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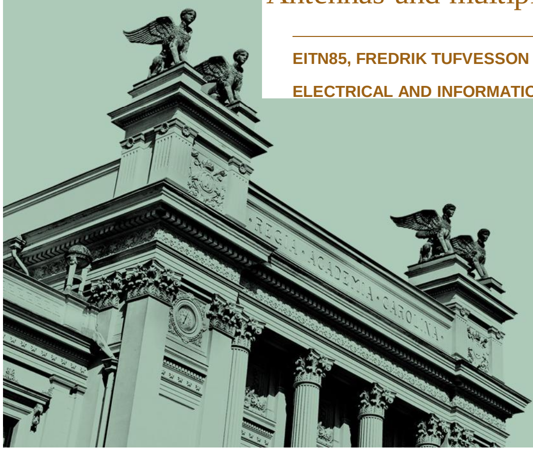
Wireless Communication Channels, Lecture 8: Antennas and multiple antenna systems

EITN85, FREDRIK TUFVESSON

ELECTRICAL AND INFORMATION TECHNOLOGY



Antennas in real channels

One important aspect is how the channel and antenna interact

- The antenna pattern determines what the system sees
- Delay spread and angular spread affected by the antenna pattern

The user may have a large influence on the behavior of the antenna

- Change in antenna pattern
- Change in efficiency – mismatch

What is "the antenna"?

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What do we mean by real channels?

At the mobile side:

- Mock-up terminals (handsets, lap-tops) with antenna and casing
- Near-by scattering environments
  - User influence
  - Indoor environments
  - In vehicles

At the base station side:

- Type of installation – roof-top, wall mount.
- Obstacles or buildings near-by or obstructive to the installation

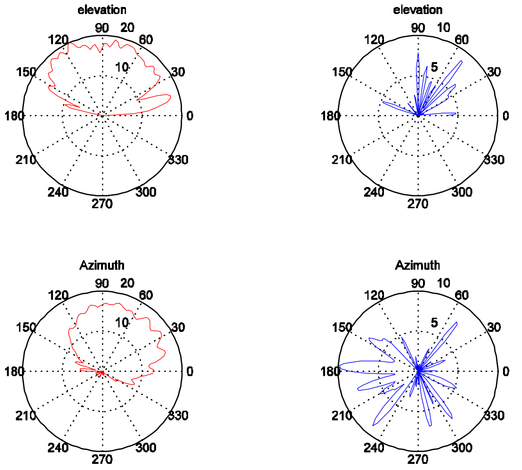
Important antenna parameters

- Directivity
  - Total power in a certain direction compared to total transmitted power
- Efficiency

$$h = \frac{R_{rad}}{R_{rad} + R_{ohmic} + R_{match}}$$

- Q-factor
  - Stored energy compared to dissipated energy
- Mean effective gain
  - Include influence of random channel
  - Average received power compared to average received power by isotropic antenna in real environment
- Polarization
- Bandwidth

Example, antenna pattern



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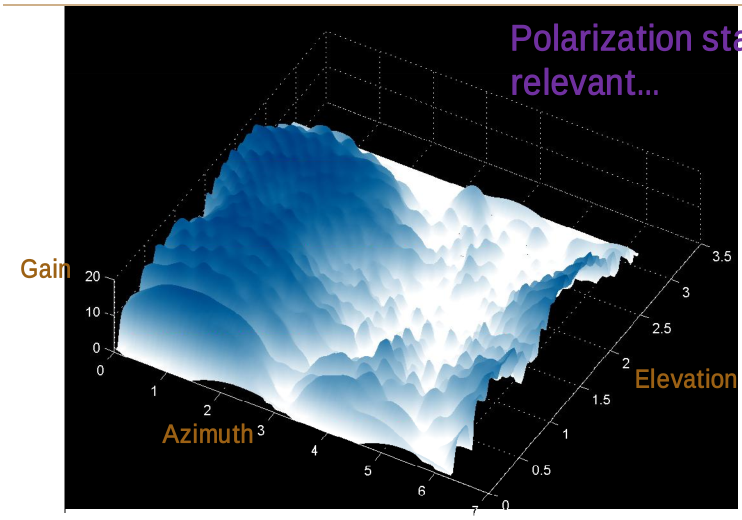
3D antenna pattern



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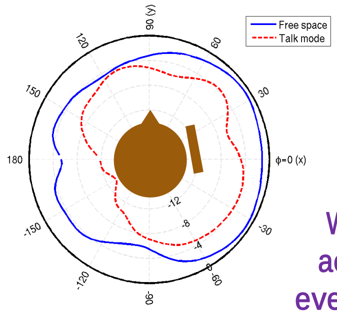
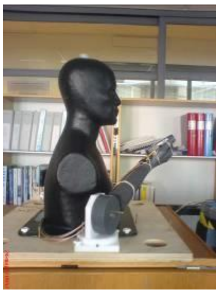
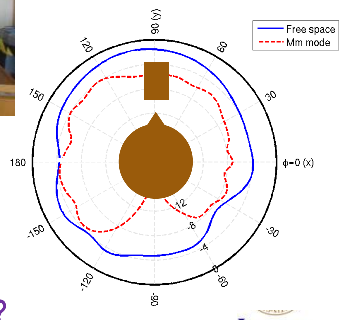
Influence of a user

Talk mode





Data mode



Why lower gain across the head even in free space?

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Influence of a user - continued

Channel Characteristics and User Body Effects in an Outdoor Urban Scenario at 15 and 28 GHz

Kun Zhao, Carl Gustafson, *Member, IEEE*, Qingbi Liao, Shuai Zhang, Thomas Bolin, Zhinong Ying, *Senior Member, IEEE* and Sailing He, *Fellow, IEEE*

Paper submitted in 2016 to TAP:

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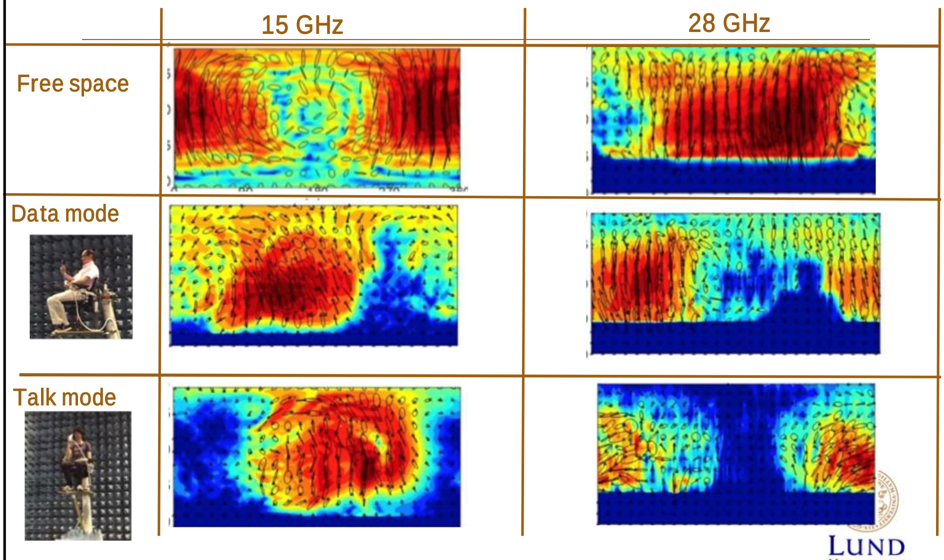
Influence of a user – continued

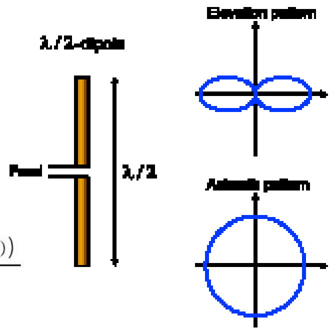


Common antenna types

- Linear antennas (dipole, monopole)
- Helical antennas
- Microstrip antennas
- PIFA and RCDLA antennas

Linear antennas

- Hertzian dipole (short dipole)
  - Antenna pattern:
    $G_{\max} = 1.5$
  - Gain $\widetilde{G}(\varphi,\theta) \propto \sin(\theta)$
- λ/2 dipole
  - Pattern $\widetilde{G}(\varphi,\theta) \propto \frac{\cos\left(\frac{\pi}{2}\cos(\theta)\right)}{\sin(\theta)}$
  - Gain $G_{\max} = 1.64$



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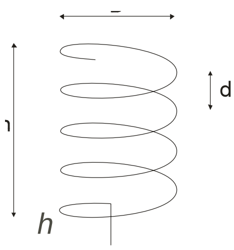
Helical antenna

- Combination of loop antenna and linear antenna
  - If dimensions much smaller than wavelength, behaves like linear antenna
  - Bandwidth, efficiency, and radiation resistance increase with increasing *h*



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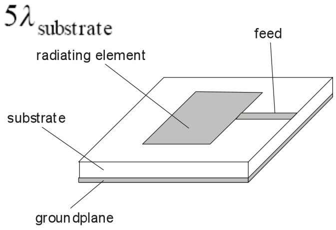
Microstrip antennas

Dielectric substrate with ground plane on one side, and metallic patch on the other. Properties determined by

- Shape of patch: size must be at least $L = 0.5\lambda_{\text{substrate}}$
- Dielectric properties of substrate

$$\lambda_{\text{substrate}} = \lambda_0 / \sqrt{\varepsilon_r}$$



Advantages:

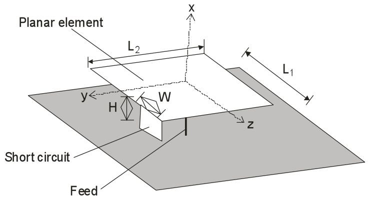
- Small; can be manufactured cheaply
- feedlines can be manufactured on same substrate as antenna
- can be integrated into the MS, without sticking out from the casing

Drawbacks:

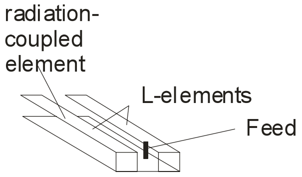
- Low bandwidth
- Low efficiency

PIFA and RCDLA

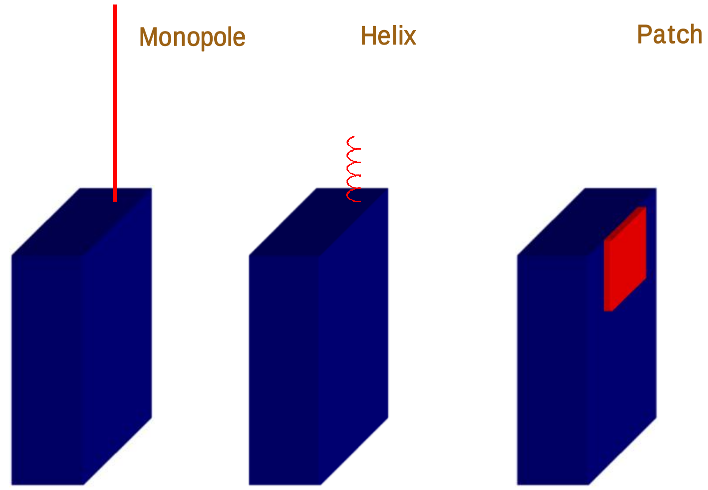
- PIFA (Planar inverted F antenna)



- RCDLA (Radiation-coupled dual-L antenna)



Mobile station antennas



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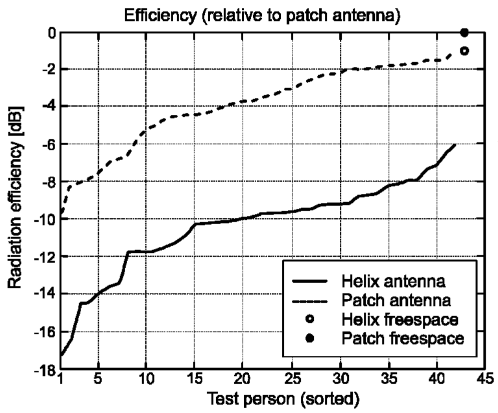
Impact of user on MS antenna

The efficiency depends on many parameters, but a very important one is its environment. Below you can see differences in antenna efficiency for 42 test persons holding the mobile.



Up to around 10 dB difference, depending on person.

What is a "typical" person/grip position? (e.g. Death grip for I-Phone 4)

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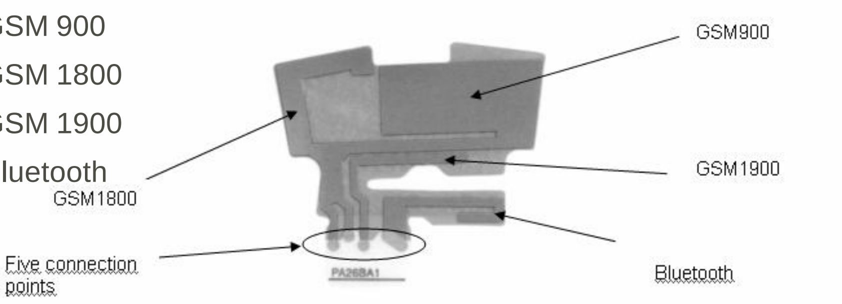
Multiband antennas

For many applications, different wireless services need to be covered

Example: an old cellular handset

- GSM 900
- GSM 1800
- GSM 1900
- Bluetooth



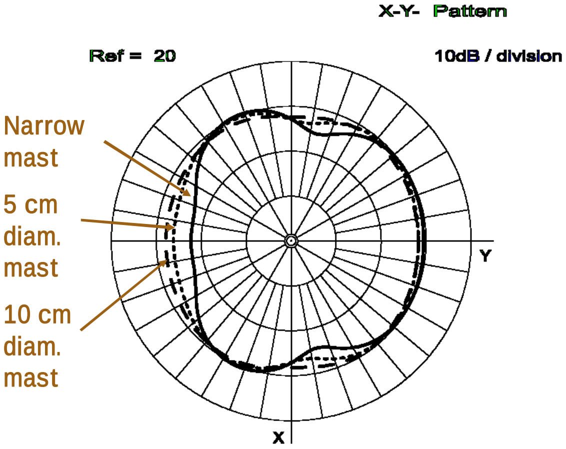
Base station antennas




Courtesey: Andrew Corp.

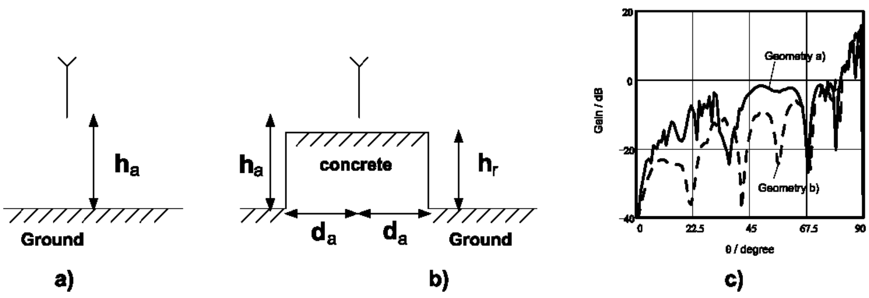
Base station antennas

Base station antenna pattern affected by the mast (30 cm from antenna).



Base station antennas

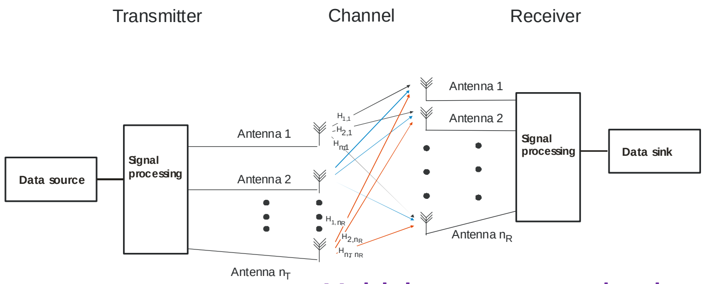
Base station antenna pattern affected by a concrete foundation.



Multiple antenna systems

What are MIMO systems?

A MIMO system consists of several antenna elements, plus adaptive signal processing, at both transmitter and receiver, the combination of which exploits the **spatial dimension** of the mobile radio channel.



Multiple antennas make the transceiver spatially sensitive

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Benefits

- We can gain
  - higher capacity (bits/s/Hz)
    spectrum is expensive; number of base stations limited
  - better transmission quality
  - increased coverage
  - improved user position estimation

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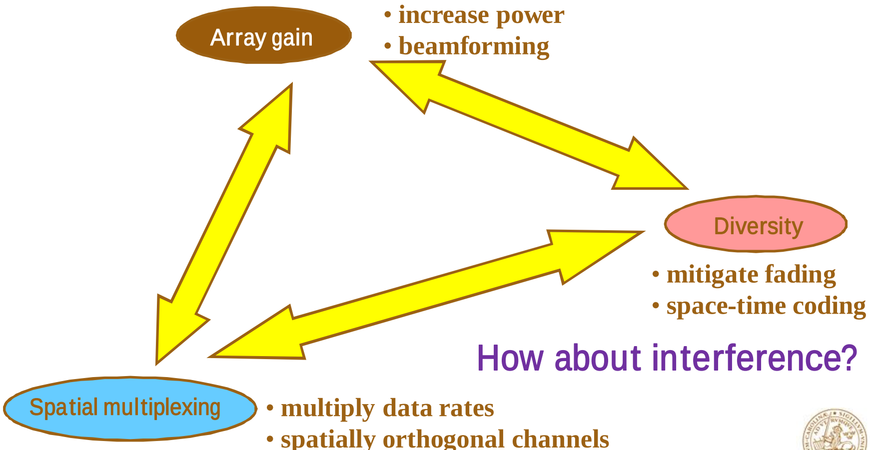
Goals of MIMO



How about interference?

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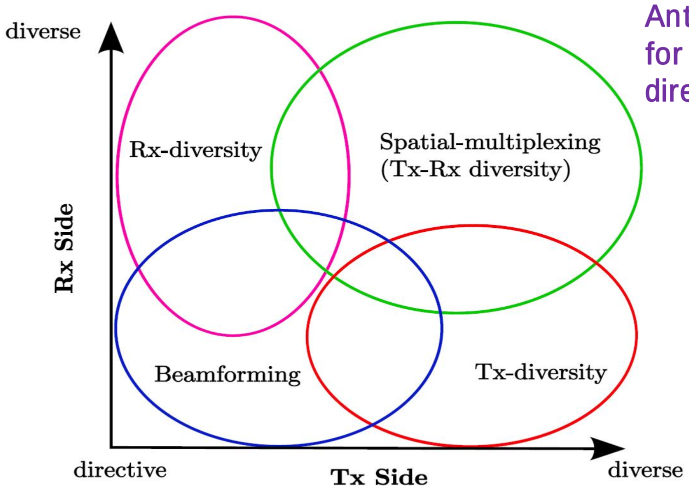
Goals of MIMO



Antenna spacing for diverse vs. directive modes?

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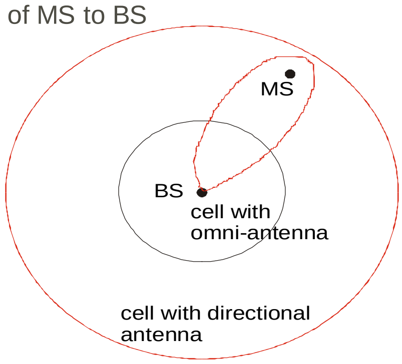
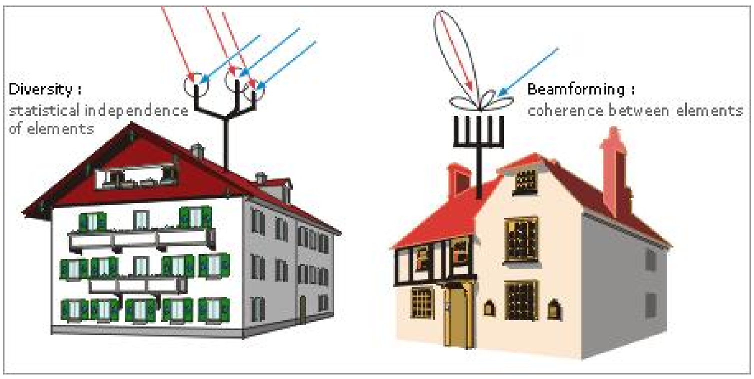
Array gain

- Directional antennas have gain
- Received power: $P_R = G_T G_R P_T (\lambda/4\pi d)^2$
- Mobile station moves: follow user with main beam of BS; point main beam of MS to BS



Diversity vs. beamforming

Diversity: statistical independence of elements
Beamforming: coherence between elements



Spatial multiplexing

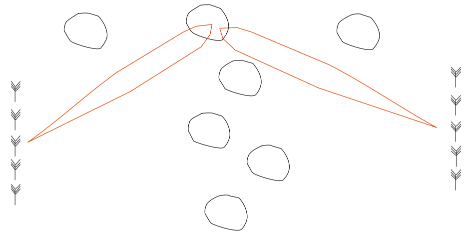
Each MPC can carry independent data stream

Beamforming view:

– TX antenna "targets" energy onto one scatterer

– RX antenna receives only from that direction

Capacity goes linearly with number of antennas



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History

- Diversity:
  - Receive diversity: since 1940s
  - Transmit diversity: early 1990s
    - » Wittneben; Winters
  - Space-time codes in late 1990s
    - » Tarokh et al.; Alamouti
- Spatial multiplexing:
  - Invented by Winters 1987
  - Theoretical treatment in mid-1990s
    - » Paulraj; Foschini&Gans; Telatar; Raleigh and Cioffi

Examples of wireless systems with MIMO technology?

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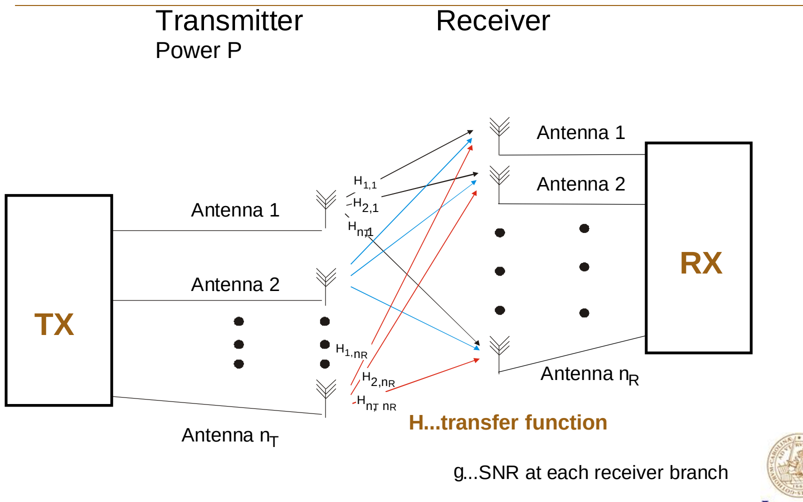
Signal model



Narrow-band vs broad-band models

For a narrow-band channel:

$\mathbf{H}$ is an $n_{\mathrm{Rx}} \times n_{\mathrm{Tx}}$ matrix.

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}, \text{ where}$$

$$\mathbf{y} = [y_1 \; y_2 \; \ldots \; y_{n_{Rx}}]^{\mathrm{T}},$$ ← receive signal vector

$$\mathbf{x} = [x_1 \; x_2 \; \ldots \; x_{n_{Tx}}]^{\mathrm{T}},$$ ← transmit signal vector

$\mathbf{n}$ is a noise vector where :

$$\mathbb{E}\left[\mathbf{n}\mathbf{n}^{\mathrm{H}}\right] = \sigma^2 \mathbb{I}_{n_{Rx} \times n_{Rx}}$$

Ideally, $\mathbf{H}$ is assumed to be i.i.d. ← Often not true!

Wideband channel matrix entries are frequency dependent

Capacity formula

Instantaneous channel characterized by matrix ***H***

- Shannon's formula (for two-dimensional symbols):

$$C = \log_2(1+\gamma|H|^2)\, bits/s/Hz$$

- Foschini's formula:

$$C = \log_2\left(\det\left[\mathbf{I}_{n_R} + \frac{\gamma}{n_T}\mathbf{H}\mathbf{H}^H\right]\right) bits/s/Hz$$

Capacity in realistic channels

Influence of various effects:

- Correlation: LOS component, small angular spread
- Keyholes: uncorrelated components, but low-rank transfer matrix
- Frequency selectivity: gives additional diversity
- Limited number of effective scatterers

Channel knowledge is important for the system

- Channel knowledge at RX
  - unknown
  - known (estimated or perfect)
- Channel knowledge at TX
  - unknown (no channel state information, CSI)
  - average CSI known
  - instantaneous CSI known (estimated or perfect)

Different strategies for different combinations!

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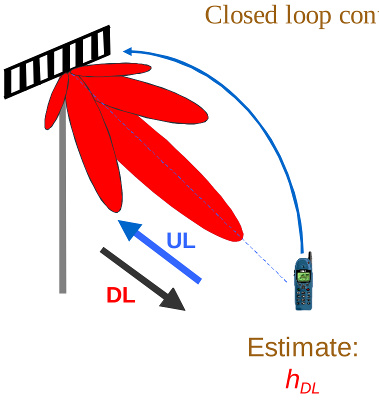
Mobile Feedback based CSI

Closed loop control:

- MS estimates h_{DL}
- Feedback of DL channel parameters



Drawbacks:

- Reduces spectral efficiency
- Feedback errors (noise, quantization)
- Sensitivity to
  - high mobile speed
  - terminal implementation

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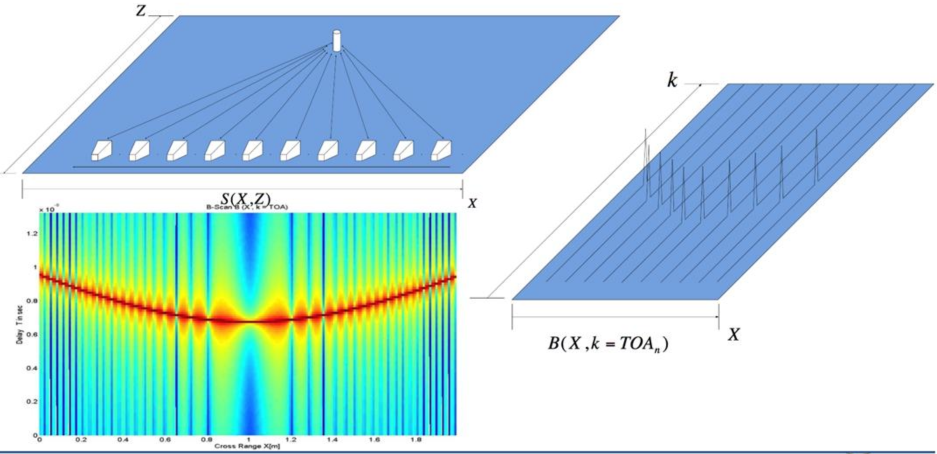
Through-the-wall imaging: Principle



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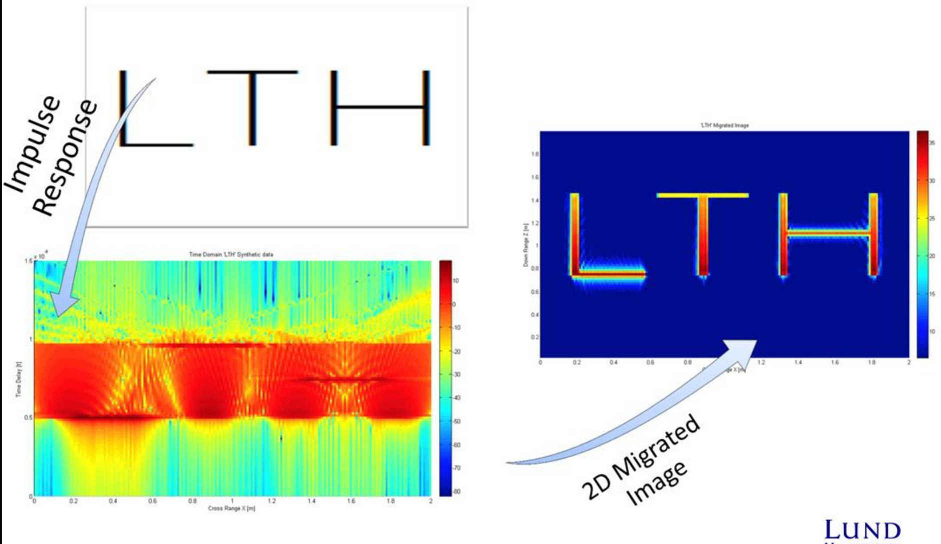
Through-the-wall imaging: synthetic data



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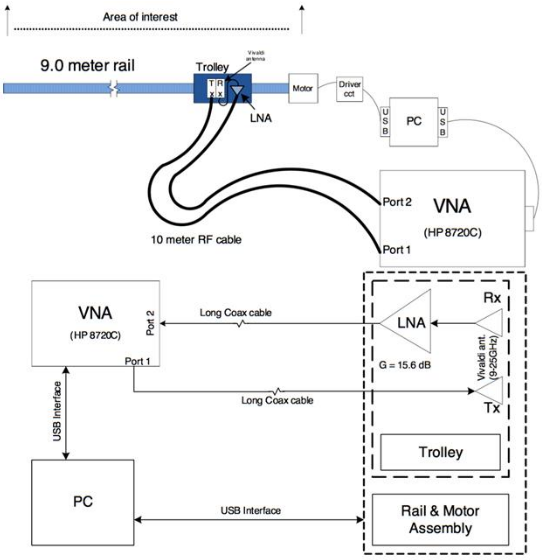
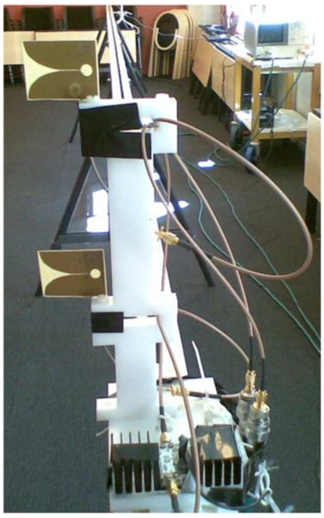
Through-the-wall imaging





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Through-the-wall imaging

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Through-the-wall imaging

Phase-Shift Method | **Diffraction Stack**