Humboldt-Universität zu Berlin, Institut für Informatik,
IHP, Leibniz Institut für innovative Mikroelektronik, Frankfurt (Oder)

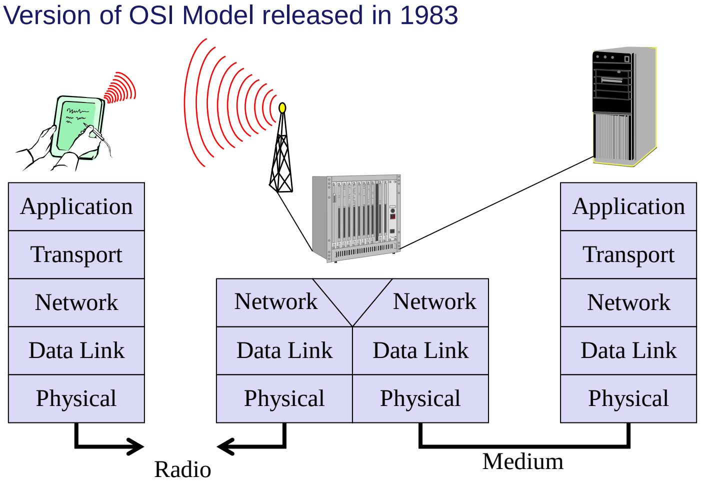
Vorlesung Drahtlose Breitbandkommunikationssysteme

Prof. Dr. Eckhard Grass grass@ihp-microelectronics.com
grass@informatik.hu-berlin.de

http://www.informatik.hu-berlin.de/~grass/bbk

Simple reference model used here (OSI-Layer Model)

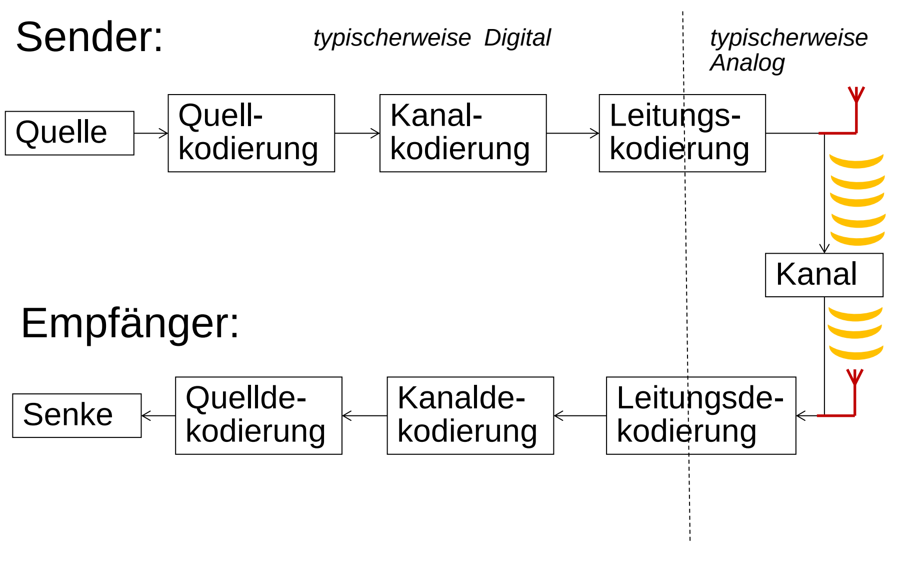
- OSI: “Open System Interconnection Reference Model” (“Offenes System für Kommunikationsverbindungen”)
- Layer Model of the International Standards Organization (ISO)
- 1st Version of OSI Model released in 1983



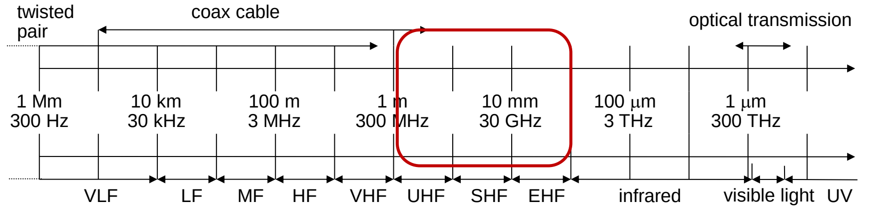
Mobile communication OSI-layer model

Layer	Functions	Examples
• Application layer	○ service location ○ new applications, multimedia ○ adaptive applications	• Application Layer • Presentation Layer • Session Layer
• Transport layer	○ congestion and flow control ○ quality of service	TCP UDP
• Network layer	○ addressing, routing, device location ○ hand-over	IP IPsec
• Data link layer	○ authentication ○ media access ○ multiplexing ○ media access control (MAC)	
• Physical layer	○ encryption ○ modulation ○ Interference ○ attenuation ○ frequency	

Breitbandkommunikation – Einführung (PHY-Modell)



Frequencies for communication



- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency
- UHF = Ultra High Frequency
- SHF = Super High Frequency
- EHF = Extra High Frequency
- UV = Ultraviolet Light

- Frequency and wave length:
- $\lambda = c/f$
- wave length λ, speed of light $c \cong 3 \times 10^8$ m/s, frequency f

Frequencies for mobile communication

- VHF-/UHF-ranges for mobile radio (~100 MHz/ 1 GHz)
  - simple, small antennas
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication (10 GHz)
  - small antenna, focusing
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF spectrum
  - some systems planned up to EHF (100 GHz)
    - E.g. IHP working on systems for 100 Gb/s at 250GHz
  - limitations due to absorption by water and oxygen molecules (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.
  - WLAN uses unlicensed spectrum in ISM-bands (Industrial, Scientific, Medical) in the 2.4 GHz and 5.2 to 5.8 GHz range and 56-66 GHz)

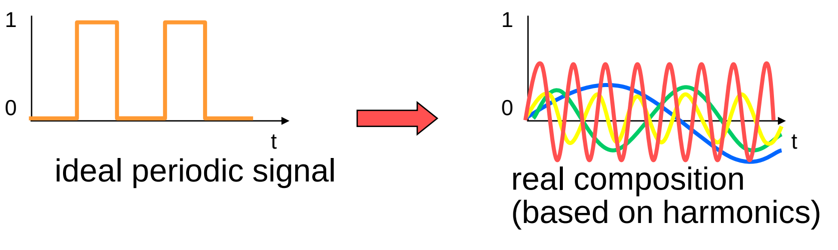
Signals I

- physical representation of data
- function of time and location
- signal parameters: parameters representing the value of data
- classification
  - continuous time/discrete time
  - continuous values/discrete values
  - analog signal = continuous time and continuous values
  - digital signal = discrete time and discrete values
  - Today also combinations are being used
    - E.g. discrete values and continuous time
- signal parameters of periodic signals:
  period T, frequency f = 1/T, amplitude A, phase shift φ
  - sine wave as special periodic signal for a carrier:

$s(t) = A_t \sin(2\pi f_t t + \varphi_t)$

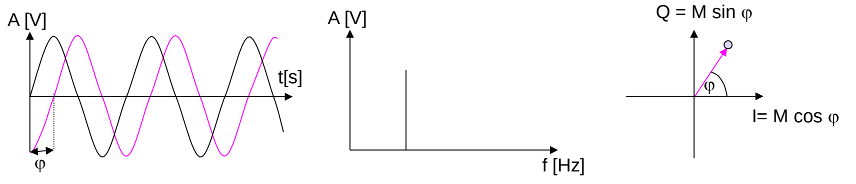
Fourier representation of periodic signals

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



Signals II

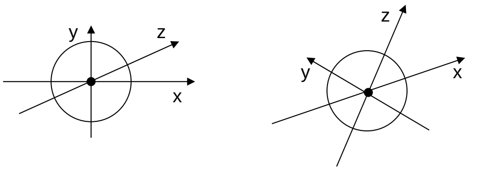
- Different representations of signals
  - amplitude (amplitude domain)
  - frequency spectrum (frequency domain)
  - phase state diagram (amplitude M and phase φ in polar coordinates)



- Composed signals transferred into frequency domain using Fourier transformation
- Digital signals need
  - infinite frequencies for perfect transmission
  - modulation with a carrier frequency for transmission (analog signal!)

Antennas: isotropic radiator

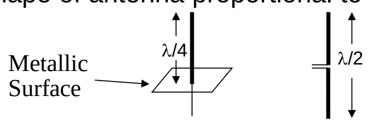
- Radiation and reception of electromagnetic waves, coupling of wires to space for radio transmission
- Isotropic radiator: equal radiation in all directions (three dimensional) - only a theoretical reference antenna
- Real antennas always have directive effects (vertically and/or horizontally)
- Radiation pattern: measurement of radiation (field strength and polarization) around an antenna
- Isotropic Radiator is used as reference for directivity of antennas (EIRP= Equivalent Isotropic Radiated Power)



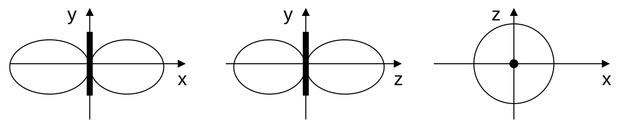
ideal
isotropic
radiator

Antennas: simple dipoles

- Real antennas are not isotropic radiators but, e.g., dipoles with lengths λ/4 on car roofs or λ/2 as Hertzian dipole
  ➔ shape of antenna proportional to wavelength



- Example: Radiation pattern of a simple Hertzian dipole



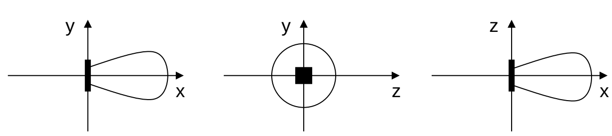
side view (xy-plane) side view (yz-plane) top view (xz-plane)

simple dipole

- Gain: maximum power in the direction of the main lobe compared to the power of an isotropic radiator (with the same average power)
- Gain measure in dBi ($10*\log_{10}P_{max}/P_i$)

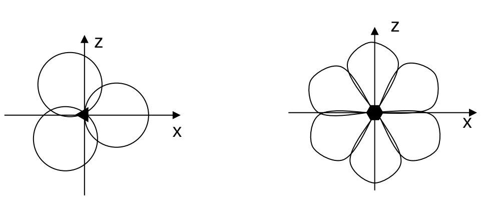
Antennas: directed and sectorized

- Often used for microwave connections or base stations for mobile phones (e.g., radio coverage of a valley)



side view (xy-plane) side view (yz-plane) top view (xz-plane)

directed antenna

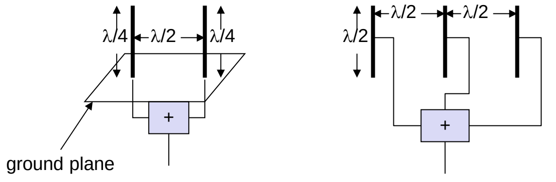


top view, 3 sector top view, 6 sector

sectorized antenna

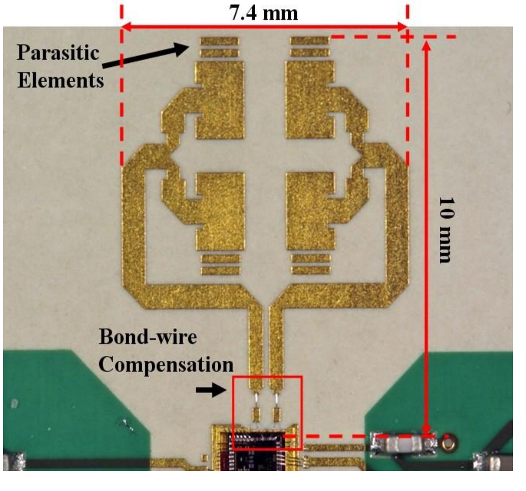
(passive) Antennas: diversity

- Grouping of 2 or more antennas
  - multi-element antenna arrays
- Antenna diversity
  - switched diversity, selection diversity
    - receiver chooses antenna with largest output
  - diversity combining
    - combine output power to produce gain
    - co-phasing needed to avoid cancellation



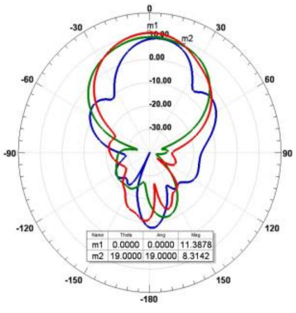
Patch Array Antenna Photo

- Four patch elements
- Four pairs of parasitic elements
- Substrate: Isola
- Bond-wire compensation
- Size: 10 mm by 7.4 mm
- Gain: ca. 8 dBi
- 3 dB beam width: ca. 35°
- Polarization: linear (horizontal)



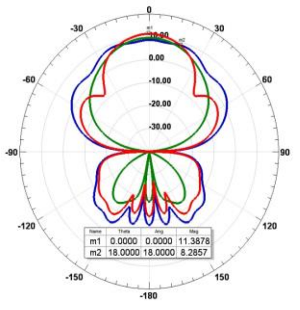
Source: Ruoyu Wang (IHP, 2011)

Simulation Results: Radiation Pattern



H-Plane

3 dB Beamwidth 38 degrees (62 GHz)

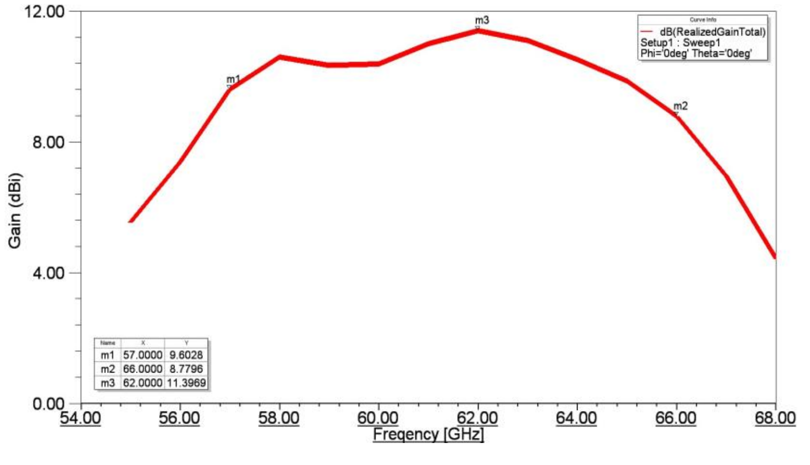


E-Plane

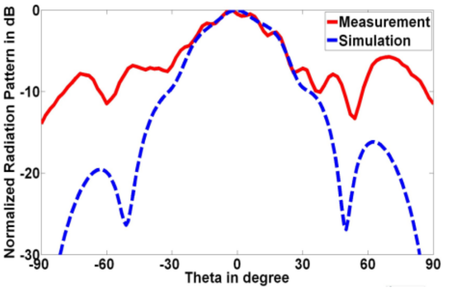
3 dB Beamwidth 36 degrees (62 GHz)

Green: 57 GHz, Red: 62 GHz, Blue: 66 GHz

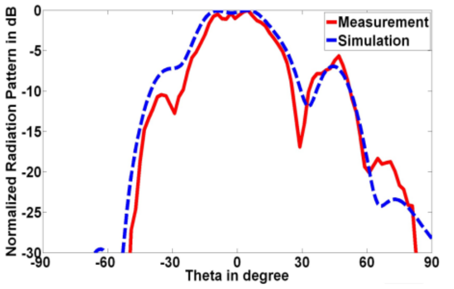
Simulation Results: Antenna Gain versus frequency



Radiation Patterns at 62 GHz (Beam Width)

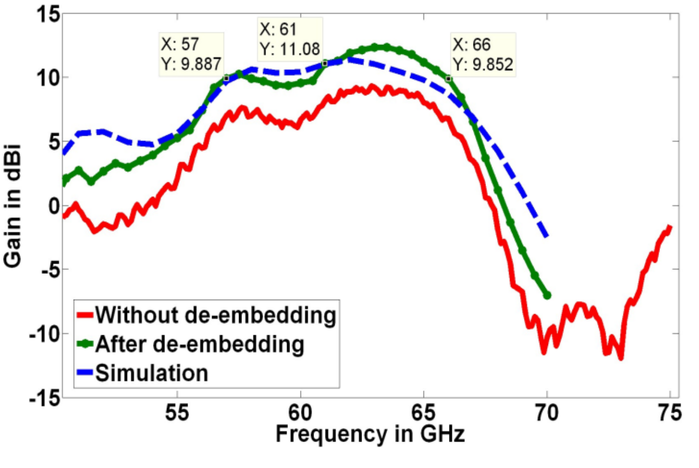


E-plane
3dB BW=36 degrees

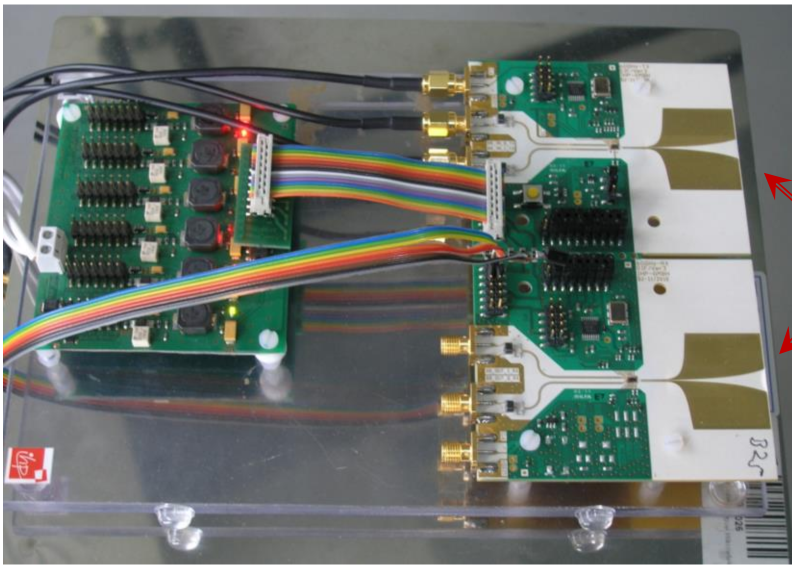


H-plane
3dB BW=32 degrees

Gain of Main Lobe against center frequency



Antenna: Example 60 GHz Vivaldi Antenna



Vivaldi or „bunny ear“ antenna

Antenna: Example Hornantenna for waveguide feed

- Frequency: 33 to 50 GHz
- Gain: 20 dBi
- 3dB beam width: ca. 10°

Other issues related to Antenna (and indirectly channel)

Open Issues
(not addressed in this lecture):

- Linear polarization
- Cross polarization
- Circular polarization
- Antenna diversity
- Antenna combining (maximum ratio)

Wireless Communication Channel

Properties of Wireless Communication Channel:

- Linear system
- Time variant system
  (for most practical consideration: time invariant; coherence time)
- Symmetrical (reciprocity **!**)
- Channel characteristics depend on antenna used
  - Antenna effects the channel model (use for parameterization)

Simplest Channel Model:

- Additive White Gaussian Noise (AWGN); no fading

Upper bound for channel capacity:

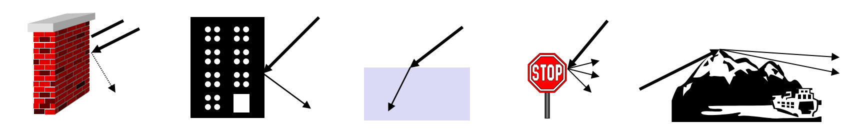
- ***Shannon*** Theorem

Free-space Path-loss:

- ***Friis Equation***

Signal propagation

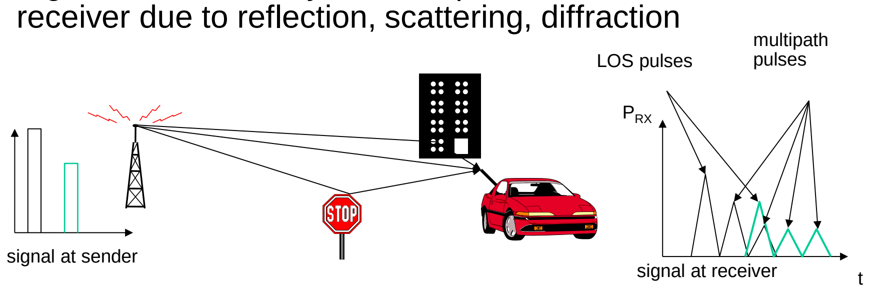
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ (d = distance between sender and receiver)
- Receiving power additionally influenced by
- fading = constructive and destructive superposition of radio waves (frequency dependent!)
- Material specific absorptions (H_2O absorption at 2.5 GHz and 5 GHz; O_2 absorption at 60 GHz, …)
- Objects with $\varepsilon_r \neq 1$ can cause:
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - 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



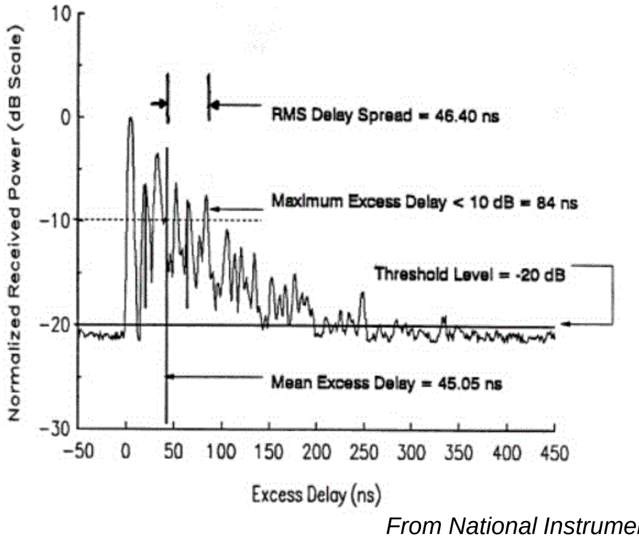
- Time dispersion: signal is dispersed over time (delay spread)

  ➔ 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

Example of channel impulse response (power delay profile)

Example of an indoor power delay profile with rms delay spread, mean excess delay, maximum excess delay (10 dB), and threshold level



From National Instruments: http://zone.ni.com

Rician / Rayleigh fading

Line-of-sight (LOS): Rician Fading
Stochastic model of power delay profile for LOS channels

-> Tafel

Non-line-of-sight (NLOS): Rayleigh Fading
Stochatstic model of power delay profile for NLOS channels

-> Tafel

RMS Delay Spread and Mean Delay

- The root mean square delay spread is a mean to describe the dispersion of the signal due to multi-path propagation.
- It takes into account the delay of all received signals with respect to the delay of the first received signal.
- Each path is weighted with the received power

$$t_d = \frac{\sum_{i=1}^{n} (t_i P_i)}{\sum_{i=1}^{n} P_i}$$ Mean Delay

$$t_{rms} = \sqrt{\frac{\sum_{i=1}^{n} \left((t_i^2 P_i \right)}{\sum_{i=1}^{n} P_i} - t_d^2}$$ RMS delay spread

- Example:

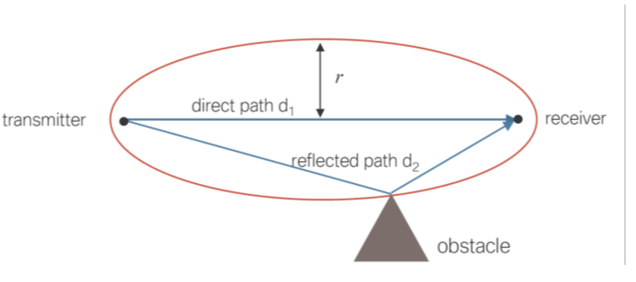
  Take this room, go up to 3 reflections, assume (worst case): no attenuation at the reflection point, take longest paths

Fresnel Zone

- First Fresnel Zone considerations for antenna heights and reference distance
- Destructive interference if: $d_2 - d_1 = \lambda / 2$
- This is true on an ellipse around TX and RX

$$r = \sqrt{\frac{d\lambda}{4}} \approx 3.5m$$

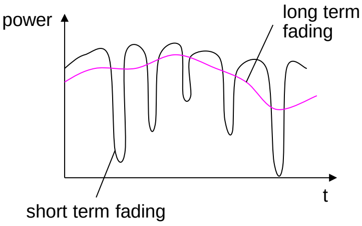
Example:
d: 3 m
λ: 5 mm (~60 GHz)
→ r = 6,1 cm



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 received power (short term fading)
  (= fast fading, = small scale fading)

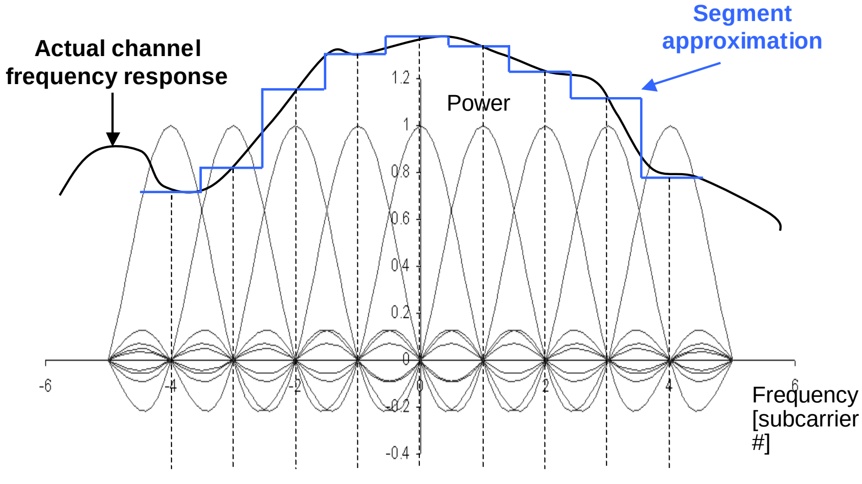
- Additional changes in
  - distance to sender
  - obstacles further away



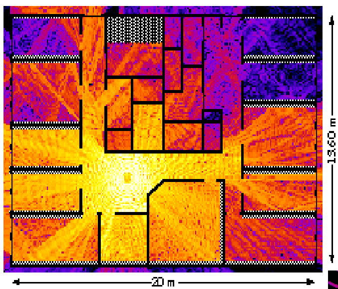
- ➔ slow changes in the average power received (long term fading),
  (= slow fading, = large scale fading)

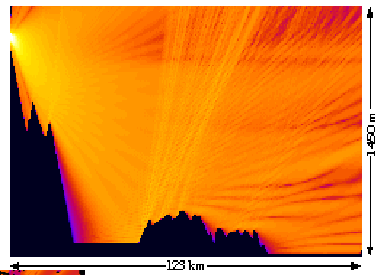
Effects of fading channels in frequency domain

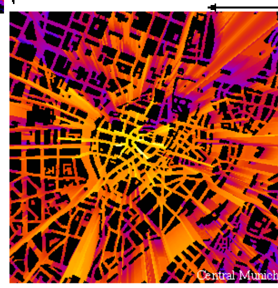
- **CHANNEL'S PIECEWISE APPROXIMATION**



Real world example







Analogien zur Akustischen Kommunikation

- Wellenlänge bei 3 kHz ca. 10 cm
  (ähnlich 2,4 GHz WLAN)

Effekte:

- Reflektionen -> Echo
- Dopplereffekt -> Frequenzverschiebung
- Rauschen (Nebengeräusche) -> Sprache

Massnahmen:

1. Gerichtete Kommunikation
2. Direkte Sichtverbindung (line-of-sight)
3. Erhöhung der Sendeleistung / Lautstärke
4. Verringern der Symbolrate / orthogonale Codes
5. Kanalwechsel (Stimmhöhe, optische Signalisierung)

Main Channel Parameters

- **Free space path-loss (Friis equation)**
  - **Path-loss exponent**
- **Delay spread**
  (RMS delay value of arriving signal power)
- Coherence time
  (time in which channel can be considered constant – 3 dB deviation)
- Coherence bandwidth (power variation over f < 3dB)
  - Small scale fading
  - Large scale fading
- Doppler shift
  - Doppler spread
- Angular parameters
  - Angle of arrival
- Noise and/or interference

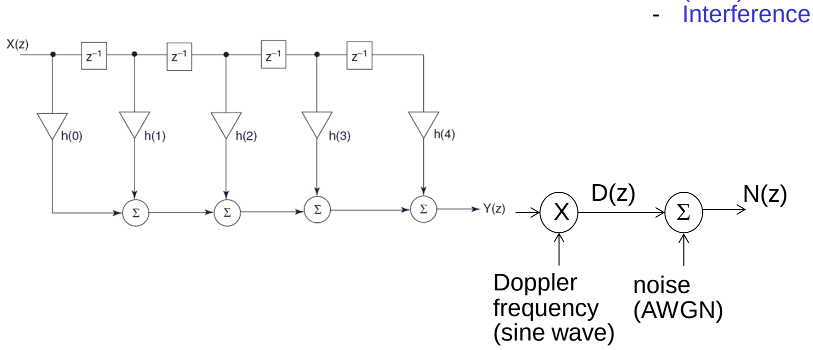
Channel Modelling – practical issues

- The channel model works in the baseband frequency domain
- The channel model uses complex signals
- With respect to the sampling rate of the system, the channel model is usually oversampled by a factor of >=4

Fading
- Multipath Propagation

Frequency offset
- Doppler effect
- Sampling rate

Noise
- Mainly at RX (LNA)
- Interference



Main Hardware Impairments

Hardware impairments can be modeled as part of the channel:

- Power amplifier non-linearity
- Phase-noise
- Frequency offset
- Phase offset
- Data converter resolution and non-linearity
- I/Q mismatch (phase, amplitude)
- Receiver (LNA) noise-figure

Signal propagation ranges depending on channel

- Transmission 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