# Channel sounding

Stochastic Channel Models - parameter values have to be obtained from measurements

Deterministic Channel Models - quality of the prediction has to be checked by comparisons with measured data

# Channel measurements

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

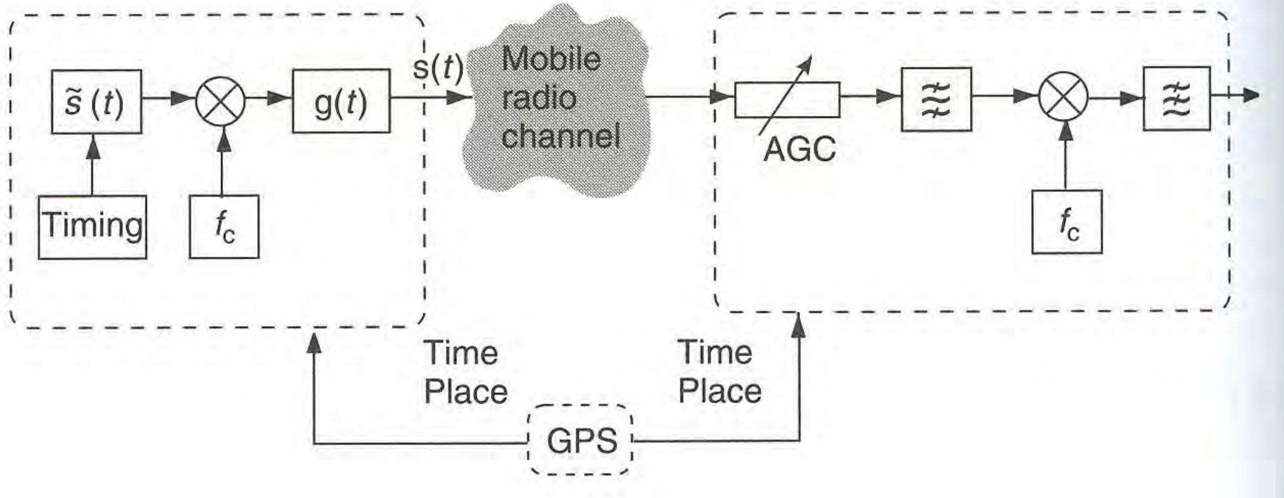
for wideband systems we'll measure the delay dispersion (impluse response) versus just measuring the signal strength as was done for narrowband 2G systems

- Time domain measurements
  - impulse sounder
  - correlative sounder
- Frequency domain measurements
  - Vector network analyzer (VNA)

- Directional measurements
  - directional antennas
  - real antenna arrays
  - multiplexed arrays requires double-directional impulse responses
  - virtual arrays

# Channel Sounder Block Diagram

s(t) – periodic pulses




- Transmitter and receiver are closely synchronized (cable or GPS)
- Duration of the sounding signal not longer than channel coherence time (constant channel)
- Time bandwidth of the sounding signal is longer than the inverse of the system bandwidth
- Constant power-spectral density – uniform across the signal bandwidth with no side lobes
- Low crest factor where $C_{crest}$ = Peak Amplitude / RMS Amplitude which makes efficient use of transmitter power/dynamic range

# Basic identifiability of the channel

- The channel can be measured uniquely only if the following two opposing conditions are satisfied

a time-variant channel where the Mobile Station (MS) can be moving

This is a sampling theorem in the time domain - a sampling rate to identify a time-variant process with a band-limited Doppler spectrum

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

the sampling frequency must be twice the maximum Doppler shift frequency $\upsilon_{max}$ = MS velocity / carrier wavelength

$$T_{rep} = \frac{1}{f_{rep}} \geq \tau_{max}$$

the pulse time (width) must be more than the max excess delay of the channel or the pulses overlap (time for the delays to die out) which means the pulse time is less than the channel's coherence time (channel constant period/time invariant).

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

a compromise of sorts since the two limitations above are counter to each other
1st condition specifies how fast and the 2nd condition how slow

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

See Example 8.1 Page 149 where Trep = 7.5 mS which is a much larger period than the normal wireless channel delays which are in the nanoSecond (nS) range

- This condition is fulfilled in all practical wireless applications

fulfills Nyquist Criterion and implies a slowly time variant channel which has a long coherence time

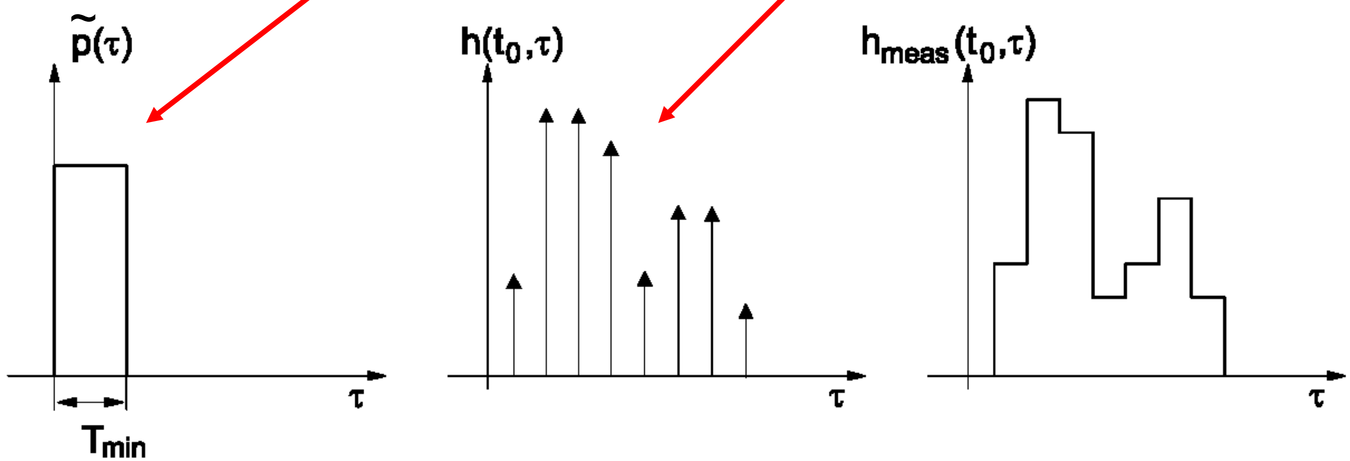
# Impulse sounder

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

impulse response of sounder

impulse response of channel

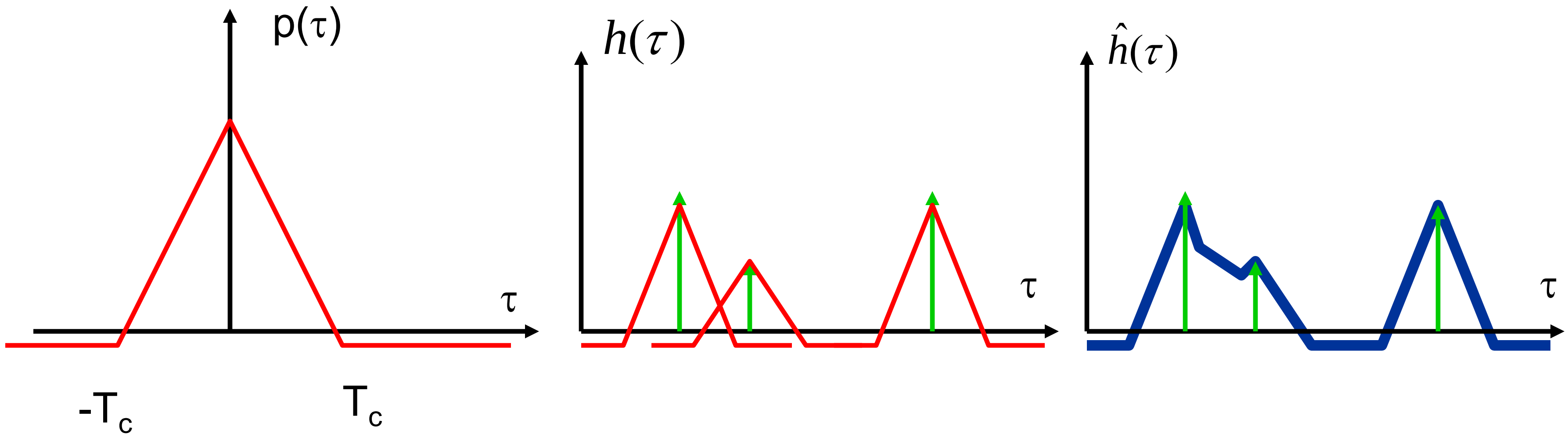
Assuming a slow time-variant channel, the impulse response of the sounder is the convolution of the TX pulse shape with the RX filter impulse response (essentially a bandpass filter response) thus the receiver should not have an impact on $h_{meas}$



# Correlative sounder

Other signals on channel (interference) make measurements difficult although the interference can usually be approximated as equivalent Gaussian noise.

Concatenation of the transmit and the receive filters have an impulse response that is identical to the autocorrelation (ACF) of the transmit filter resulting in an impulse response that is a good approximattion of a delta function. In practice, PseudoNoise (PN) sequences or chirp signals (linear frequency modulated signals) have become the prevalent sounding sequences for correlative sounder techniques.




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

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

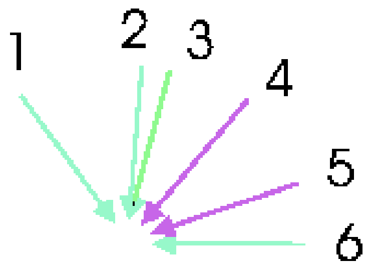
- Need to know the influence of the measurement system

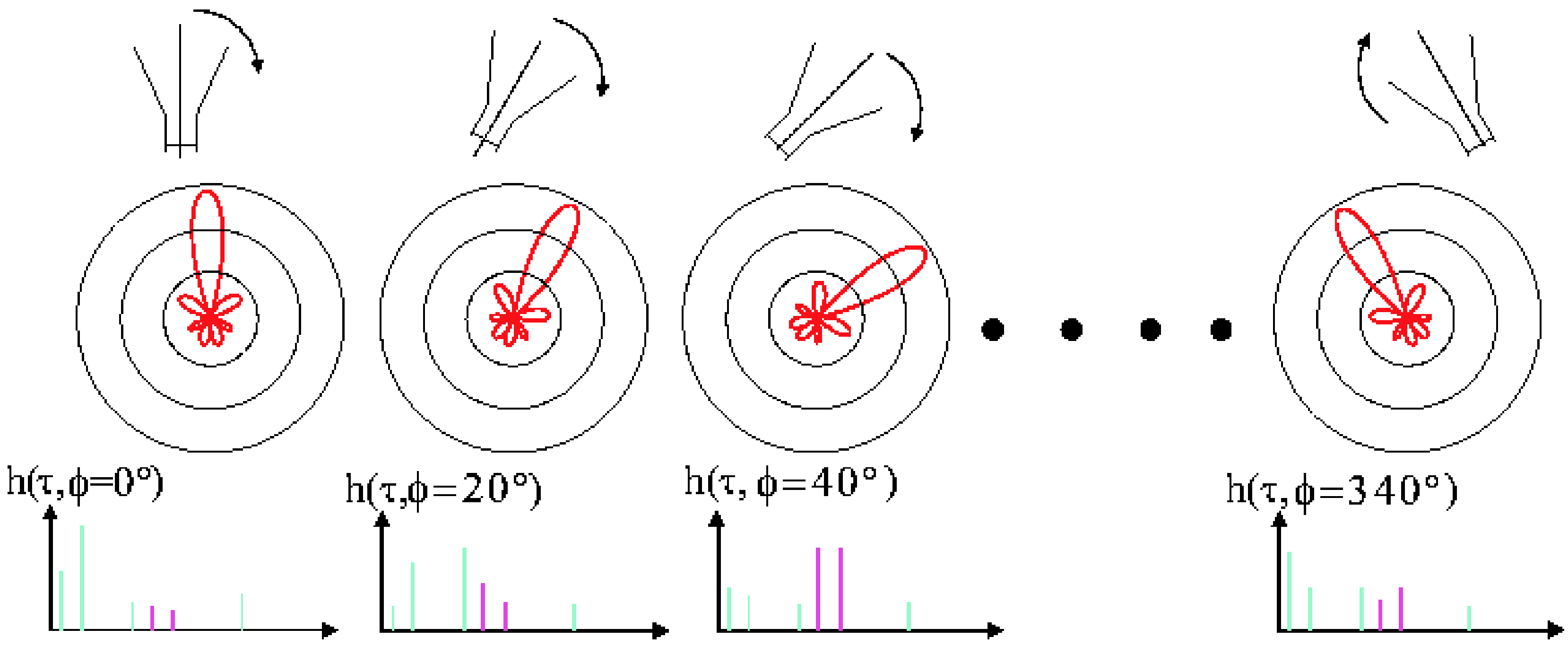
In practice Pseudo Noise (PN) sequences have become the prevalent sounding sequences where maximum-length PN sequences (m-sequences used in CDMA systems) are most popular.
The principles behind OFDM to transmit multiple frequencies at the same time (IFFT Chapter 19) are used to measure the transfer function of the channel in the frequency domain.

# Channel sounding – directional antenna

for MIMO

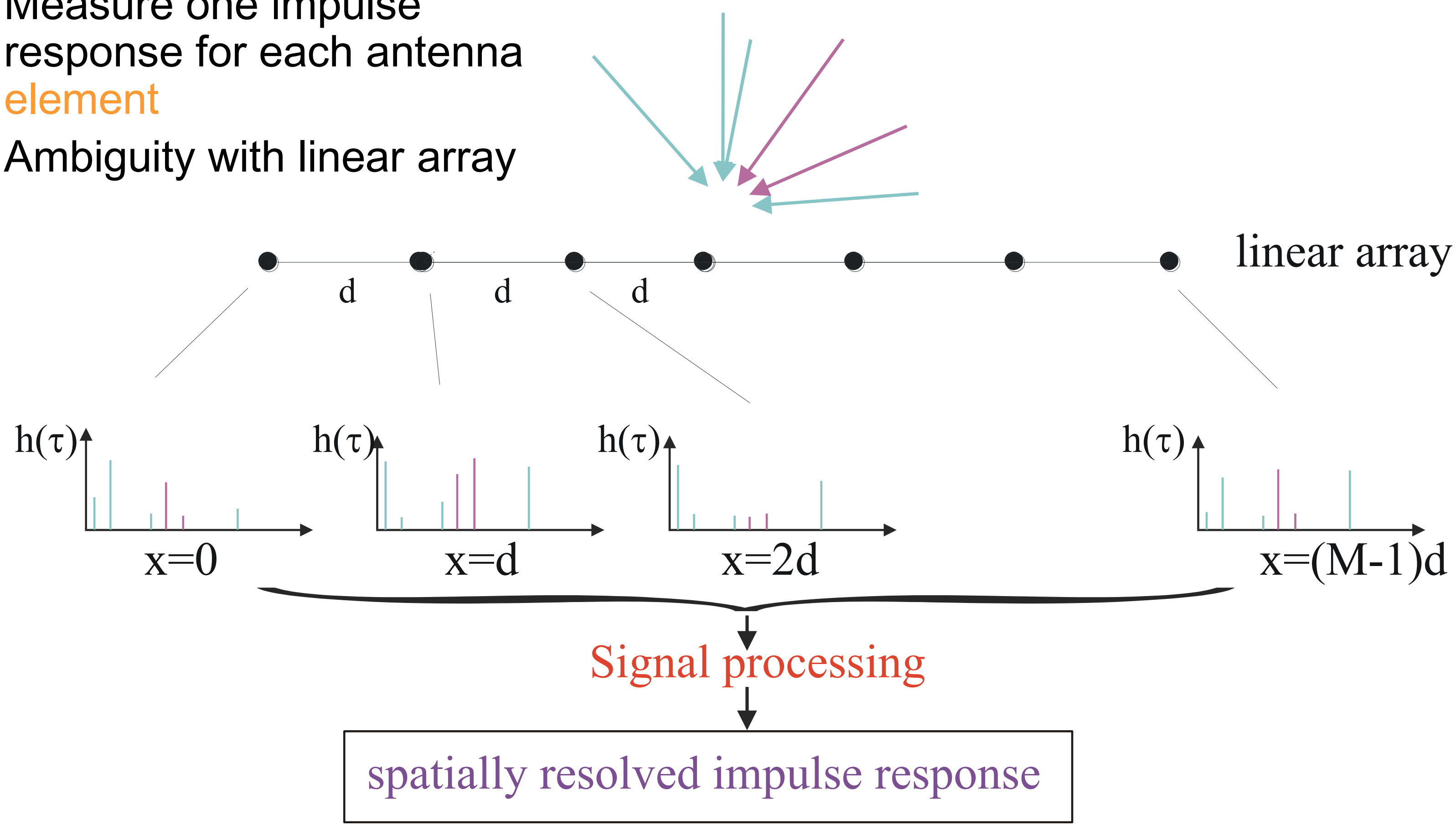
- Measure one impulse response for each antenna orientation



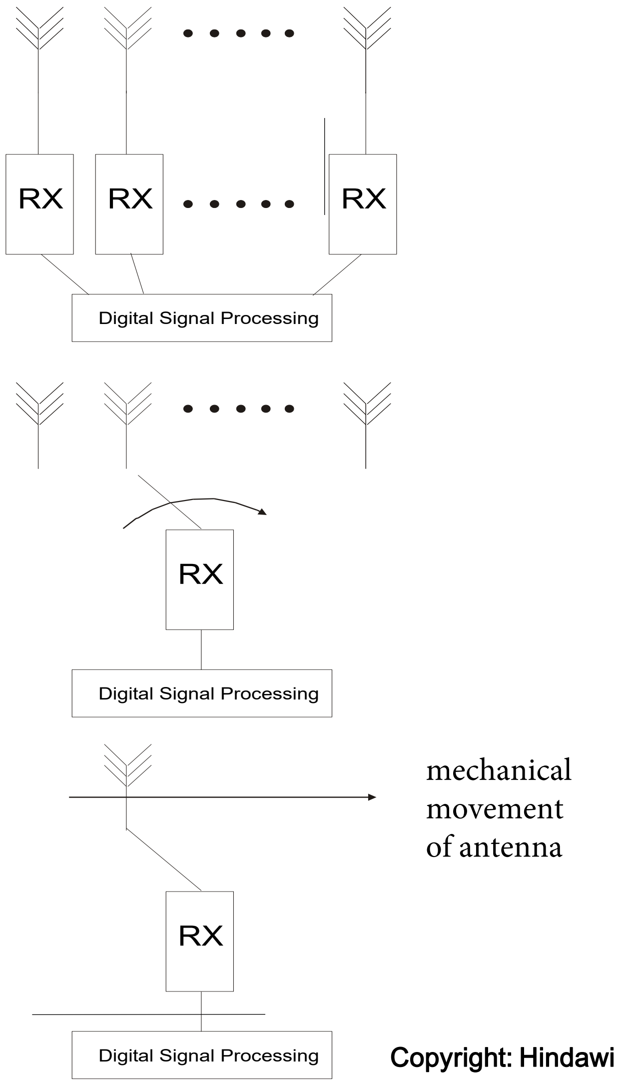
# Channel sounding – antenna array

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

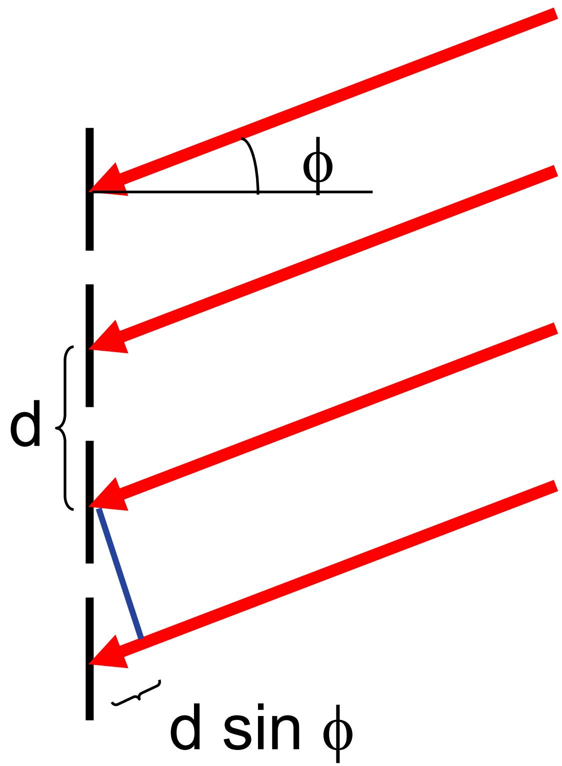


# Real, multiplexed, and virtual arrays

- 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 antennas

  →Transmit signals should be orthogonal

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