Chapter 8

Channel sounding

Channel measurements

In order to model the channel behavior we need to measure its properties

- Time domain measurements
  - impulse sounder
  - correlative sounder
- Frequency domain measurements
  - Vector network analyzer

- Directional measurements
  - directional antennas
  - real antenna arrays
  - multiplexed arrays
  - virtual arrays

Basic identifiability of the channel

- The channel can be measured uniquely only if
  - sampling theorem

$$f_{\mathrm{rep}} \geq 2\nu_{\max}$$

$$\frac{1}{f_{\mathrm{rep}}} \geq \tau_{\max}$$

- Therefore, a channel can only be measured uniquely if it is *underspread*

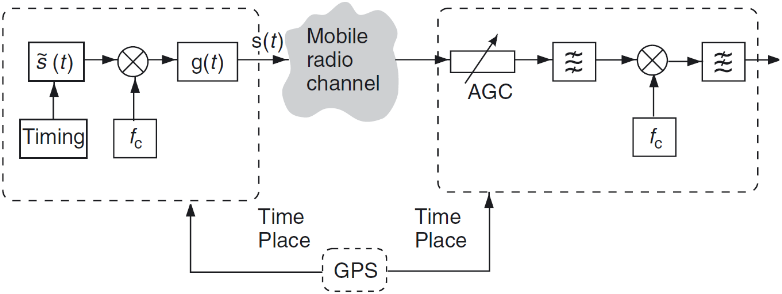
$$2\tau_{\max}\nu_{\max} \leq 1$$

- This condition is fulfilled in all practical wireless applications

Identifiability: Example

A channel sounder is in a car that moves with a speed of 36km/h. The channel sounder operates at a carrier frequency of 2GHz. At what intervals should the channel be measured? What is the maximum excess delay the channel can have to remain underspread?

Generic Sounder Stucture



Sounding signal:

$$s(t) = \sum_{i=0}^{N-1} p_{TX}(t - iT_{rep})$$

Generic Receiver Structure

Received signal:

$$r(t) = s(t) * h(t,\tau) * p_{\mathrm{RX}}(\tau) + n(t) = \sum_{i=0}^{N-1} \underbrace{p(\tau) * h(t_i,\tau)}_{h_{\mathrm{meas}}(t_i,\tau)} + n(t)$$

where

- $t_i = t - iT_{\mathrm{rep}}$,
- $h(t_i,\tau)$ constant during T_{rep}, and
- $p(\tau) = p_{\mathrm{TX}}(\tau) * p_{\mathrm{RX}}(\tau)$

Channel sounder parameters

- *Bandwidth:* determines delay resolution
- *Signal Duration:* T_{rep} should be larger than excess delay plus length of filter $p_{\text{TX}}(t)$, but smaller than coherence bandwidth
- *Time-Bandwidth product:* should be maximized to to increase SNR at RX
- *Power spectral density* of the $p_{\text{TX}}(t)$ should be uniform
- *Crest factor*
- *Correlation properties*

Synchronization

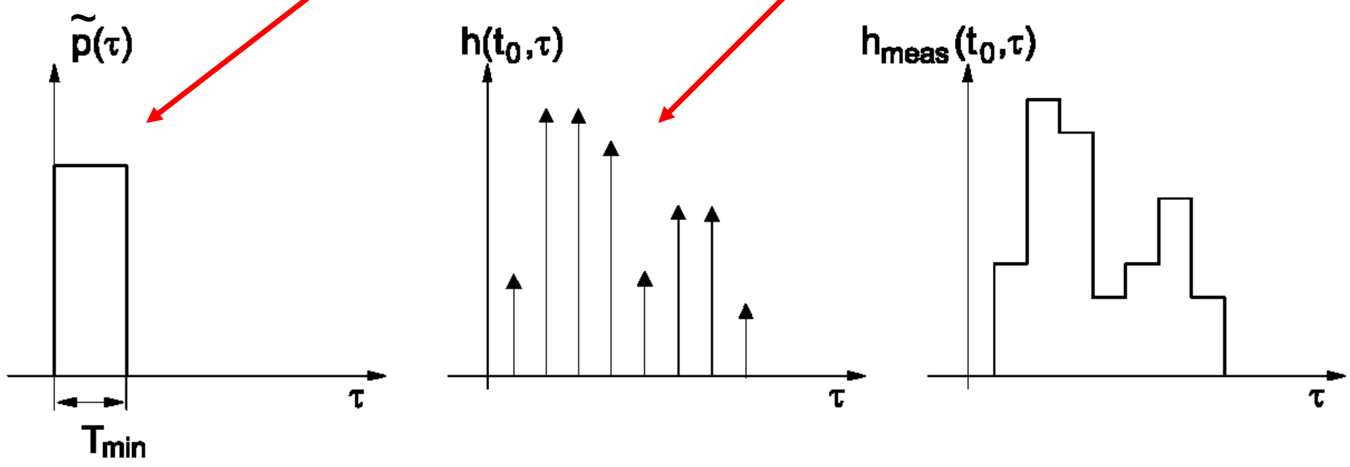
- TX and RX need to be synchronized in time, frequency, and phase!
- Cables: only for short distances
- *GPS:* only outdoor
- *Rubidium clocks:* expensive, need calibration
- *Over-the-air synchronization:* least accurate

Impulse sounder

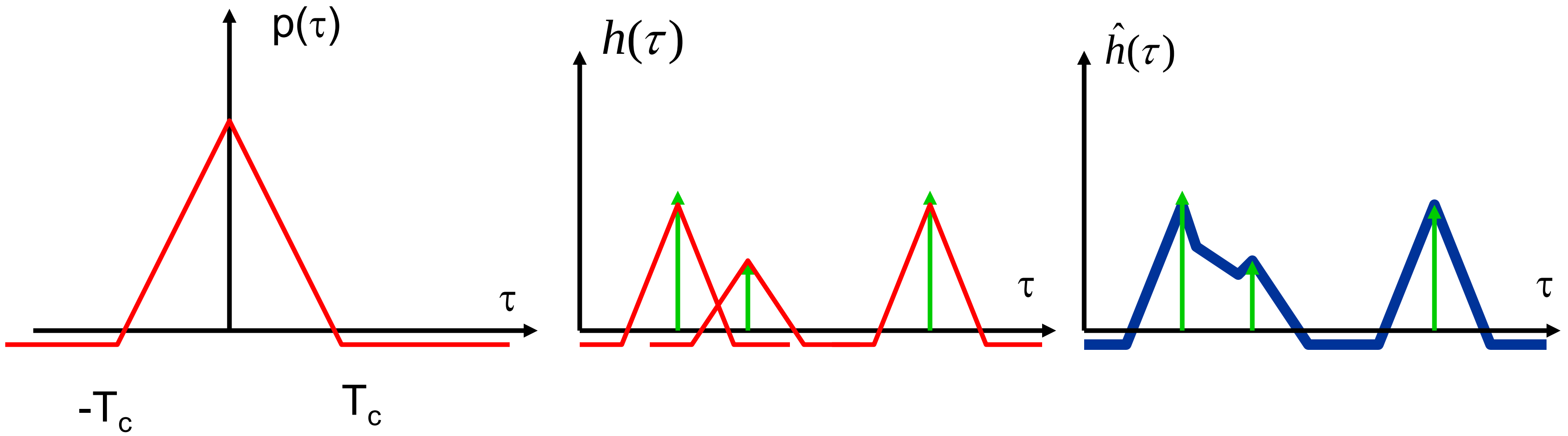
$$h_{\text{meas}}(t_i,\tau) = \widetilde{p}(\tau) * \boxed{h(t_i,\tau)}$$

impulse response of sounder

impulse response of channel



Correlative sounder



correlation peak

impulse response

measured impulse response

Frequency domain measurements

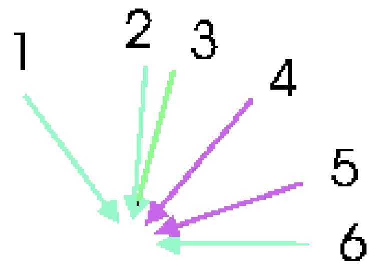
- Use a vector network analyzer or similar to determine the transfer function of the channel

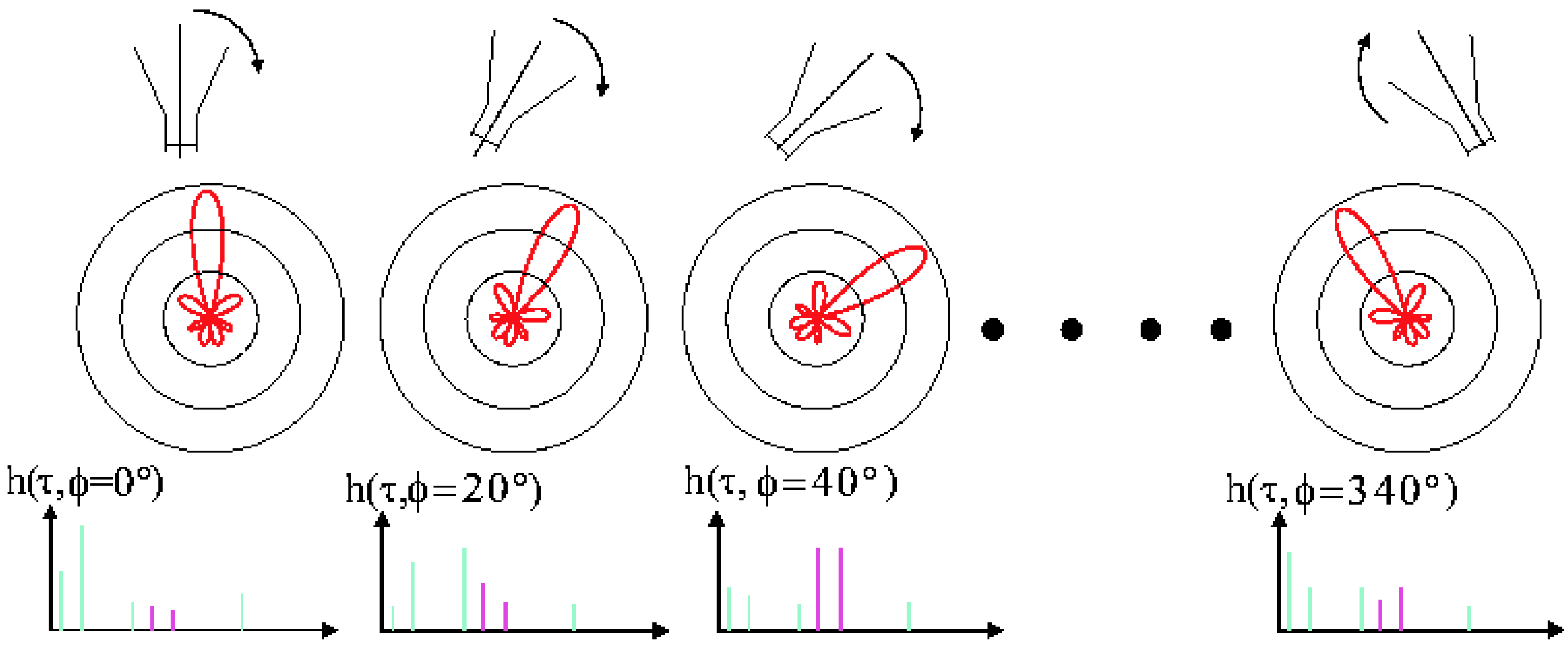
$$H_{meas}(f) = H_{TXantenna}(f) * \boxed{H_{channel}(f)} * H_{RXantenna}(f)$$

- Need to know the influence of the measurement system

Channel sounding – directional antenna

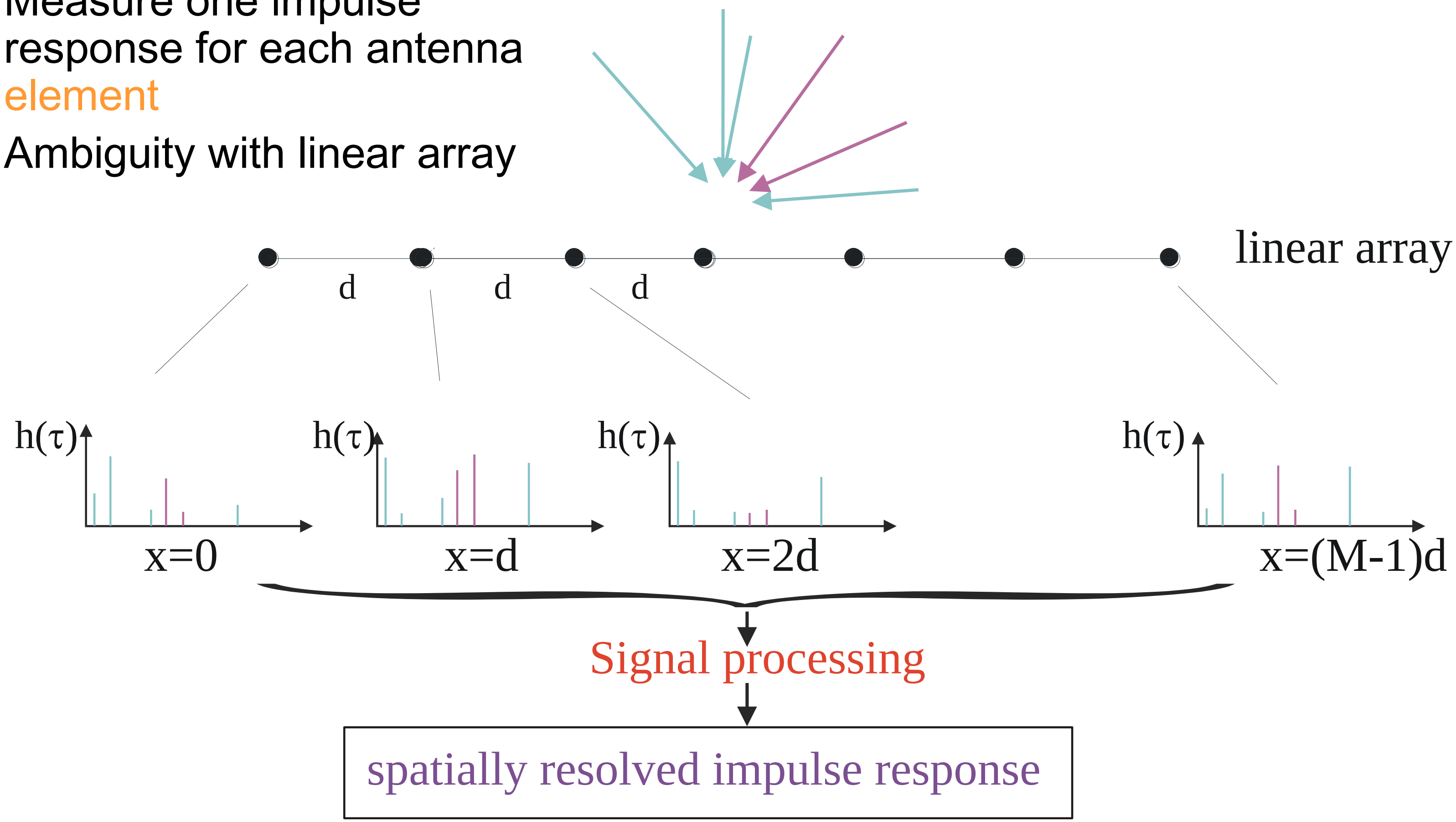
- Measure one impulse response for each antenna orientation





Channel sounding – antenna array

- Measure one impulse response for each antenna element
- Ambiguity with linear array

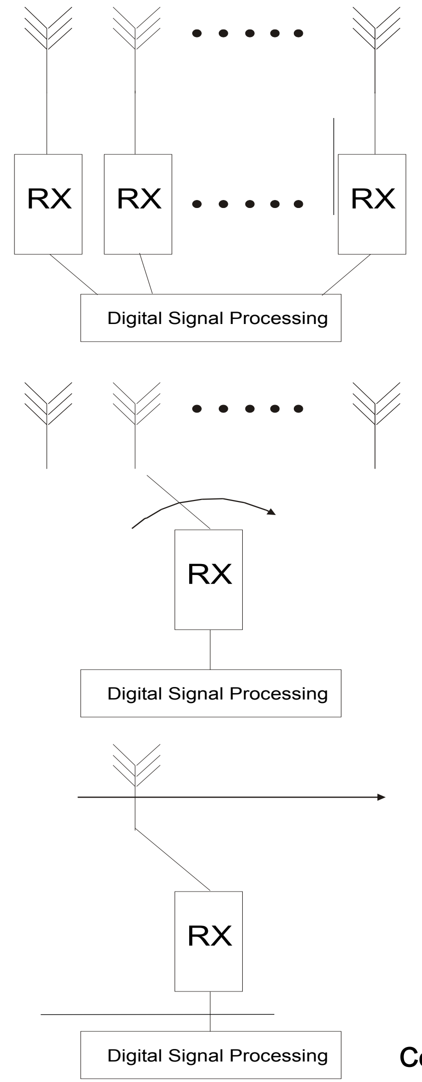


Real, multiplexed, and virtual arrays

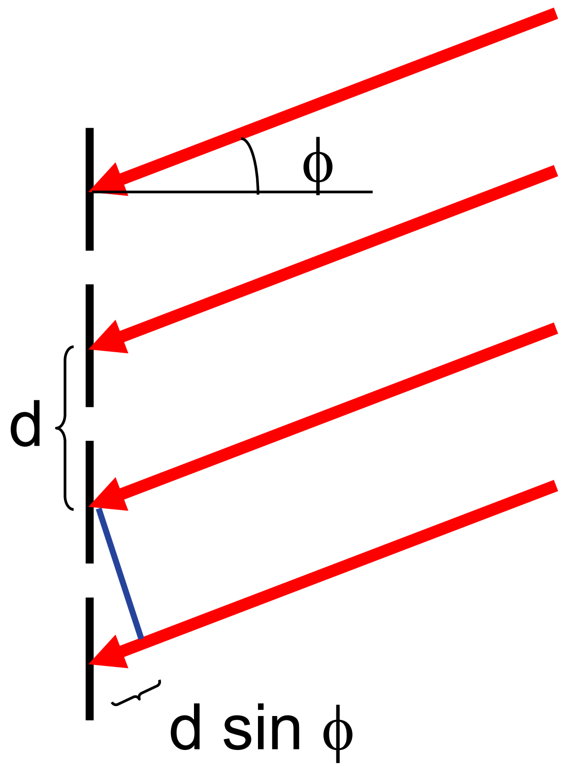
- Real array: simultaneous measurement at all antenna elements

- Multiplexed array: short time intervals between measurements at different elements

- Virtual array: long delay
  no problem with mutual coupling



Directional analysis



- 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

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

Antenna array TX

- Transmission must be done so that RX can distinguish signals from different TX receivers

  →Transmit signals should be orthogonal

- Orthogonality in time
- Orthogonality in frequency
- Orthogonality in code