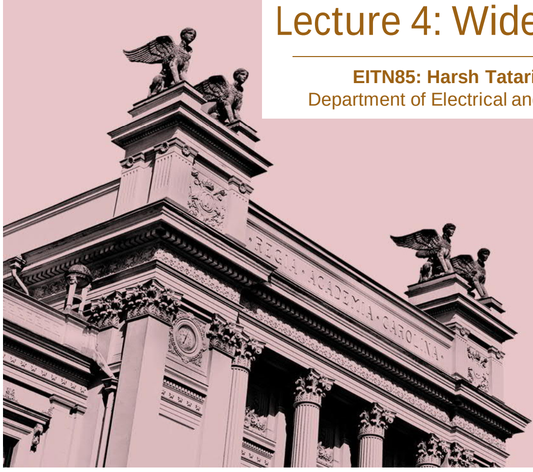
Wireless Communications Channels
Lecture 4: Wideband Characterization

EITN85: Harsh Tataria (e-mail: harsh.tataria@eit.lth.se)
Department of Electrical and Information Technology, Lund University



What have we covered thus far?

- **Recap:** Considered the effect of multipath propagation on the received field strength and its temporal variations if the TX signal is a pure sinusoid.
- Key assumption: Small system bandwidth (narrowband systems only). As a consequence, multiple directions can not be resolved by the RX and seem that they arrive almost at the same time.
- Most current and future systems however will leverage large bandwidths – why?
- Desirable to describe channel variations over a larger bandwidth range – the topic for the current lecture.
  - Wideband characterization of channels and real world examples.

Propagation Impact on Wideband Systems

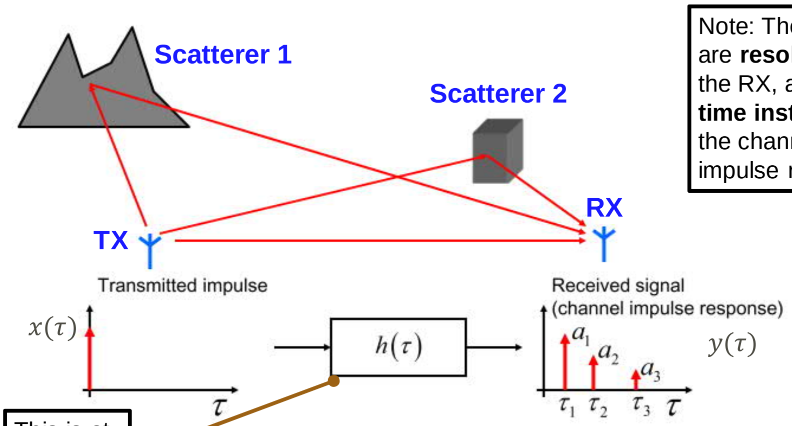
Impact interpreted in **two** different ways:

- ❑ The transfer function of the channel **varies** over the **bandwidth** of interest (a.k.a. the **frequency selectivity** of the channel).

- ❑ Impulse response of the channel is **not** a Delta function; the arriving signal has a **longer run time** than the transmitted signal (a.k.a. delay dispersion).

Question: What is the relationship between the above?

Delay Dispersion: A Simple Case

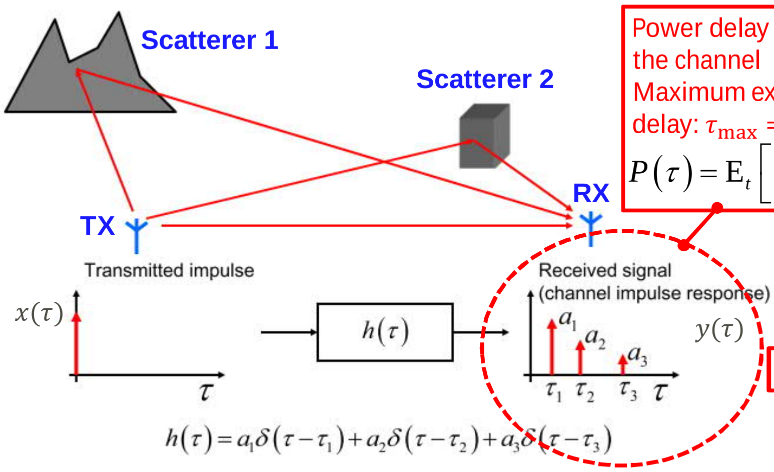


Note: The delays are **resolvable** at the RX, at a **given time instance** of the channel impulse response.

This is at **one** time instance!

$$h(\tau)=a_1\delta(\tau-\tau_1)+a_2\delta(\tau-\tau_2)+a_3\delta(\tau-\tau_3)$$

Delay Dispersion: A Simple Case



Power delay profile of the channel

Maximum excess delay: $\tau_{\max} = \tau_3 - \tau_1$

$$P(\tau) = \mathrm{E}_t\left[\left|h(t,\tau)\right|^2\right]$$

Question!

$$h(\tau) = a_1\delta(\tau-\tau_1) + a_2\delta(\tau-\tau_2) + a_3\delta(\tau-\tau_3)$$

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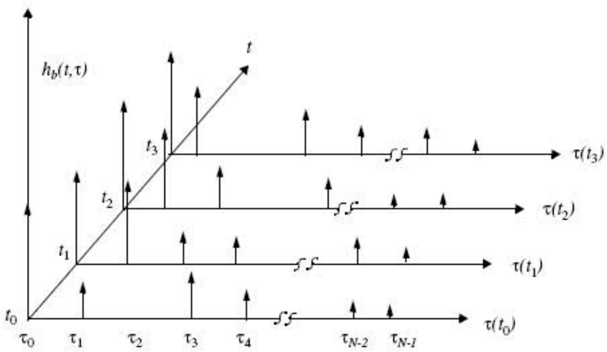
Power delay profile over time

The General Description



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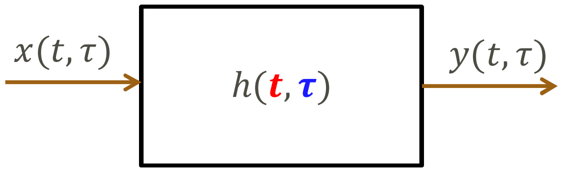
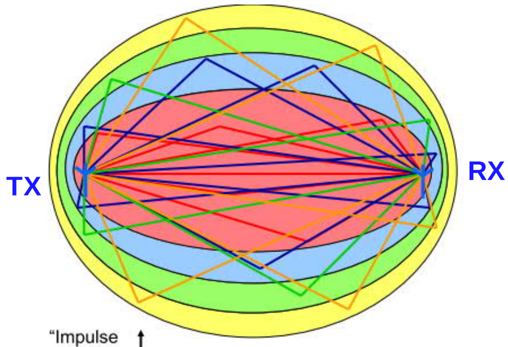
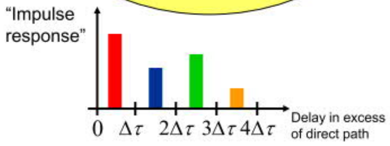
Consequence of Wideband Channels



So, what about this?
What can we infer from a system view point?

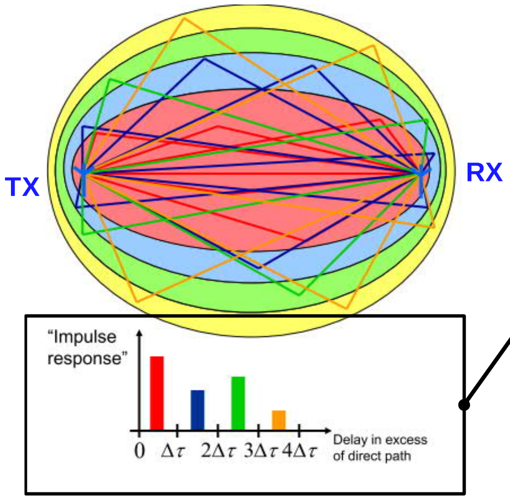
Delay dispersion: Many paths, a model





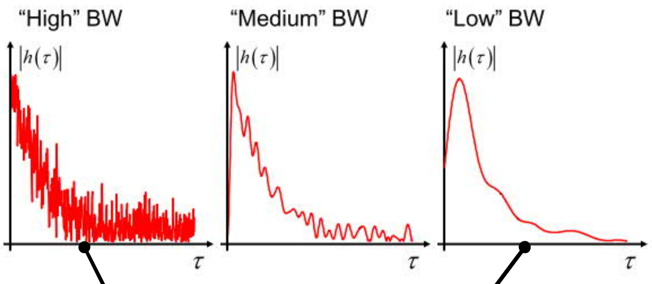
- Scatterers/Interacting objects placed anywhere along the plane
- Elipse which is characterized by its focal points, i.e., TX and RX locations, as well as the eccentricity determining the run time of multipath components
- Single interaction on ellipse → arrive at the RX at the same time. Interaction on different ellipses → arrive at different times

Delay dispersion: Many paths, a model



Discrete time-domain approximation to the impulse response of a wideband channel obtained by: dividing the impulse response into **different time intervals (each containing multiple delays)** and **summing** over the number of multipath components within **each** bin.

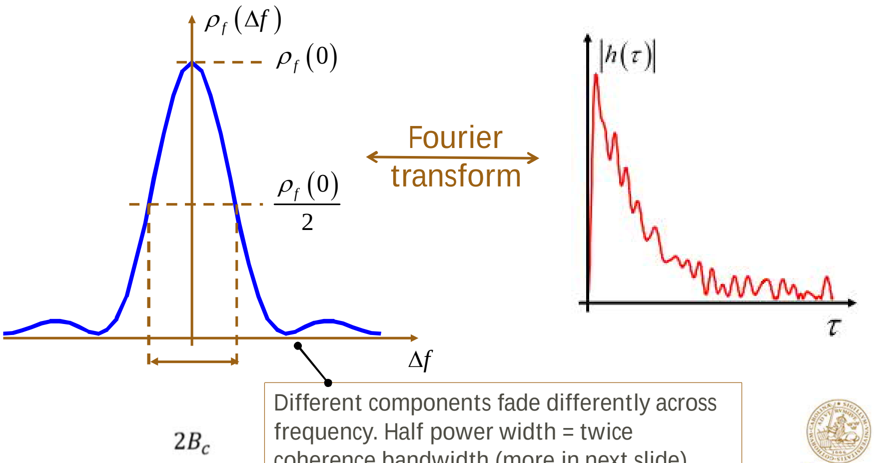
Narrowband vs. Wideband Channels Bandwidth Dependency



Much better resolvability of multipath components

Narrowband if $\frac{1}{B} \gg \tau_{max}$

Power delay profile vs. frequency correlation function



Different components fade differently across frequency. Half power width = twice coherence bandwidth (more in next slide)

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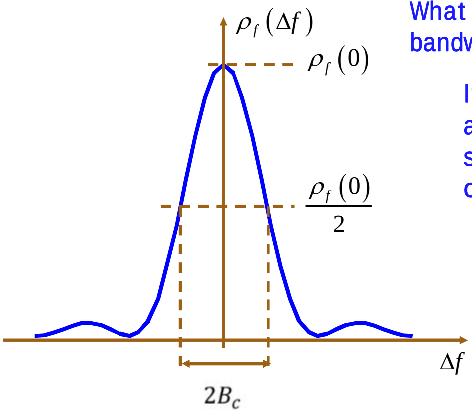
Condensed parameters
Coherence bandwidth

Given the frequency correlation of a channel, we can define the coherence bandwidth B_C:



What does the coherence bandwidth tell us?

It shows us over how large a bandwidth we can assume so that the channel is fairly constant.

Radio systems using a bandwidth much smaller than B_C will not notice the frequency selectivity of the channel.

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Condensed parameters Power delay profile (cont.)

We can infer many useful parameters from the power delay profile

Total power (time integrated):

$$P_m = \int_{-\infty}^{\infty} P(\tau)\, d\tau$$

Average mean delay (first moment of the PDP)

$$T_m = \frac{\int_{-\infty}^{\infty} \tau P(\tau)\, d\tau}{P_m}$$

Average RMS delay spread (second moment of the PDP)

$$S_\tau = \sqrt{\frac{\int_{-\infty}^{\infty} \tau^2 P(\tau)\, d\tau}{P_m} - T_m^2}$$

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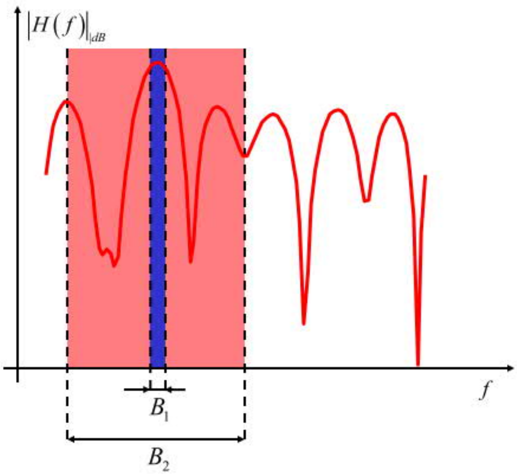
Narrow vs. wideband frequency response



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Widely used ”rules-of-thumb”

$$Tc \approx \frac{1}{D_s}$$

$$Bc \approx \frac{1}{S_\tau}$$

$$Tc = \frac{9}{16\pi D_s}$$

time over which the time correlation function is above 0.5

$$Bc = \frac{1}{5S_\tau}$$

band over which the frequency correlation function is above 0.5

$$T_c = \frac{0.423}{D_s}$$

less restrictive and widely used

$$Bc = \frac{1}{50S_\tau}$$

band over which the frequency correlation function is above 0.9

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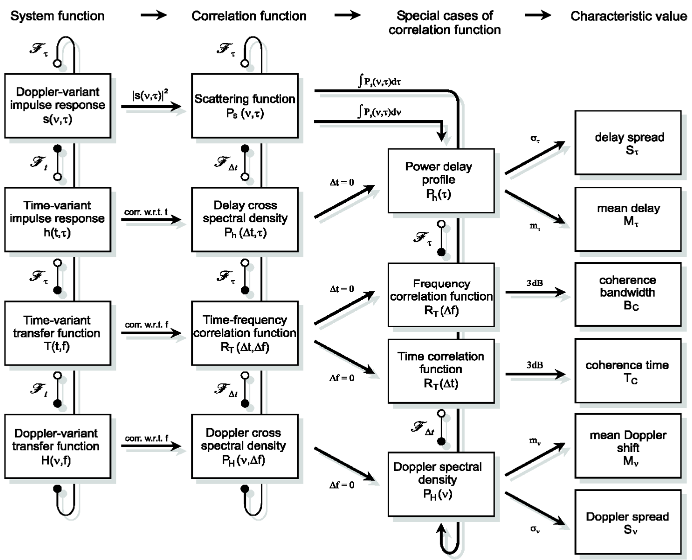

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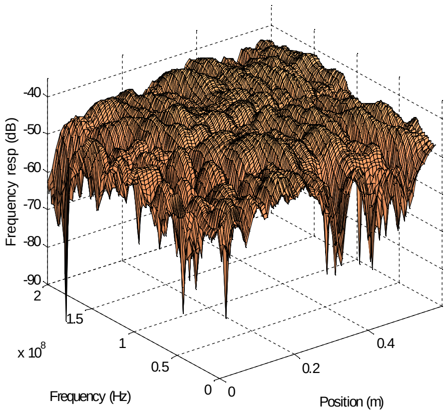
Time variant channel transfer function



Measurement in the lab with a vector network analyzer

- Center frequency 3.2 GHz
- Measurement bandwidth 200 MHz, 201 frequency points
- 60 measurement positions, spaced 1 cm apart

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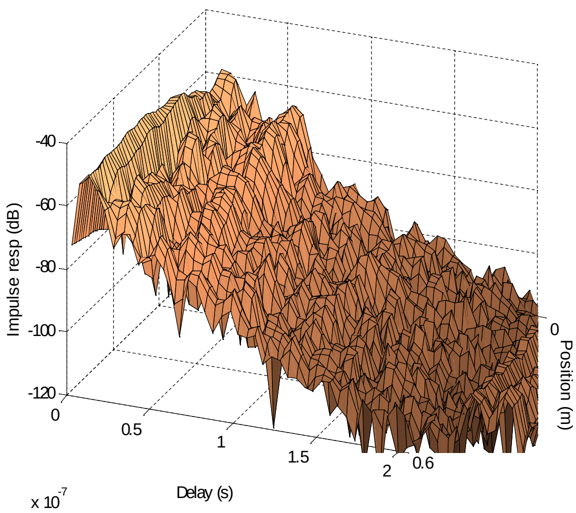
Time variant channel impulse response



What are the delays?
How is the signal affected for different delays?
How does it change with time?

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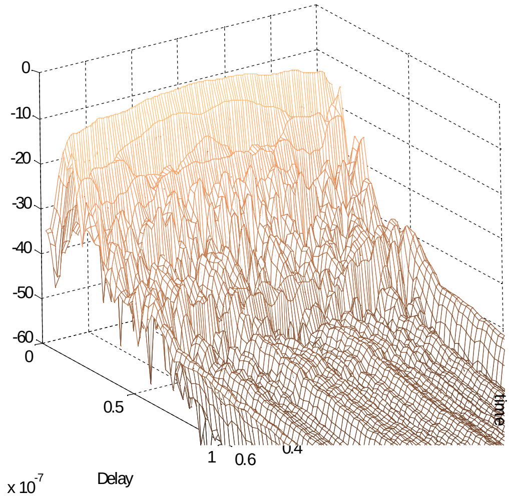
Delay cross spectral density



How is the power for different delays correlated in time?

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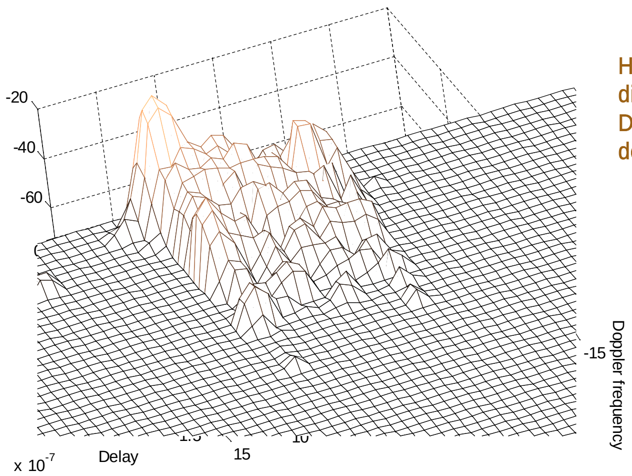
Spreading function of the channel



How is the power distributed in the Doppler and delay domains?

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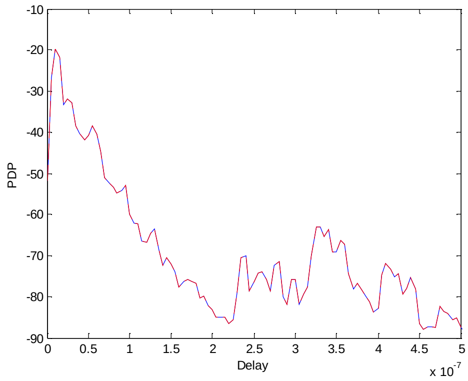
Integrating the spreading function over the Doppler – the delay domain



How is the power distributed in the delay domain?

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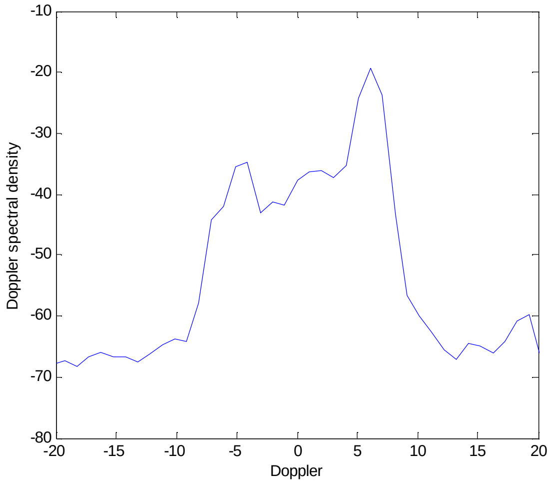
Integrating the spreading function over the delay – the Doppler spectral density



How is the power distributed in the Doppler domain?

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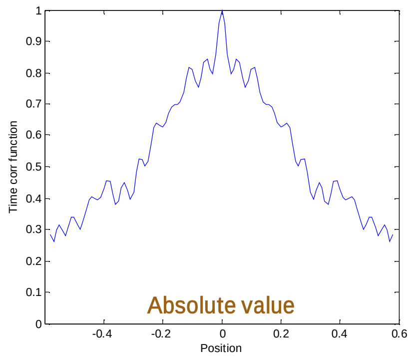
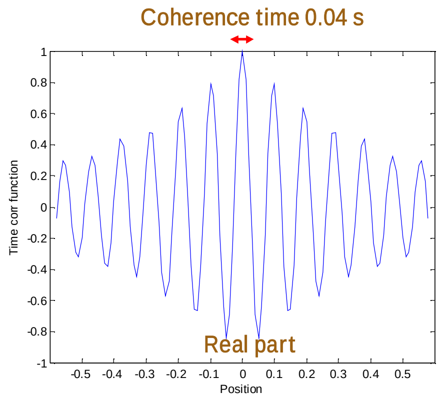
Measured time correlation function





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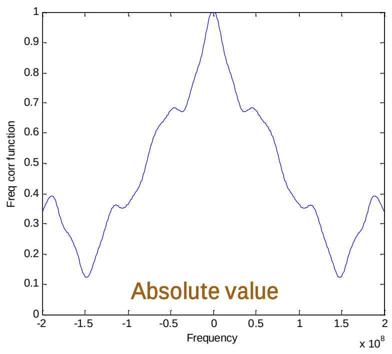
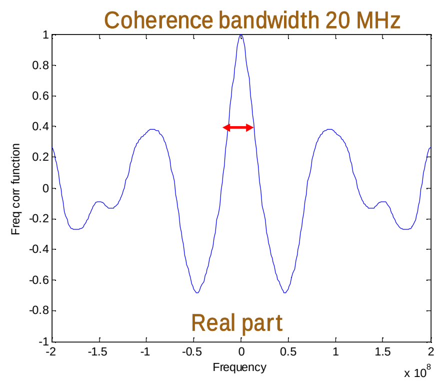
Measured Frequency correlation function





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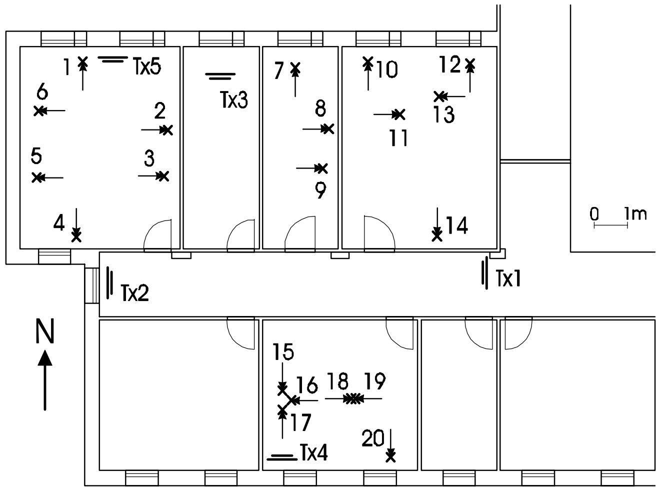
Measurements performed at typical work positions



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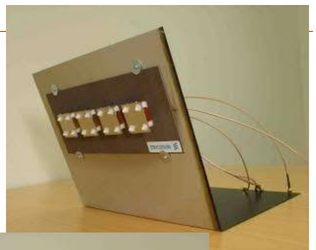
2.6 GHz antennas

2 port hand held



PC

4 port hand held

Fixed device

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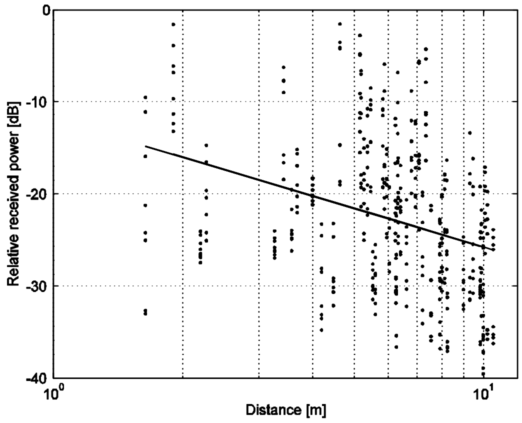
Total received power vs. link distance



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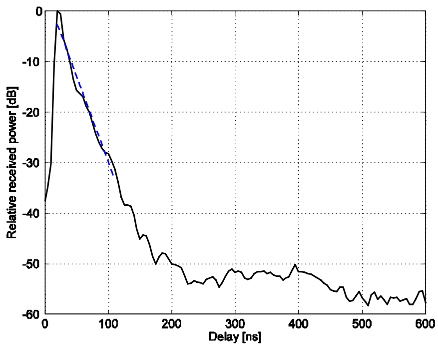
Power delay profile



- exponential decay

$$P(\tau) = |\beta|^2 e^{-\tau/\gamma}$$

- mean 10 - 13 ns
- standard deviation 1.2 - 2.1 ns

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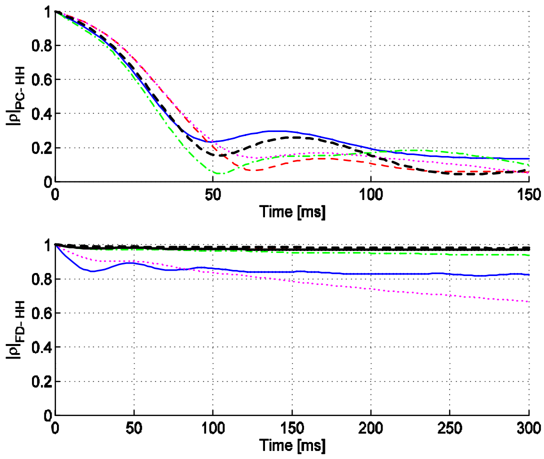
Variation of coherence time vs. measured environment



PC-HH

moving receiver

FD-HH

person moving in corridor

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Measurements in an industrial UWB channel

4.9 GHz bandwidth
49 TX-RX positions 49
7*7 Virtual MIMO system
Antenna array elements separation 5cm
TX-RX Separations 3,6,10,12m

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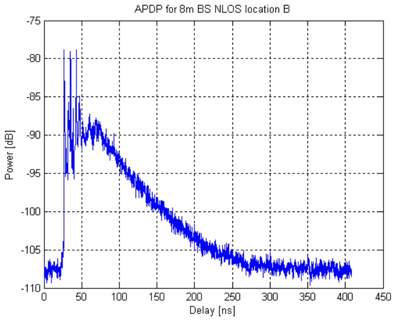
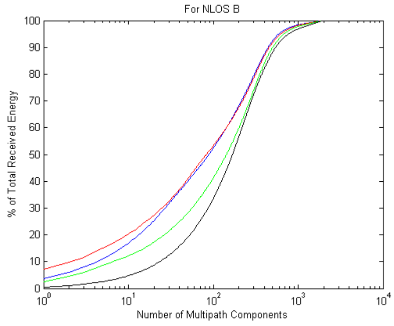
UWB channels – PDP





Huge bandwidth – possible to identify single multipath componenets
Need a large number of fingers in a special type of receiver (so called RAKE receiver)

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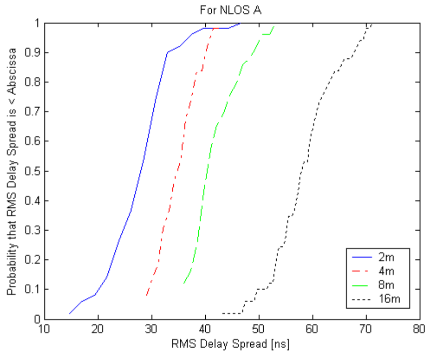
UWB channels

Delay spread is mainly dependent on distance to the scatterers, since it influences the resolvability of the system to identify potential multipath components.



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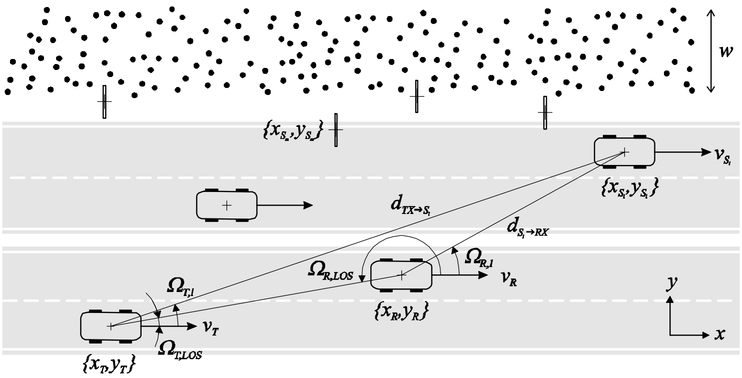
Car to car communication

Cars driving in same direction with a distance of 50 m, 70 km/h, rural area



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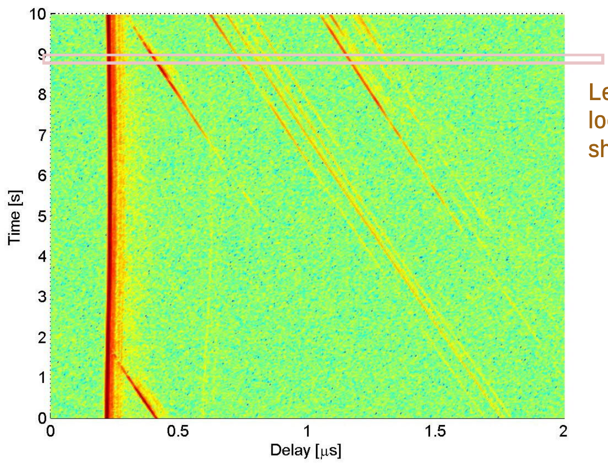
Time variant impulse response



Let's take a closer look at the Doppler shifts here

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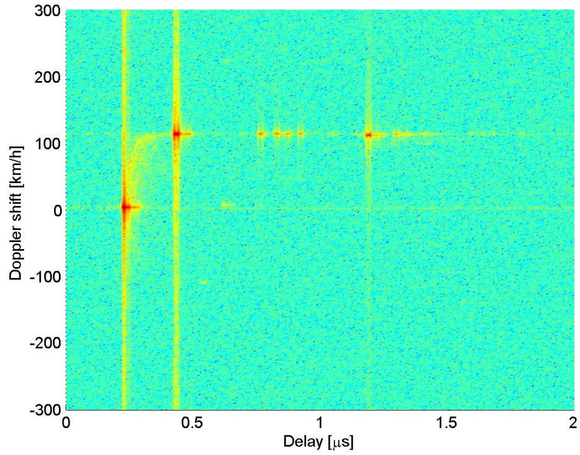
Scattering function, t=8.5-8.65 s



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