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Wireless Communications Channels
Lecture 9: Channel Sounding

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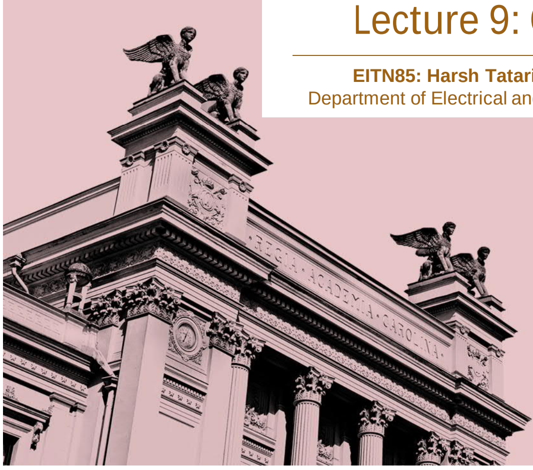

Channel measurements – why?

To model the channel behavior, we need to measure its properties → measuring propagation channel properties is known as channel sounding!

Question: What properties?

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Channel measurements – how?

- ❑ Time domain measurements:
  - ❑ Impulse sounder
  - ❑ Correlative sounder
- ❑ Frequency domain measurements:
  - ❑ Vector network analyzer
- ❑ Directional measurements:
  - ❑ Directional antennas
  - ❑ Real antenna arrays
  - ❑ Multiplexed arrays
  - ❑ Virtual arrays

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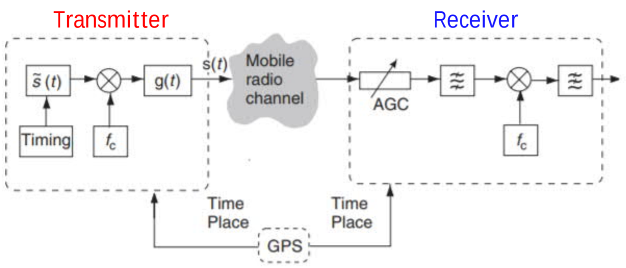
Generic sounder structure – I

Principle: The TX sends out a signal that excits – “sounds” the channel. Output of channel “listened” by the RX and “stored”. From knowledge of TX and RX signal, the time variant impulse can be extracted.



Conceptually most simple!

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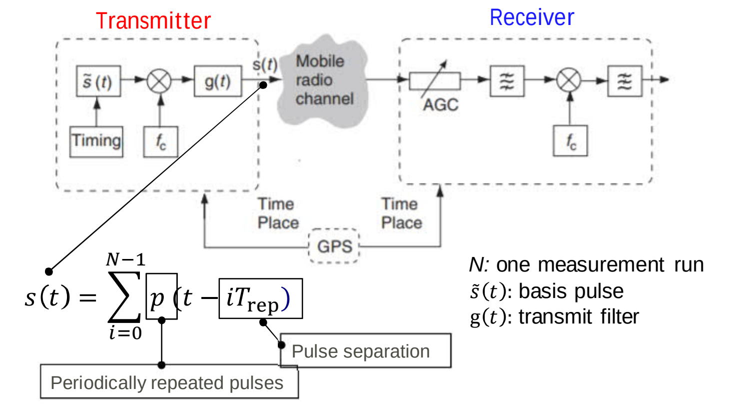
Generic sounder structure - II



Type of sounder depends on the sounding waveform!

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Properties of an ideal sounding signal

❑ Large bandwidth: inversely proportional to the shortest temporal changes in the signal, which determines delay resolution.

❑ Large time-bandwidth product: Sounding signal should have a duration longer than inverse of bandwidth. They also need to have good autocorrelation properties.

❑ Signal duration: The sounding signal should also not be too long, in particular exceeding the channel coherence time. Pulse repetition time longer than a single pulse duration and maximum access delay of channel.

❑ Power spectral density: Sounding signal power spectral density should be uniform across bandwidth of interest. This yields same quality of channel estimates across the range of bands interested.

❑ Peak-to-average power: Relatively high for high amplifier efficiency.

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Channel measurements: A warning

Impulse response measurements carry undesired components:

1. **Interference** from other (independent) signal sources that also somehow interact and use the channel. Created especially when measurements are to be done in environments with other exisiting wireless services.
2. Additive white Gaussian **noise**.

So, what is the implication of this?

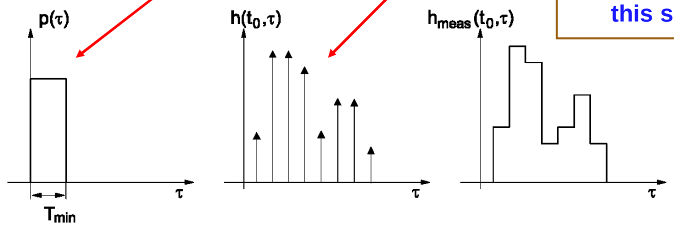
Time domain measurements: Impulse Sounder

$$h_{\text{meas}}(t_i,\tau) = \tilde{p}(\tau) * h(t_i,\tau)$$

impulse response of sounder

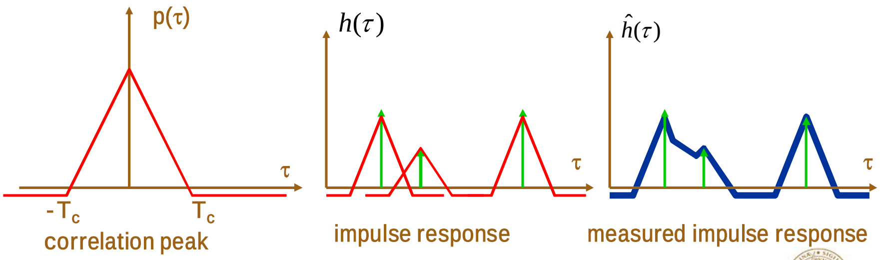
impulse response of channel

What is a limitation of this sounder?



Correlative sounder

- Transmit a pseudo-noise sequence and correlate with the same sequence at the receiver:
  - Compare conventional CDMA systems
  - Correlation peak for each delayed multipath component



Frequency domain measurements

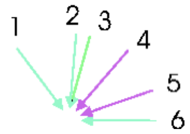
Use a vector network analyzer or similar to determine the transfer function of the channel

$$H_{meas}(f) = H_{TXantenna}(f) * \boxed{H_{channel}(f)} * H_{RXantenna}(f)$$

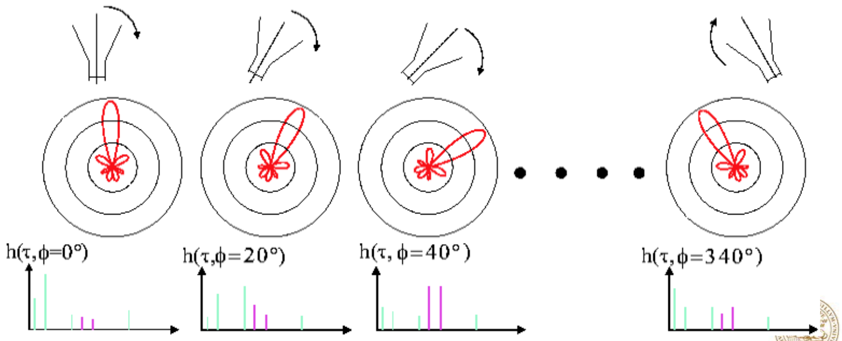
- Time domain properties via FFT
- Using a large frequency band it is possible to get good time resolution
- As for time domain measurements, we need to know the influence of the measurement system

Directional channel measurements

Measure one impulse response for each antenna orientation



What is the drawback of this approach?



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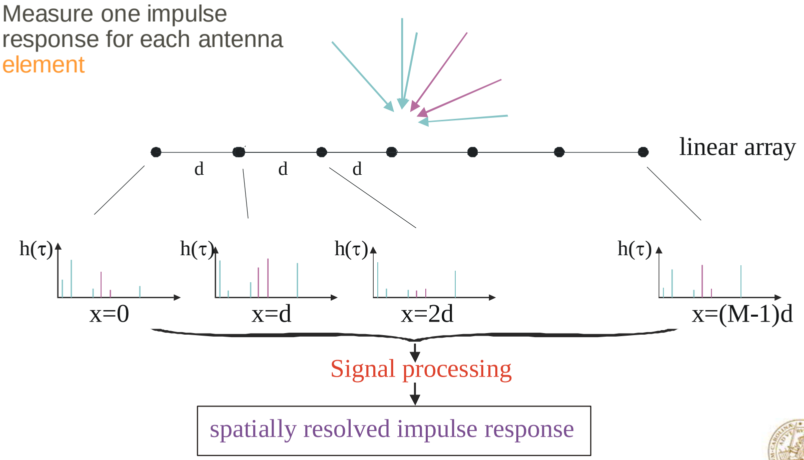
Channel sounding: Multielement array

- Measure one impulse response for each antenna element



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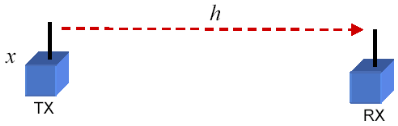
Channel sounding with multiple antennas

- In practice we measure the transfer functions between each of the antenna elements, and we calculate the parameters of interest



No diversity (SISO):

$$y = hx + n$$

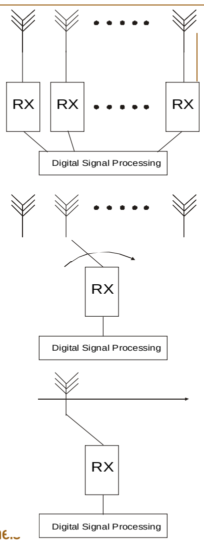
TX&RX diversity (MIMO):

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} & h_{2,1} \\ h_{1,2} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

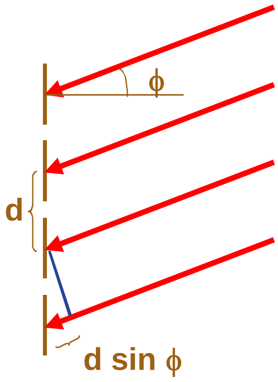
Real, multiplexed, and virtual arrays

- Real array: simultaneous measurement at all antenna elements
- Multiplexed array: short time intervals between measurements at different elements
- Virtual array: long delay

  no problem with mutual coupling



Directional analysis: DOA estimation



The DoA can, e.g., be estimated by correlating the received signals with steering vectors.

$$\vec{a}(\phi) = \begin{pmatrix} 1 \\ \exp(-jk_0 d\cos(\phi)) \\ \exp(-j2k_0 d\cos(\phi)) \\ \vdots \\ \exp(-j(M-1)k_0 d\cos(\phi)) \end{pmatrix}$$

An element spacing of d=5.8 cm and an angle of arrival of ϕ =20 degrees gives a time delay of $6.6 \cdot 10^{-11}$ s between neighboring elements

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High resolution algorithms

- In order to get better angular resolution, other techniques for estimating the angles are used, e.g.:
  – MUSIC, subspace method using spectral search
  – ESPRIT, subspace method
  – MVM (Capon’s beamformer), rather easy spectral search method
  – SAGE, iterative maximum likelihood method
- Based on models for the propagation
- Rather complex, one measurement point may take 15 minutes on a decent computer

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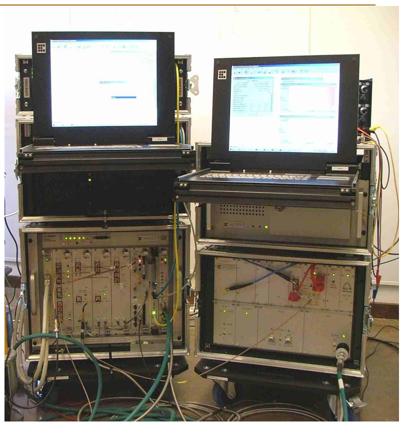
RUSK LUND broadband channel sounder

- A fast switched measurement system for radio propagation investigations at 300 MHz, 2 GHz and 5 GHz.
- Financed by Knut and Alice Wallenbergs stiftelse, FOI and LTH
- MIMO capacity limited by the switches, currently 32 elements at each side.

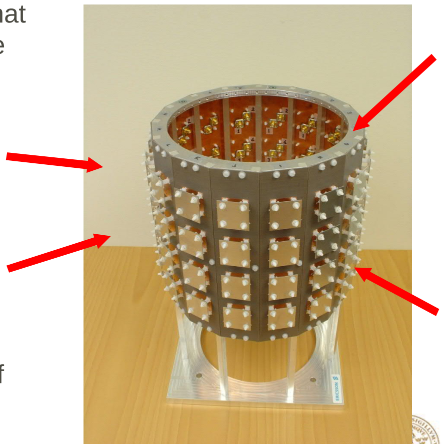


It's all about measuring some delays...

In MIMO systems we use the fact that there are several paths between the transmitter and receiver

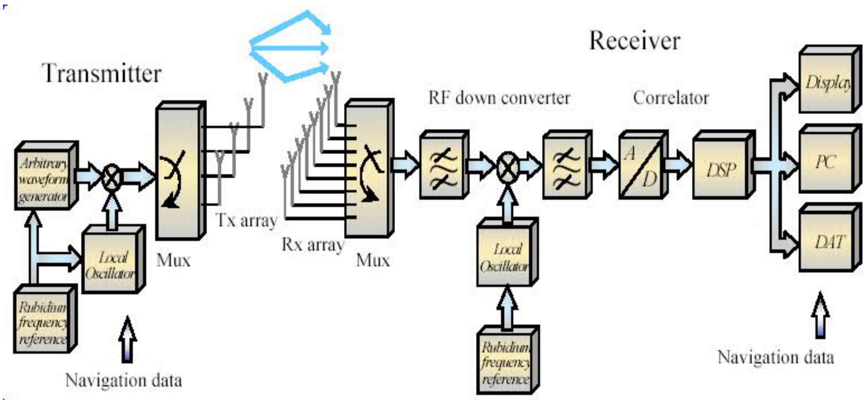
These paths are characterized by a

- time delay,
- phase shift,
- attenuation,
- angle of departure and
- angle of arrival



The angle of departure and angle of arrival result in a slight difference in time delay for each of the antenna elements

Lund University MIMO Sounder



Courtesy
MEDAV

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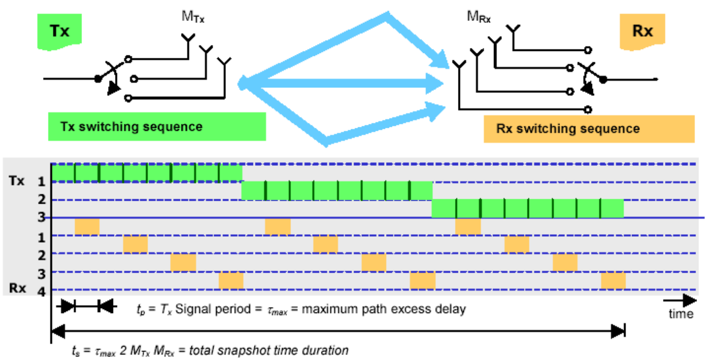
TX-RX timing diagram



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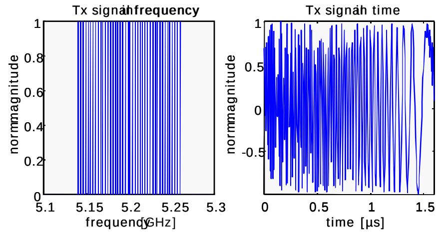
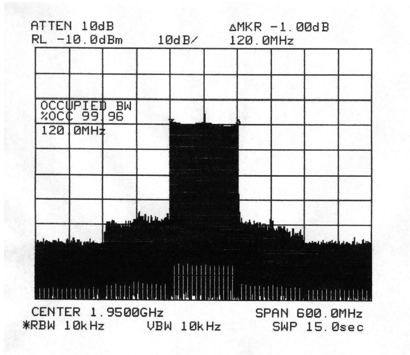
Test signal – Multicarrier spread spectrum



MLS - Test Squence

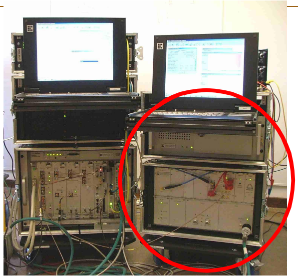
- **periodic broadband Signal**
- **high Correlation Gain**
- **low Crest Factor**
- **inherently band limited**
- **flexible in generation**
- **multiband possibility (Up- /Downlink)**



The measurement system

- 200 kg of batteries to allow for 6 hours of mobile measurements
- 640 MHz sampling frequency, to allow high Doppler frequencies
- 2 separate PCs to manage the data flow from the A/D converters
- Oven controlled rubidium clocks to maintain synchronization during wireless measurements
- GPS and wheel sensors to position the system
- Broadband patch antennas with 128 antenna ports at 2.6 GHz
- Circular 300 MHz antennas with a diameter of 1.5 m

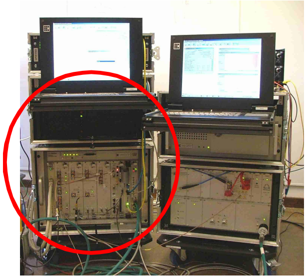
RUSK LUND transmitter



- bandwidths: up to 240 MHz
- frequency grid 10 MHz
- max. power 500 mW, with possibility for 10 W external amplifier
- carrier frequency ranges
  - 2200 – 2700 MHz,
  - 5150 – 5750 MHz
  - 235-387 MHz (20W)
- Power Supply 24 V DC and 230 V AC

- Baseband (Arbitrary Wave Form) Signal Generator
- Frequency Synthesizer
- Rubidium Reference
- Modulator
- Power Amplifier
- MIMO Control Unit
- GPS

RUSK LUND receiver



- GPS Receiver
- Odometer Interface
- total amplification 72 dB
- AGC dynamic range 51 dB , adjustable in 3 dB steps,
- intermediate frequency 160 MHz
- bandwidth 240 MHz
- Spurious free dynamic range 50 dB

- RF-Tuner
- High Speed ADC
- Automatic Gain Control (AGC)
- MIMO Control Unit
- Rubidium Reference
- High Speed Data Recorder 320 MByte/s, 500 GByte

How important are antennas?

To get good resolution we want large size arrays

4x16 dual polarized circular patch array

4x8 dual polarized rectangular array

RUSK LUND, Key Parameters

- RF carrier frequency range
  - 235-387 MHz
  - 2200 – 2700 MHz,
  - 5150 – 5750 MHz
- RF carrier frequency grid:
  - 1 MHz (300 MHz)
  - 10 MHz (2 and 5 GHz)
- Measurement bandwidth up to 240 MHz (null-to-null bandwidth)
- MIMO capability:
  - 16 TX antennas and 8 RX antennas (300 MHz)
  - 32 TX antennas and 32 RX antennas simultaneously (2 and 5 GHZ)
- Power: TX
  - 20 W (300 MHz)
  - 500 mW and 10 W high power extension (2 and 5 GHz)
- Antennas:
  - 7+1 circular monopole antenna array (300 MHz),
  - 4x8 element planar array, dual polarized (2 GHz)
  - 4x16 element circular array, dual polarized (2 GHz)
  - various application specific antennas

Some real world examples

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