Wireless Communications Channels
Lecture 8: Channel Sounding

EITN85: Meifang Zhu(e-mail: meifang.zhu@eit.lth.se)
Department of Electrical and Information Technology, Lund University

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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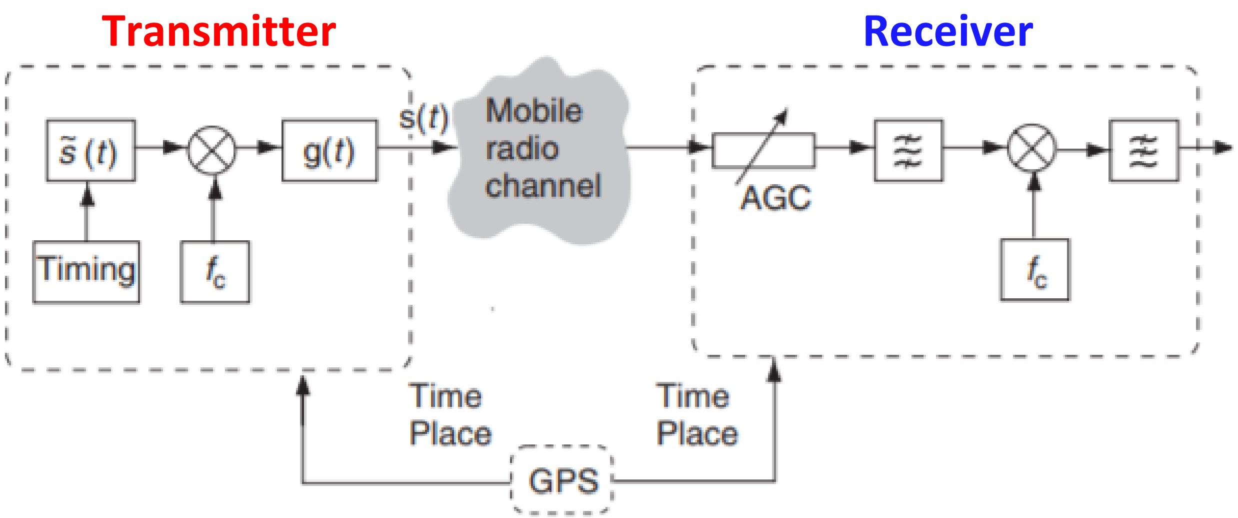
Channel measurements – how?

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

Multiple antenna sounding techniques

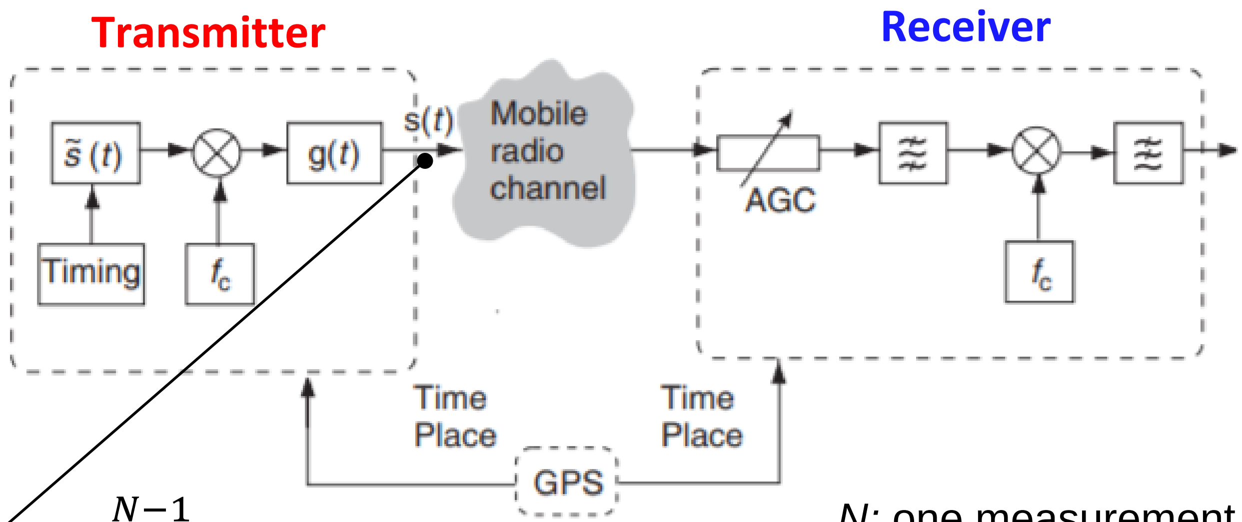
Generic sounder structure – I

<u>Principle</u>: 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!

Generic sounder structure - II



$$s(t) = \sum_{i=0}^{N-1} p\,(t - iT_{\mathrm{rep}})$$

Periodically repeated pulses

Pulse separation

N: one measurement run

$\tilde{s}(t)$: basis pulse

$g(t)$: transmit filter

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.

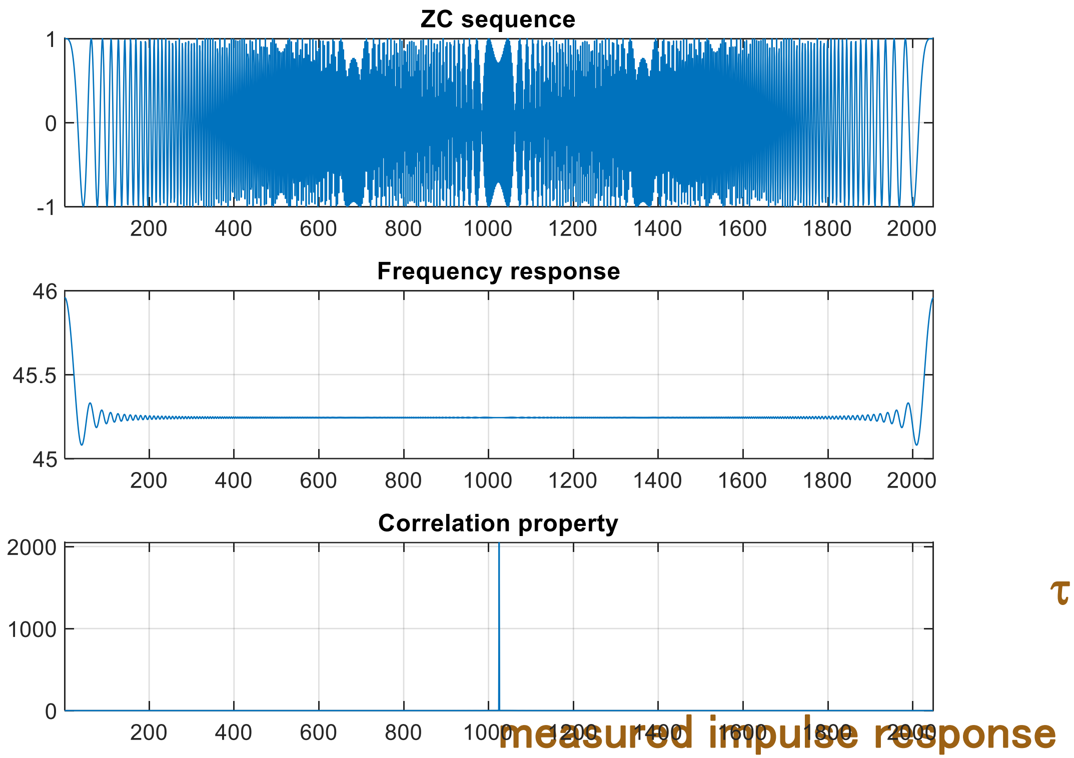
- **Signal duration:** The sounding signal should also not be too long, in particular exceeding the channel coherence time. Pulse repetition time longer than a single pulse duration and maximum access delay of channel.

- **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.

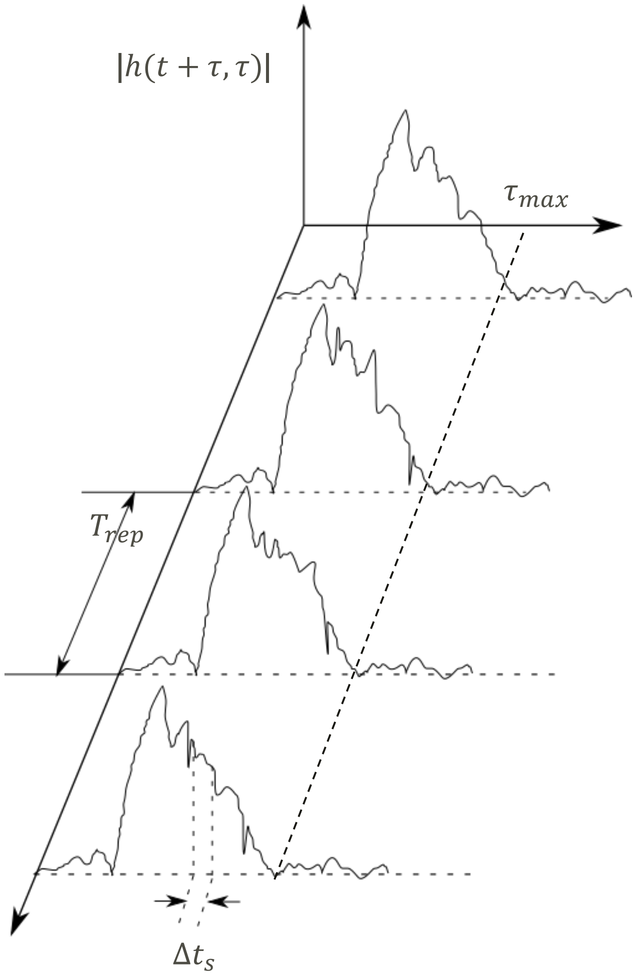
- **Peak-to-average power:** Relatively high for high amplifier efficiency.

Example of a sounding sequence

- Power spectral density should be flat over the entire band
- Good correlation properties



Identifiability of wireless channels



- time variant channel

- T_{rep} Smaller than the time over the channel changes, so for a time of channel, can measure multiple times

- T_{rep} should be larger than τ_{max}

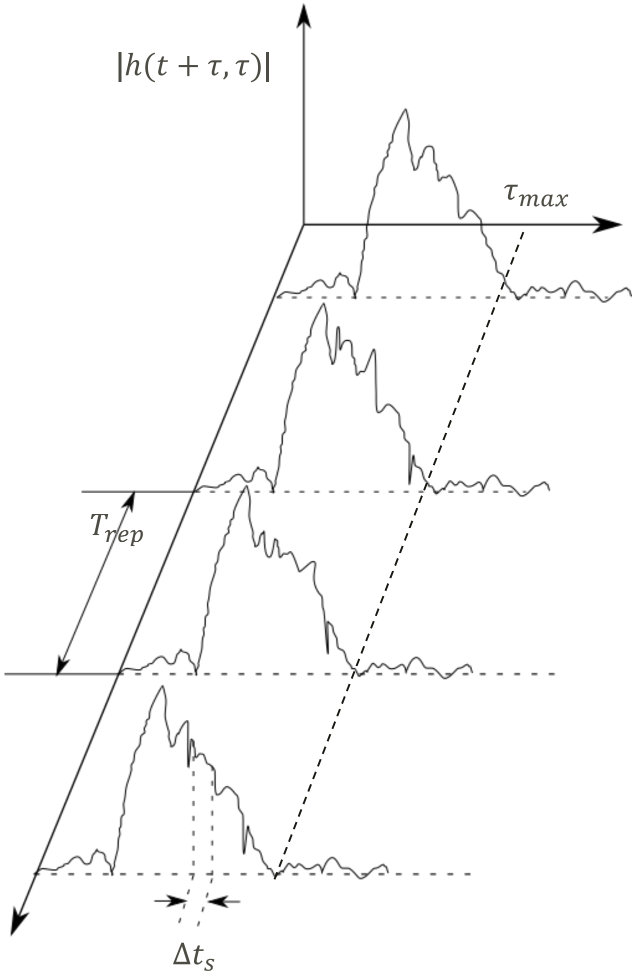
- Similar to the Nyquist sampling theorem,

$$f_{rep} \geq 2v_{max}$$

- $T_{rep} \leq \frac{c}{2fV_{max}}$

- The time the channel varies should smaller than the T_{rep}

Identifiability of wireless channels



- time variant channel

- $\frac{V}{\Delta x} \gg T_{rep} \geq \frac{2fV_{max}}{c} = \frac{2V_{max}}{\lambda}$

$\Delta x \leq \frac{V}{V_{max}}\frac{\lambda}{2} \leq \frac{\lambda}{2}$,

At least 2 measurements for a wavelength

- Channel is defined as underspread

  $1/T_{rep} \geq 2v_{max}$ ⇒ $T_{rep} \leq 1/2v_{max}$

  ⇒ $\tau_{max} \leq T_{rep} \leq 1/2v_{max}$

  ⇒ $2\tau_{max}v_{max} \leq 1$

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?

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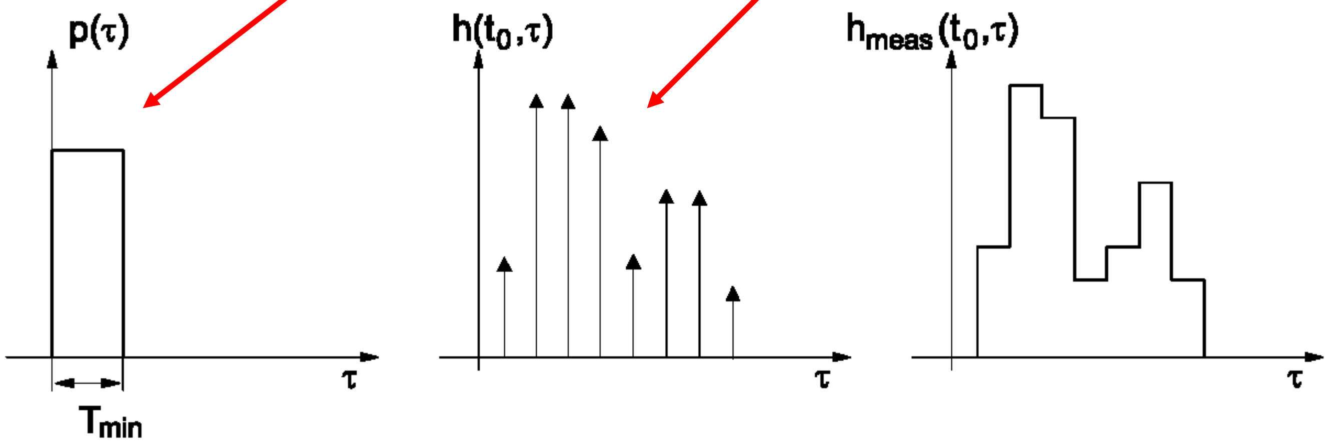
Time domain measurements: Impulse Sounder

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

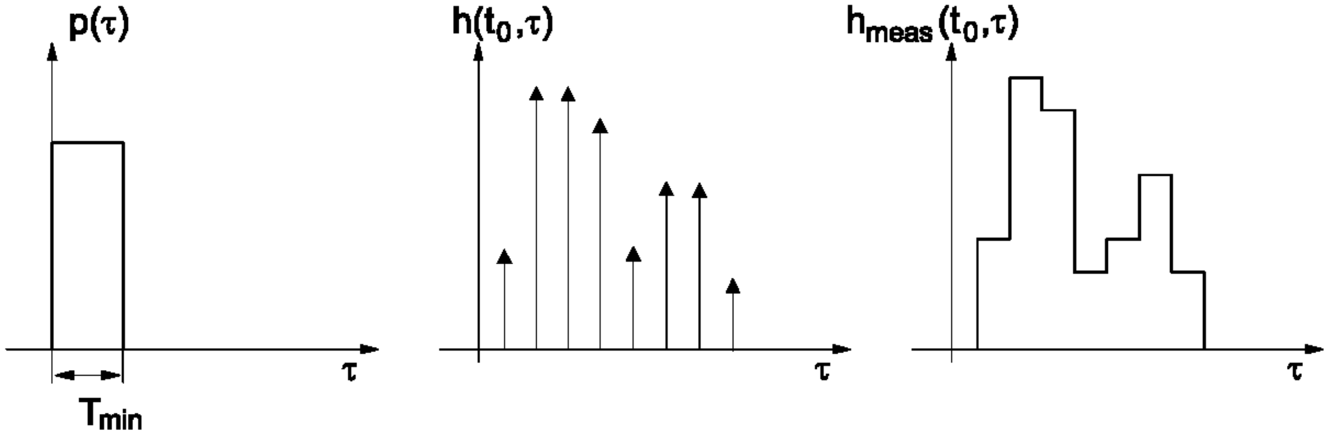
impulse response of sounder

impulse response of channel



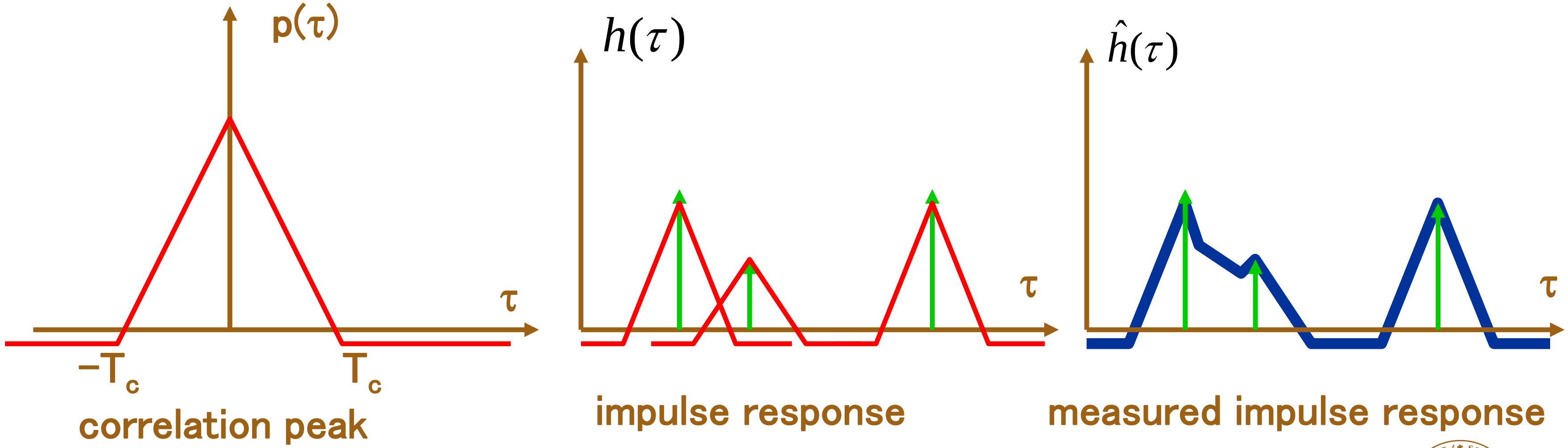
Time domain measurements: Impulse Sounder

- Sounding signal duration is short and high power
- Amplifier design is expensive to cover such power dynamics
- Low resistance to interference



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



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Frequency domain measurements

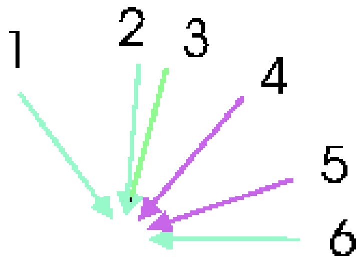
Use a vector network analyzer or similar to determine the transfer function of the channel

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

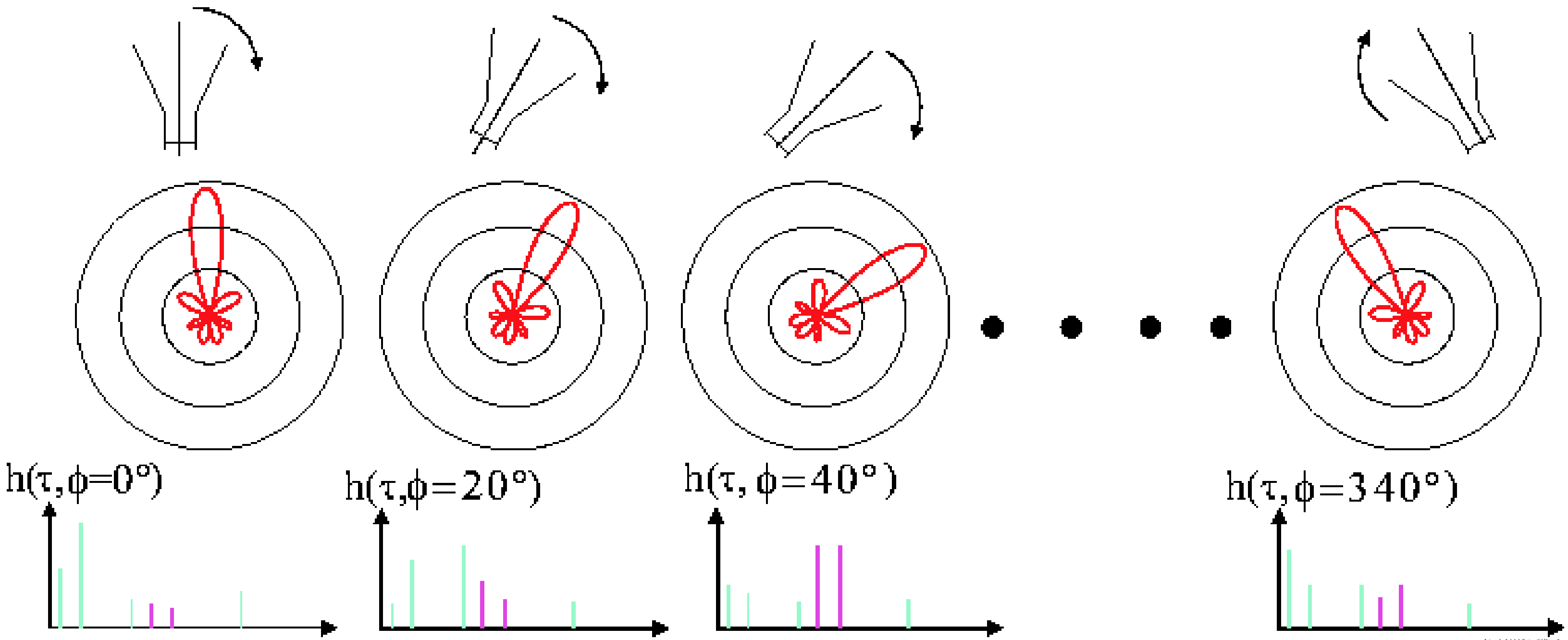
- Time domain properties via FFT
- Using a large frequency band it is possible to get good time resolution
- As for time domain measurements, we need to know the influence of the measurement system

Directional channel measurements

Measure one impulse response for each antenna orientation



What is the drawback of this approach?



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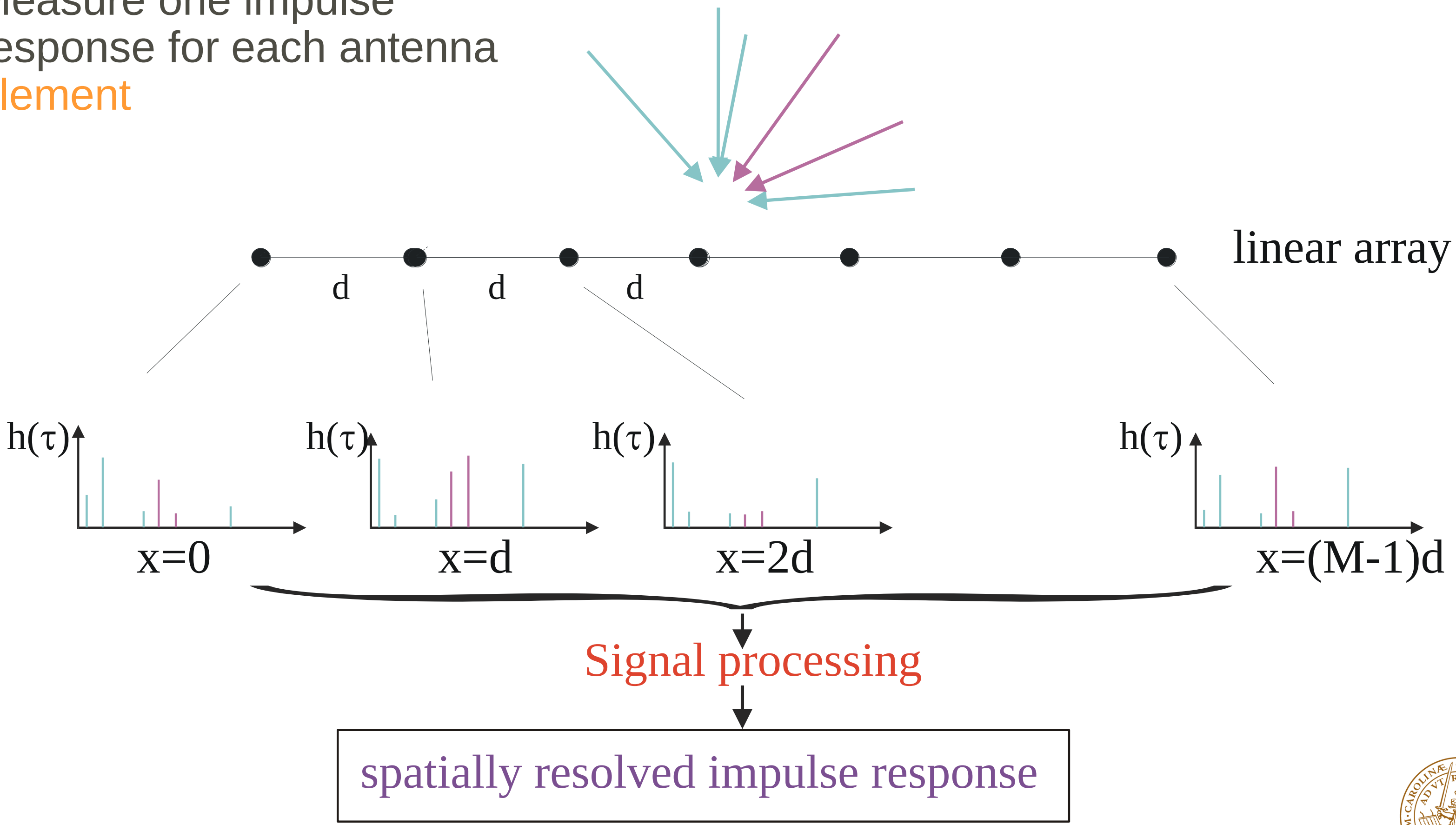
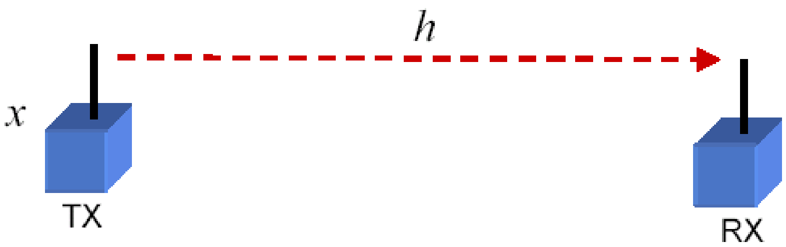
Channel sounding: Multielement array

- Measure one impulse response for each antenna element



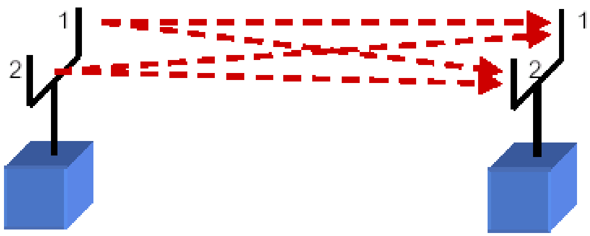
Channel sounding with multiple antennas

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



No diversity (SISO):

$$y = hx + n$$

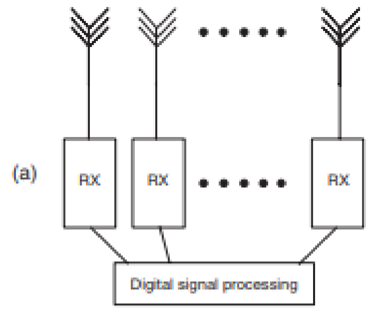


TX&RX diversity (MIMO):

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

Real, multiplexed, and virtual arrays

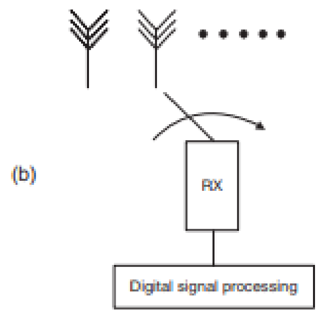
- Real array: simultaneous measurement at all antenna elements **(a)**



- Drawbacks:
  - Complexity
  - Integration chanllenge
  - Expensive
- Advantages:
  - Measurement done at the same time by once

Real, **multiplexed**, and virtual arrays

- Multiplexed (Switched) array: short(er) time intervals between measurements at different elements **(b)**
- Drawbacks:
  - Switching time is critical
  - Switch introduce insertion loss
- Advantages:
  - Relatively less cost
  - Easier to integrate from baseband



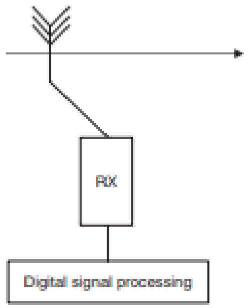
Real, multiplexed, and **virtual** arrays

- Virtual array: long delay

  no problem with mutual coupling **(c)**

- Drawbacks:
  - Cannot work in a dynamic environmnet
  - Time to measure is large
  - Loss some spatial properties
- Advantages:
  - Relatively less cost
  - Digital array
  - Easier to integrate from baseband

(c)



General Tradeoffs for all designs: Expense, angular resolution, phase noise, calibration and static environment or not!

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