than digital-to-analog equipment
- Analog data, digital signal
  - Conversion permits use of modern digital transmission and switching equipment
- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - Examples include optical fiber and satellite
- Analog data, analog signal
  - Analog data easily converted to analog signal

Some Terms about Channel Capacity

- Data rate - rate at which data can be communicated (bps)
- Bandwidth - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- Noise
- Channel Capacity – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions
- Error rate - rate at which errors occur

Signal-to-Noise Ratio

- Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission
- Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

$$(SNR)_{\mathrm{dB}} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

  - $= 10 \log_{10} \mathrm{SNR}$
  - A high SNR means a high-quality signal.
  - SNR sets an upper bound on the achievable data rate.

Shannon Capacity Formula

- The max. channel capacity:

$$C = B\log_2\left(1+\mathrm{SNR}\right)$$

  - note: SNR not in db.
- In practice, only much lower rates are achieved
  - Formula assumes white noise (thermal noise)
  - Impulse noise is not accounted for
  - Attenuation distortion or delay distortion not accounted for

Classifications of Transmission Media

- Transmission Medium
  - Physical path between transmitter and receiver
- Guided Media (e.g., wire)
  - Waves are guided along a solid medium
  - E.g., copper twisted pair, copper coaxial cable, optical fiber
- Unguided Media
  - Provides means of transmission but does not guide electromagnetic signals
  - Usually referred to as wireless transmission
  - E.g., atmosphere, outer space

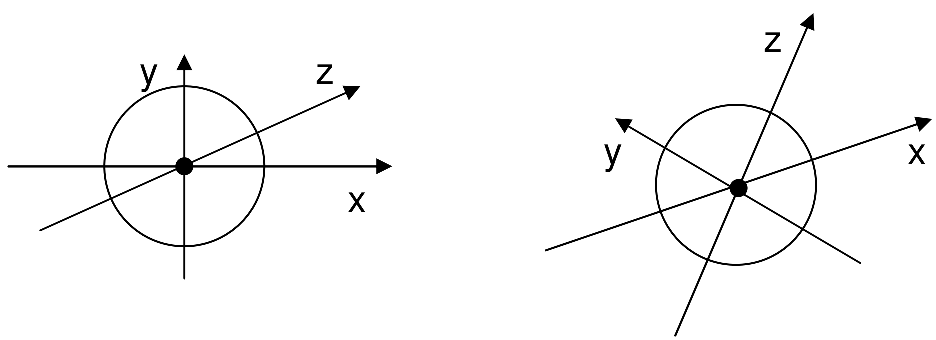
General Frequency Ranges

- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for long-distance, point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Infrared frequency range
  - Roughly, 3×10^{11} to 2×10^{14} Hz
  - Useful in local point-to-point multipoint applications within confined areas

Wireless Transmission

Antennas

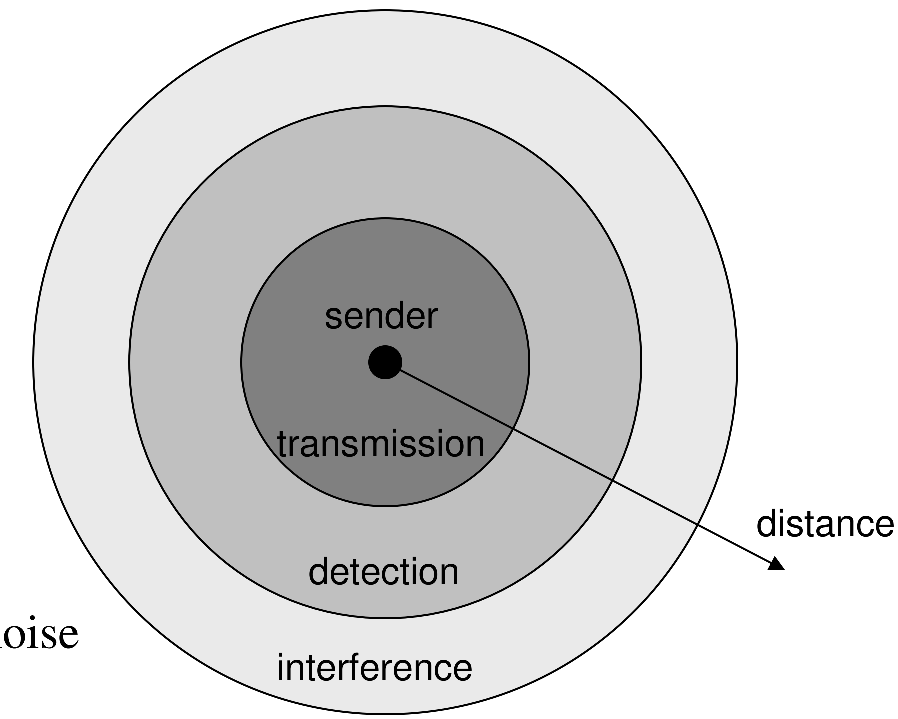
- Isotropic radiator: equal radiation in all directions (three dimensional) - only a theoretical reference antenna
- Real antennas always have directive effects (vertically and/or horizontally).
- One can use multiple antennas to emulate isotropic radiator.



ideal isotropic radiator

Signal propagation ranges

- Transcription range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise

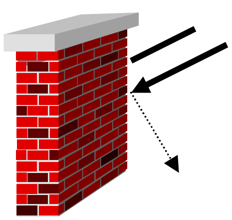


Signal propagation

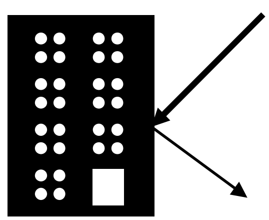
- Propagation in free space always like light (straight line)
- Free-space loss: receiving power proportional to $1/d^2$ in vacuum. (d = distance between sender and receiver)
- Intuition: the signal propagates as a spherical shape. The surface area is ~ d^2.
- In real environments the power is between 2 and 5.
- Other effects:
  - Fading
  - Multi-path propagation
  - Movement.

Signal propagation

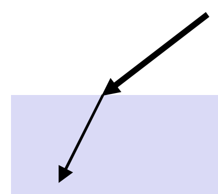
- Receiving power additionally influenced by
  - Shadowing (blocks the signal)
  - reflection at large obstacles (with dimension very large compared to the wave's wavelength)
  - refraction depending on the density of a medium
  - scattering at small obstacles (with dimensions in the order of the wavelength)
  - diffraction at edges



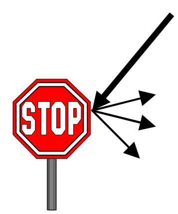
shadowing



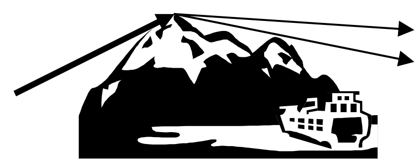
reflection



refraction



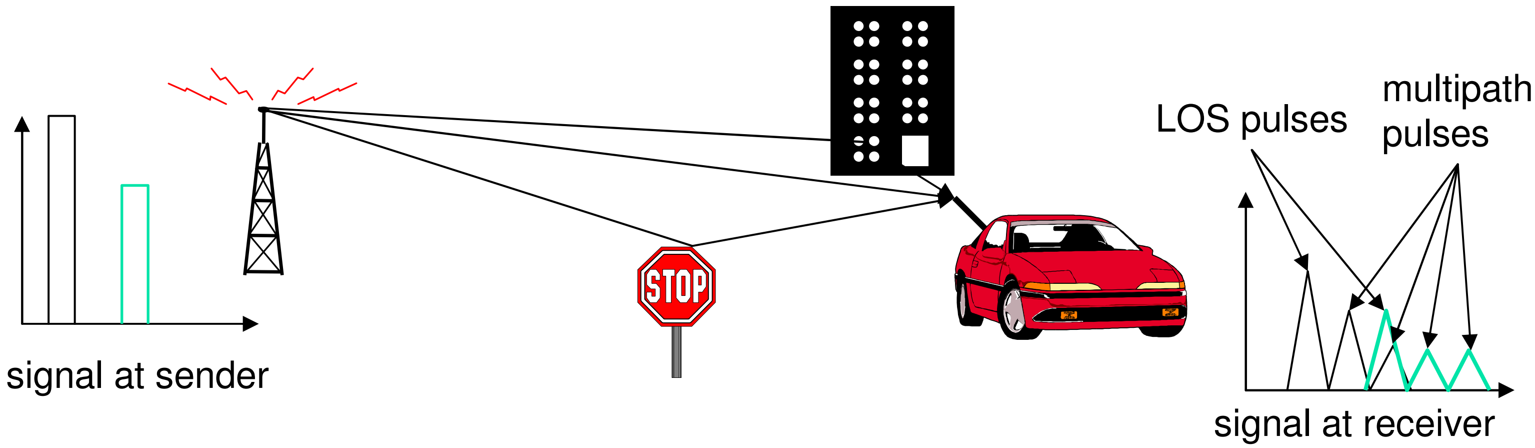
scattering



diffraction

Multipath propagation

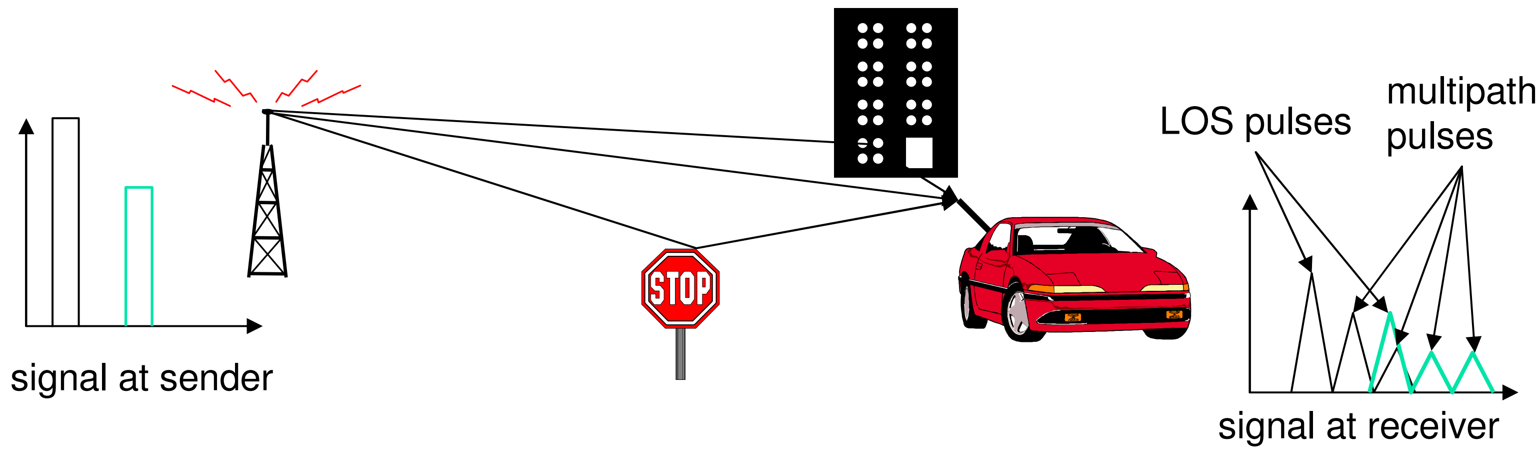
- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



- Fast fading: waves traveling along different paths may be completely out of phase when they reach the antenna (thereby canceling each other out!)

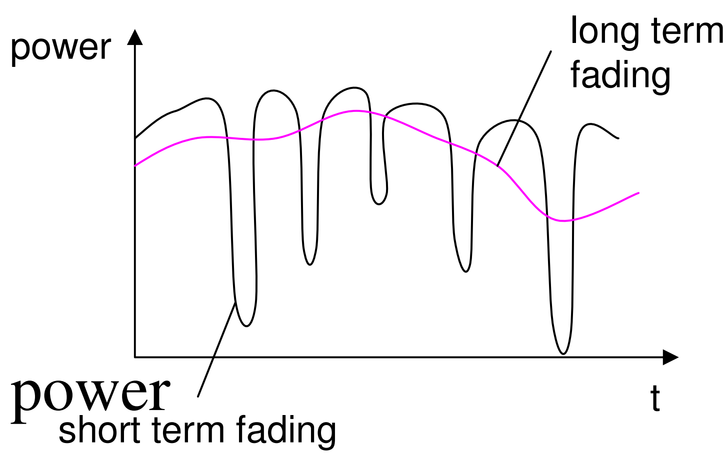
Multipath propagation

- Time dispersion: signal is dispersed over time
- ➔ interference with “neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
- ➔ distorted signal depending on the phases of the different parts



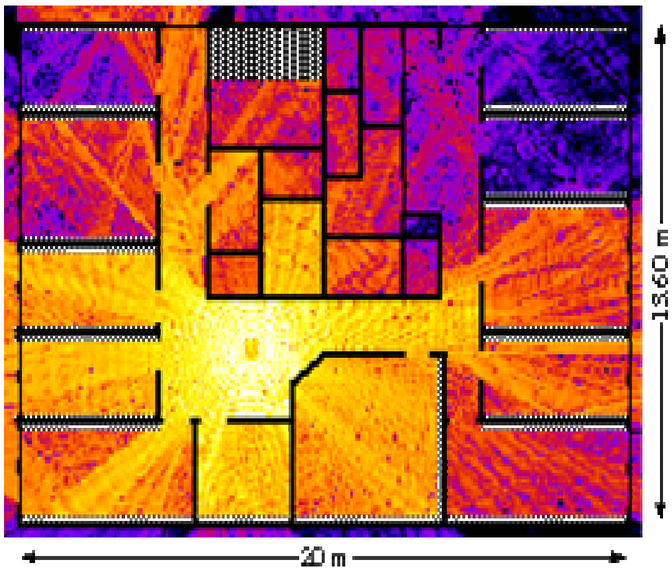
Effects of mobility

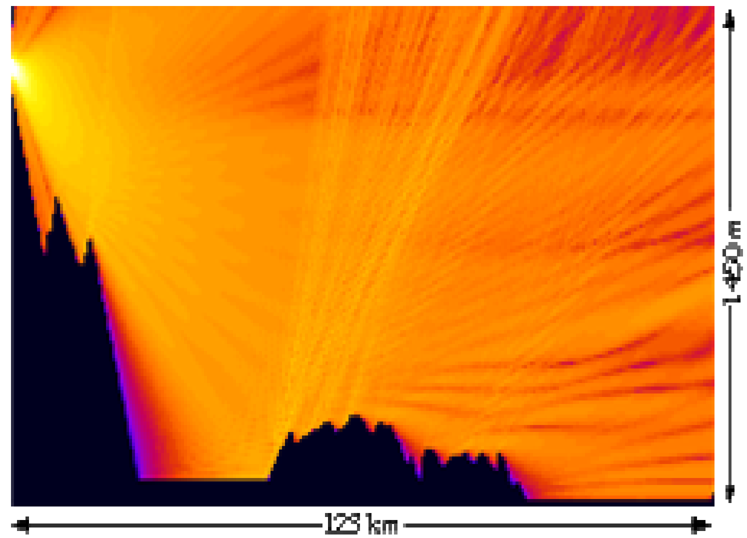
- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
- ➔ quick changes in the power received (short term fading)

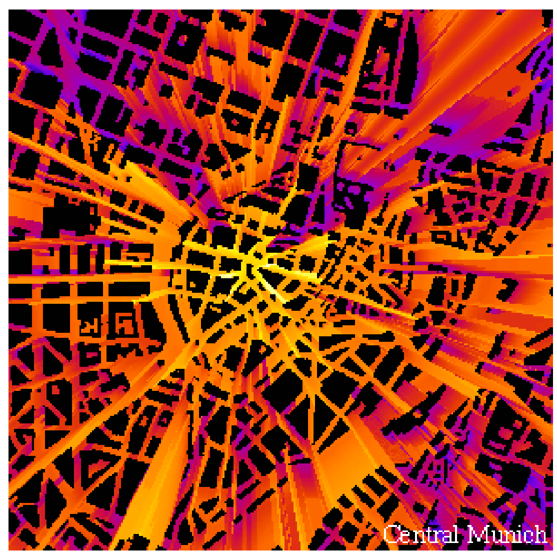


- Additional changes in
  - distance to sender
  - obstacles further away
- ➔ slow changes in the average power received (long term fading)

Real world example







How to model signal propagation?

- Free space Line-of-sight (LOS) model.
  - Too simplified.
- Ray tracing approximation
  - Represent wavefronts as simple particles
  - Geometry determines received signal from each signal component
  - Typically includes reflected rays, can also include scattered and defracted rays.
  - Requires site parameters
    - Geometry
    - Dielectric properties
  - Computer packages often used
- Empirical models

Summary

- signal
- analog vs. digital transmissions
- channel capacity
- transmission media
- Signal propagation
- Path loss
- Multi-path propagation