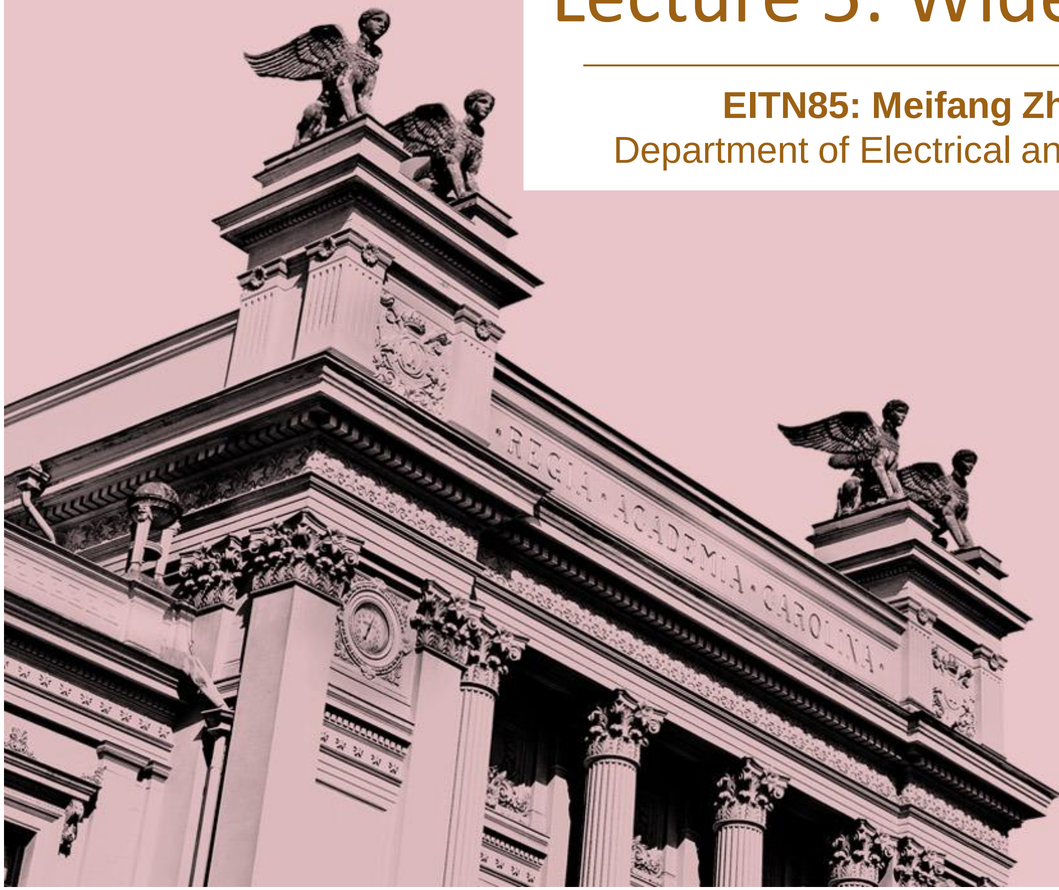
Wireless Communications Channels
Lecture 5: Wideband Characterization

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



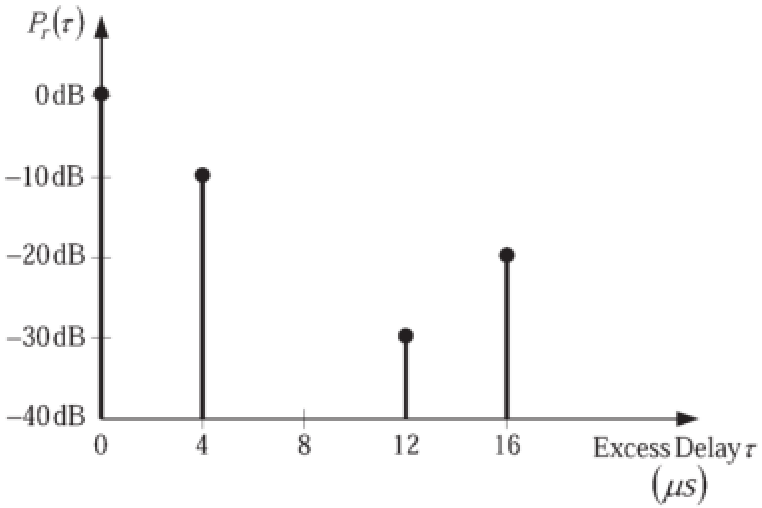
Recap: small/large scale fading

Receiver can handle loss maximum to 135dB

- Assume only large scale fading, which is log-normal distributed with σ_F = 7dB
- What is the outage probability of the user?
- How we can do to lower the outage probability for the user?

$$pdf\left(L_{|dB}\right) = \frac{1}{\sqrt{2\pi}\sigma_{F|dB}} \exp\left(-\frac{\left(L_{|dB} - L_{0|dB}\right)^2}{2\sigma_{F|dB}^{\;\;2}}\right)$$

Recap : power delay profile



- What is the maximun access delay?
- What is the mean delay and rms delay spread?
- If bandwidth of the system is 5MHz, determine if the channel will undergo frequency flat or frequency selective fading?

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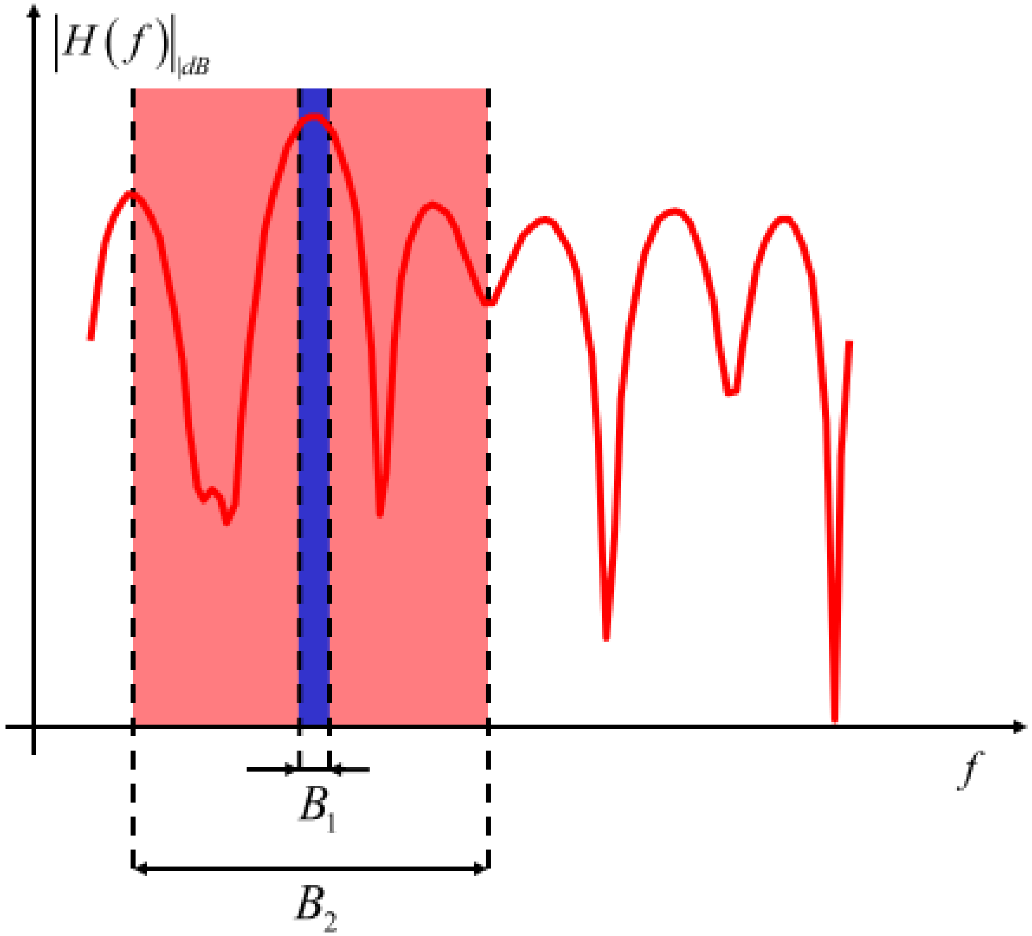
Recap: frequency flat vs frequency selective



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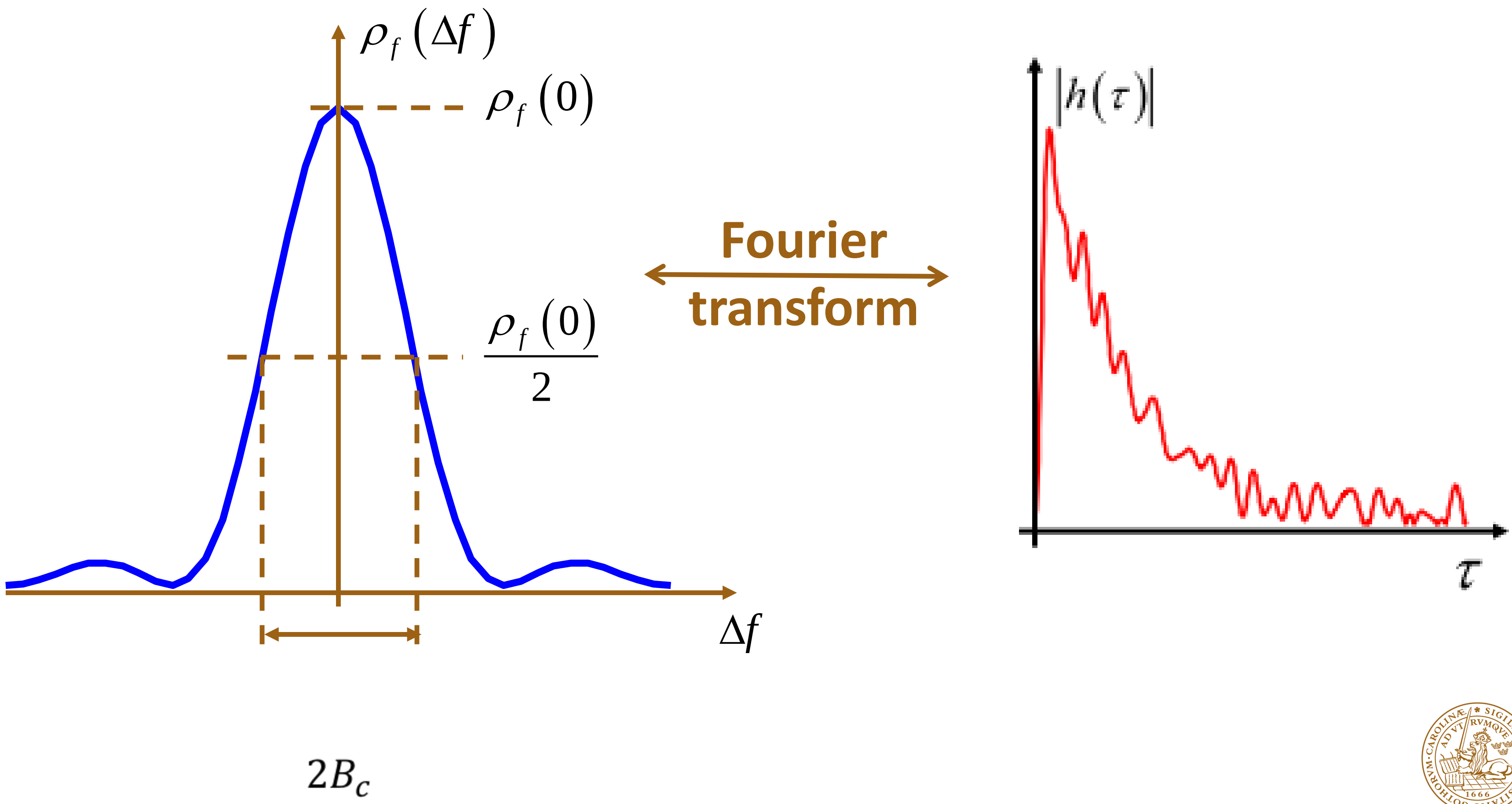
Recap: Power delay profile vs. frequency correlation function



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Mathematical background

$$H(t,f) = \int_{-\infty}^{\infty} h(t,\tau) e^{-j2\pi f_\tau} d\tau$$

Frequency correlation →

$$E\{H(t_1,f_1)H^*(t_2,f_2)\} = \iint_{-\infty}^{\infty} h(t_1,\tau_1) e^{-j2\pi f_1} h^*(t_2,\tau_2) e^{-j2\pi f_2} d\tau_1 d\tau_2$$

WSSUS →

$$R_H(\Delta f) = \int_{-\infty}^{\infty} \underbrace{E\{|h(\tau)|^2\}}_{\text{PDP}} \underbrace{e^{-j2\pi \Delta f \tau} d\tau}_{\text{FFT}}$$

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Power delay profile in a dynamic environment

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

Does WSS still hold in a dynamic environment over time?

- WSS: the statistical properies of the channel not change with time
- Requries: mean power and Doppler spectrum do not change with time.
- Typically holds over an area of 10 wavelength.

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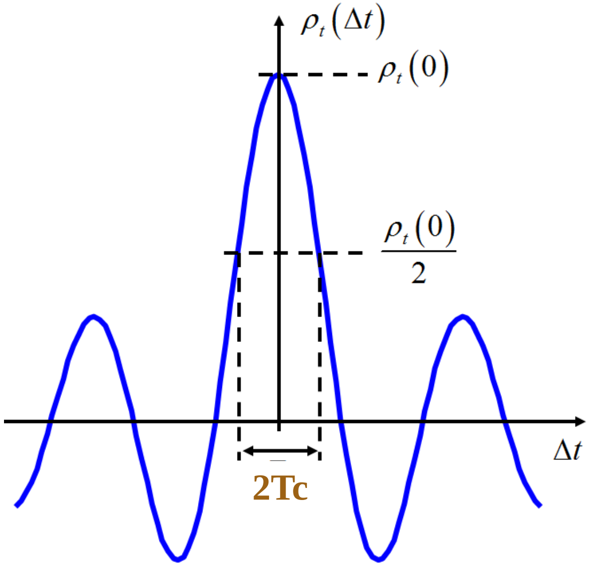
Doppler spectrum vs. the time correlation function

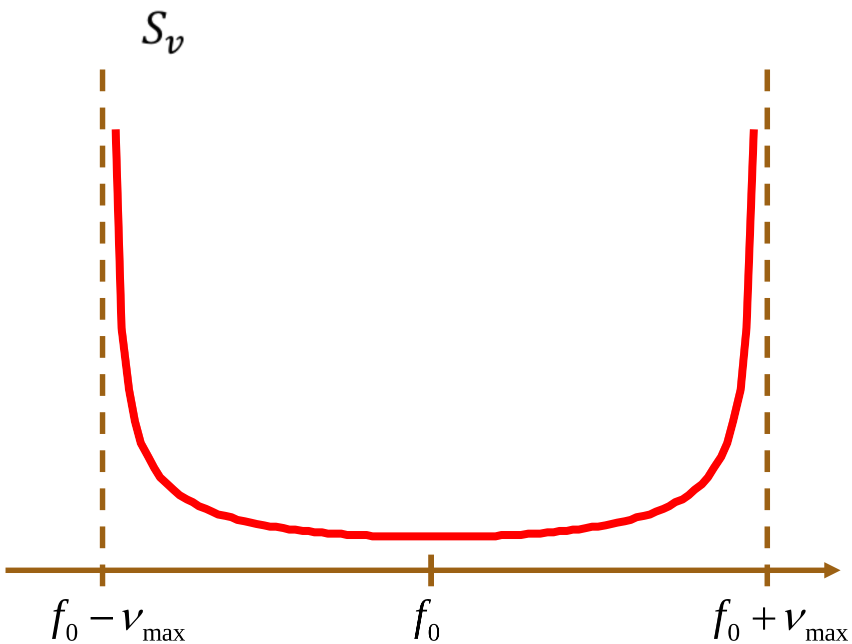
Doppler spectrum and the time correlation of the signal are related to each other by Fourier transformation



time correlation function

Fourier

transforms



Doppler power spectrum

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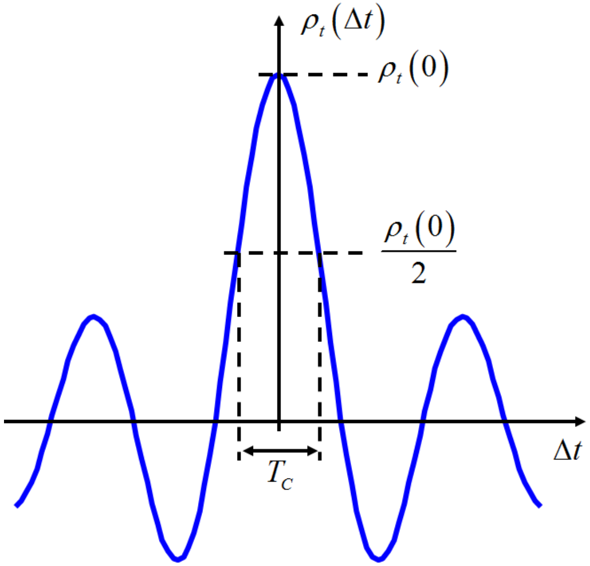
Condensed parameters Coherence time

Given the time correlation of a channel, we can define the coherence time T_C:



What does the coherence time tell us?

It shows us over how fast a Channel changes

Radio systems update channel status parameters that is smaller than the coherence time

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Condensed parameters Doppler spectra

We can infer many useful parameters from the power delay profile

Total power (Doppler frequency integrated):

$$P_{B.m} = \int_{-\infty}^{\infty} P_B(v)dv$$

Average Doppler shift (first moment of the Doppler spectra)

$$v_m = \frac{\int_{-\infty}^{\infty} P_B(v)dv}{P_{B,m}}$$

Average RMS Doppler spread (second moment of the Doppler spectra)

$$D_s = \sqrt{\frac{\int_{-\infty}^{\infty} P_B(v)v^2dv}{P_{B.m}} - {v_m}^2}$$

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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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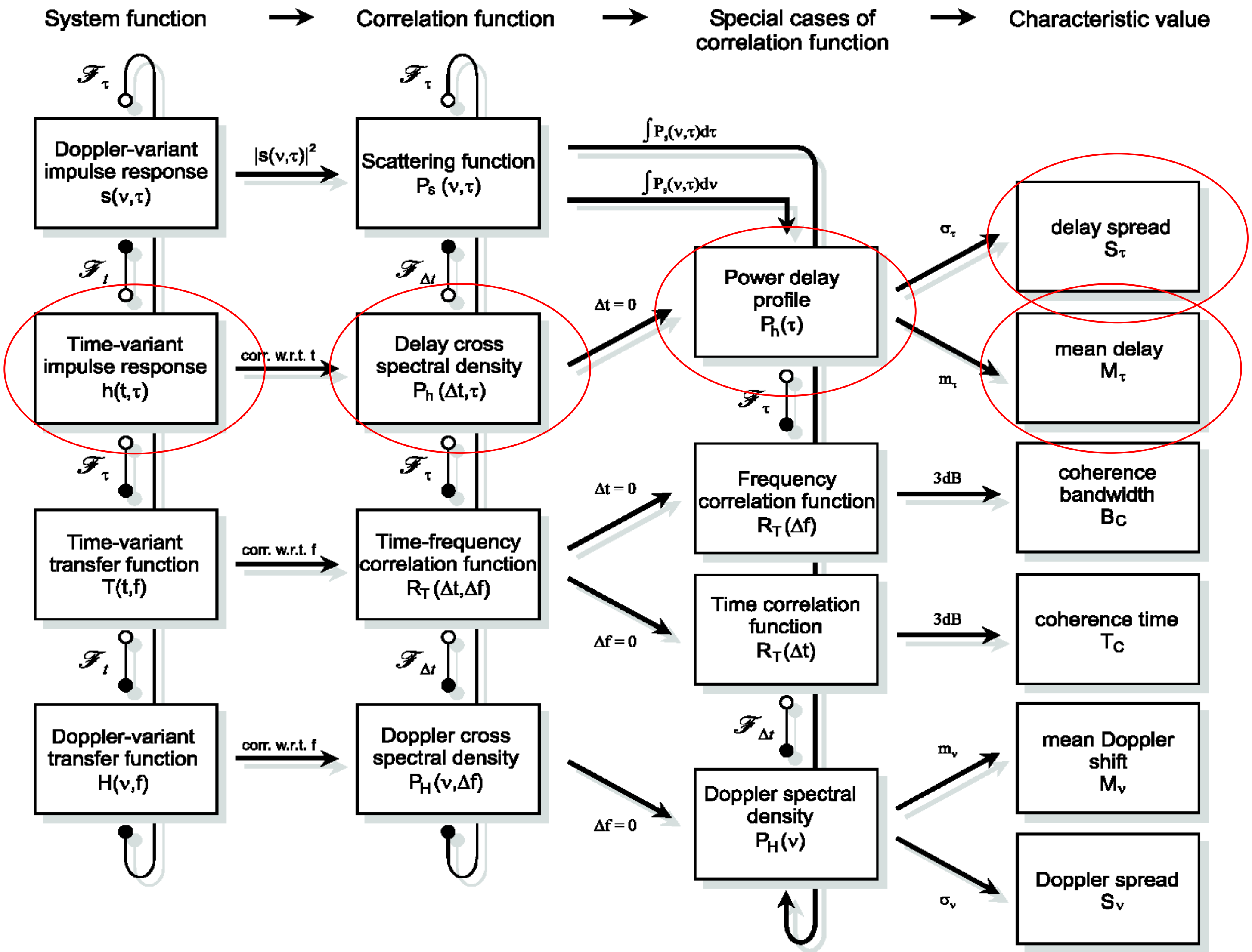
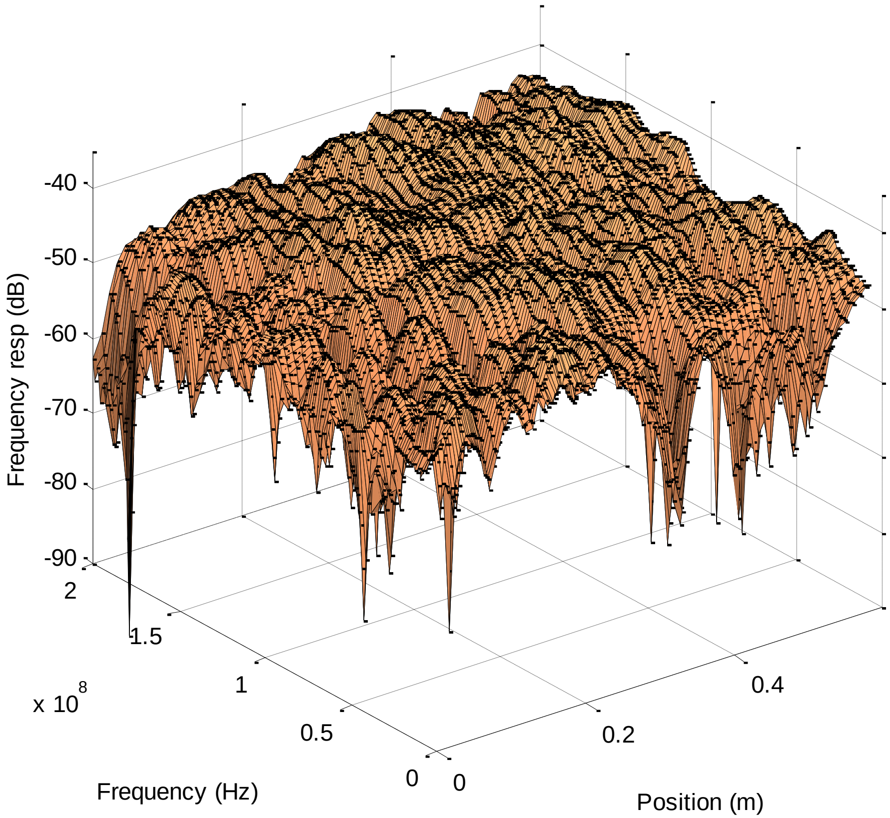

System function
Correlation function
Special cases of correlation function
Characteristic value
Doppler-variant impulse response s(ν,τ)
|s(ν,τ)|²
Scattering function Ps (ν,τ)
∫Ps(ν,τ)dτ
∫Ps(ν,τ)dν
Time-variant impulse response h(t,τ)
corr. w.r.t. t
Delay cross spectral density Ph (Δt,τ)
Δt = 0
Power delay profile Ph(τ)
στ
delay spread Sτ
mτ
mean delay Mτ
Time-variant transfer function T(t,f)
corr. w.r.t. f
Time-frequency correlation function RT (Δt,Δf)
Δt = 0
Frequency correlation function RT(Δf)
3dB
coherence bandwidth BC
Δf = 0
Time correlation function RT(Δt)
3dB
coherence time TC
Doppler-variant transfer function H(ν,f)
corr. w.r.t. f
Doppler cross spectral density PH(ν,Δf)
Δf = 0
Doppler spectral density PH(ν)
mν
mean Doppler shift Mν
σν
Doppler spread Sν

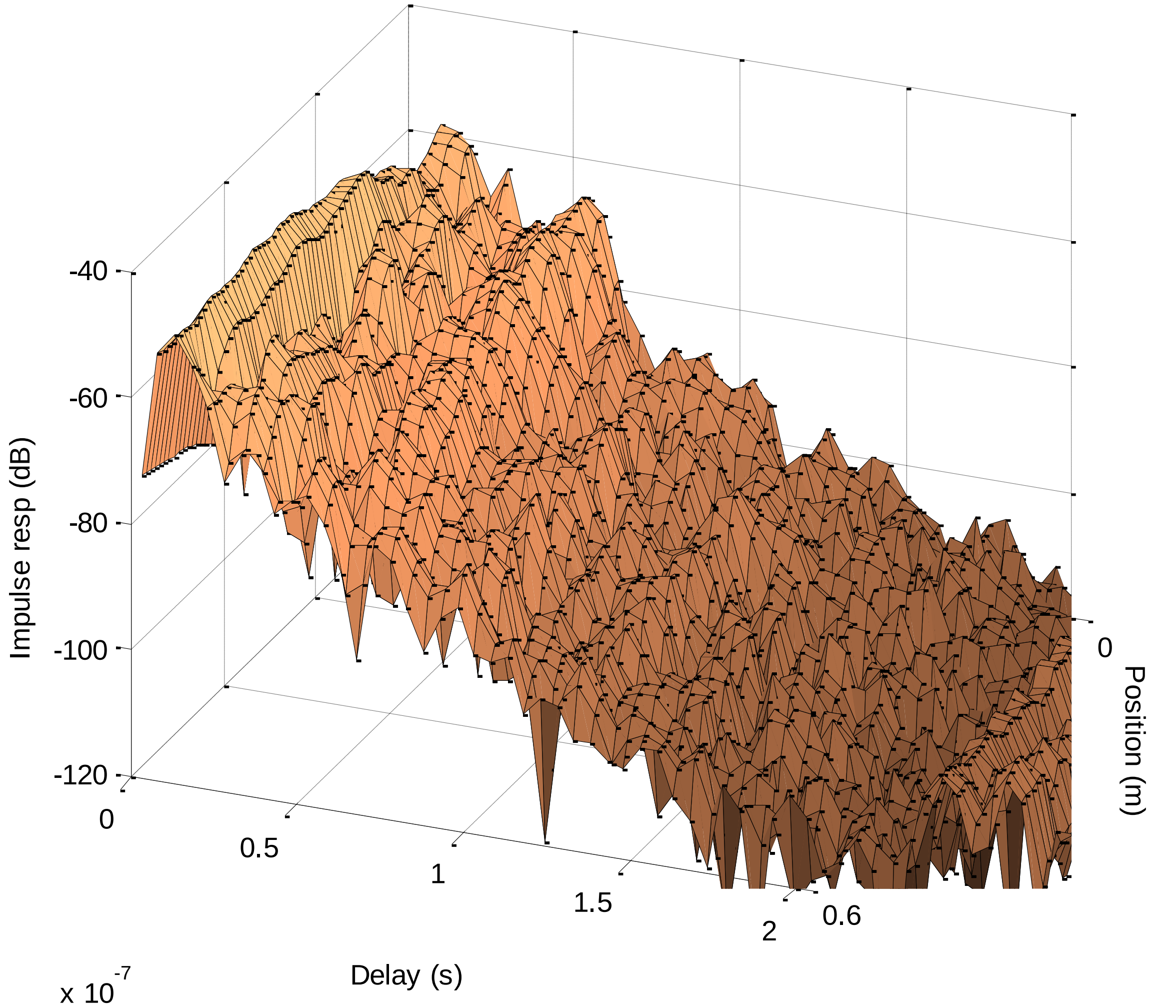
Time variant channel **transfer function**



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**

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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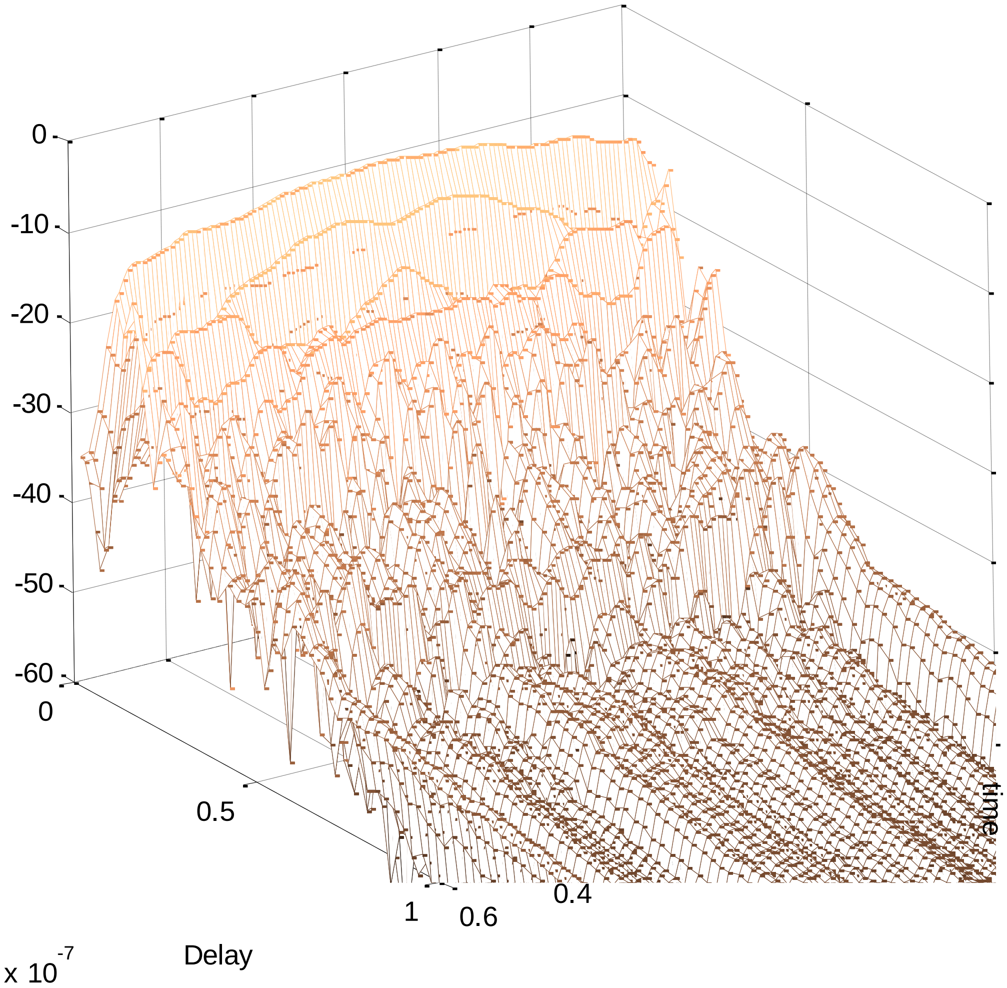
Delay cross spectral density



How is the power for different delays correlated in time?

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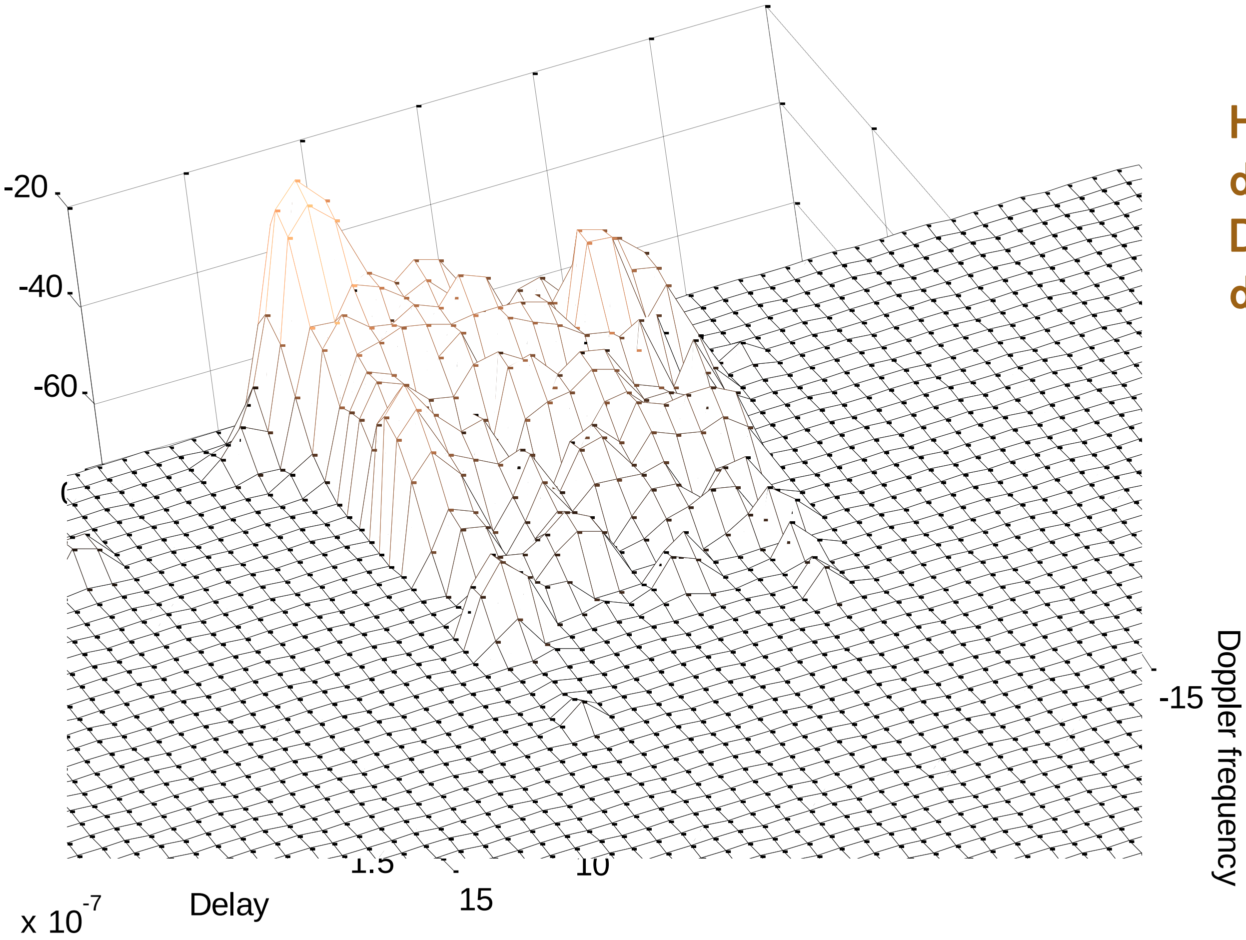
Spreading function (Doppler-variant transfer function)of the channel



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

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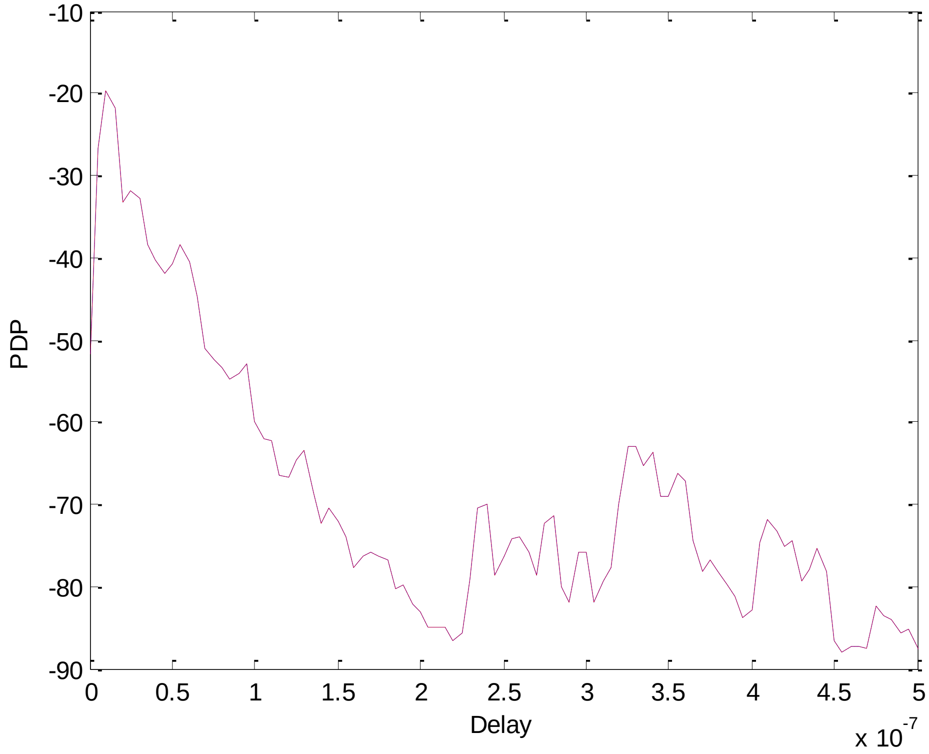
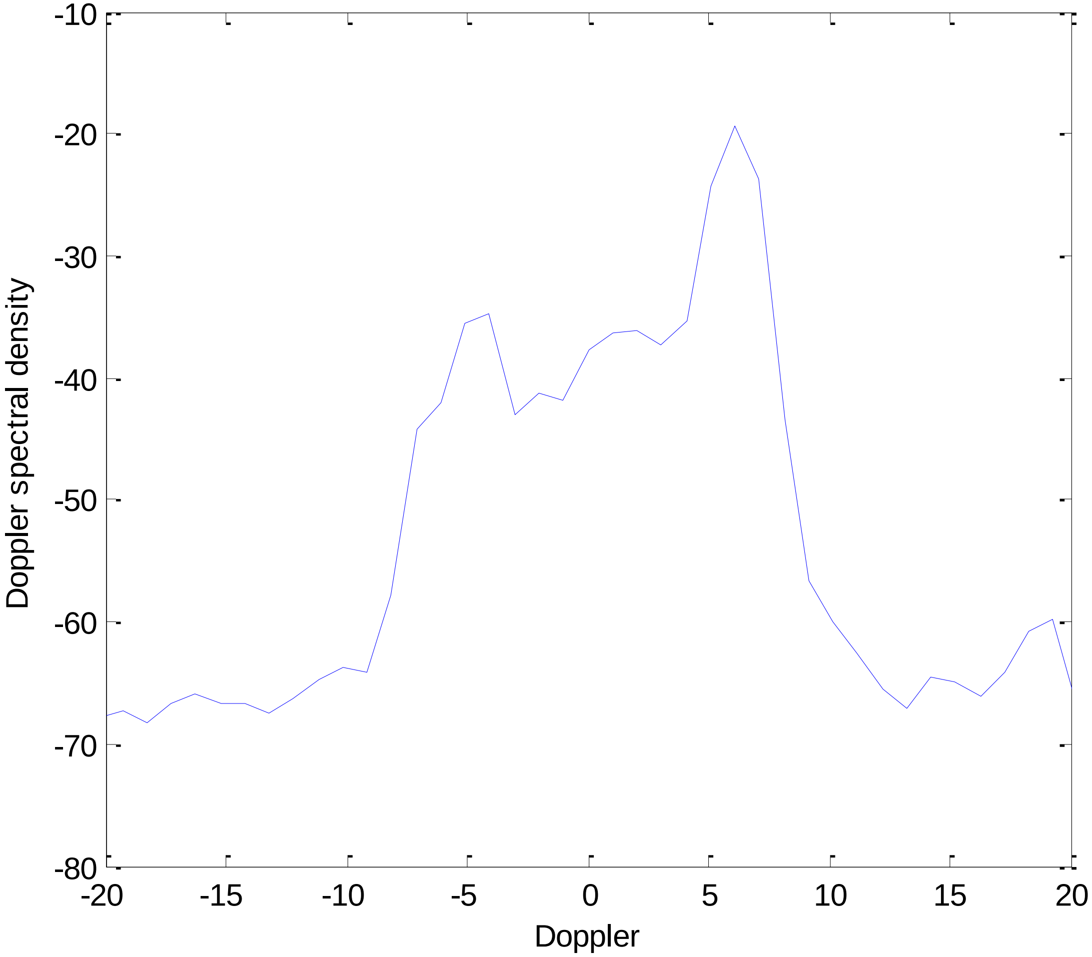
Integrating the spreading function over the Doppler – the delay domain



How is the power distributed in the delay domain?

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



How is the power distributed in the Doppler domain?

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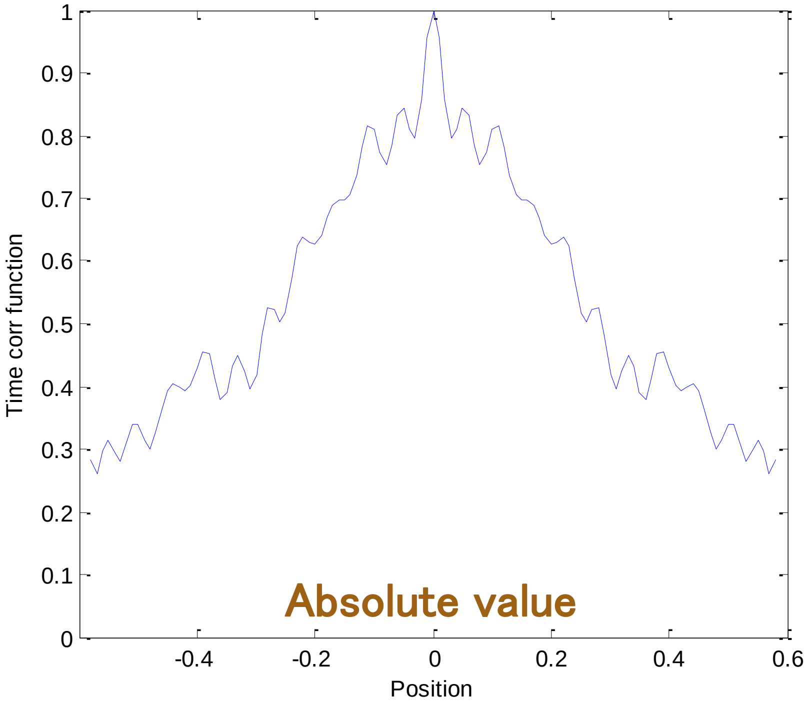
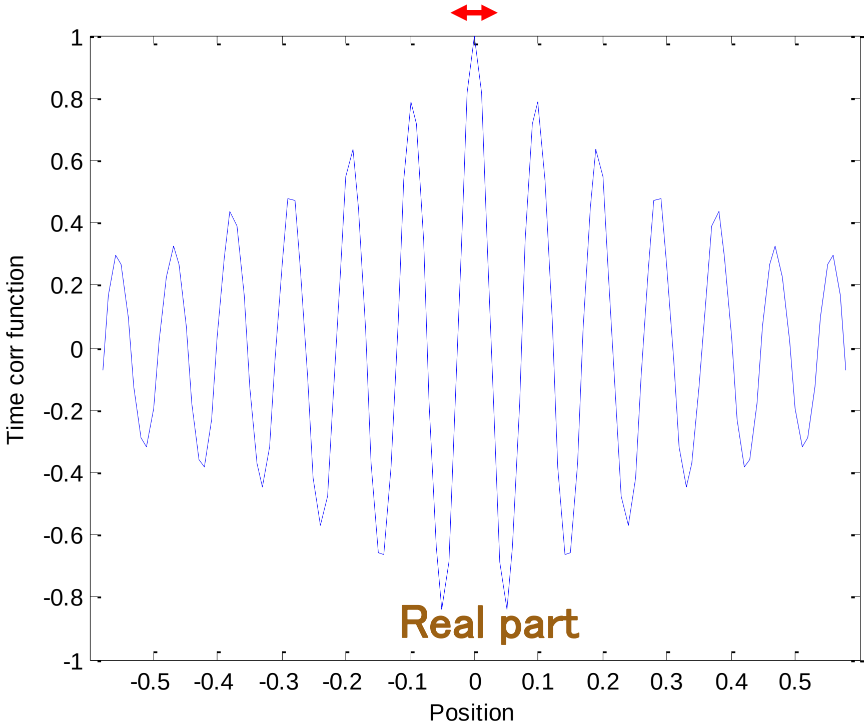
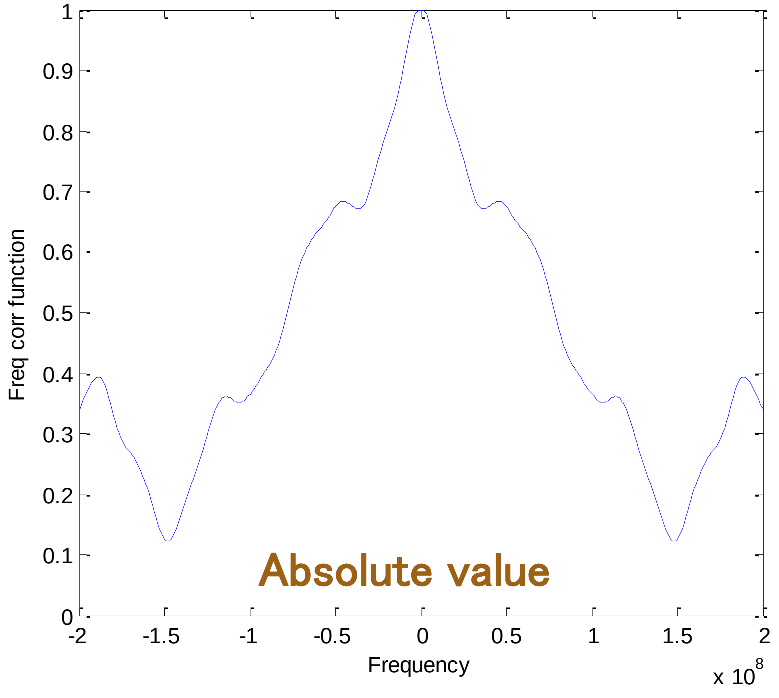
Measured time correlation function

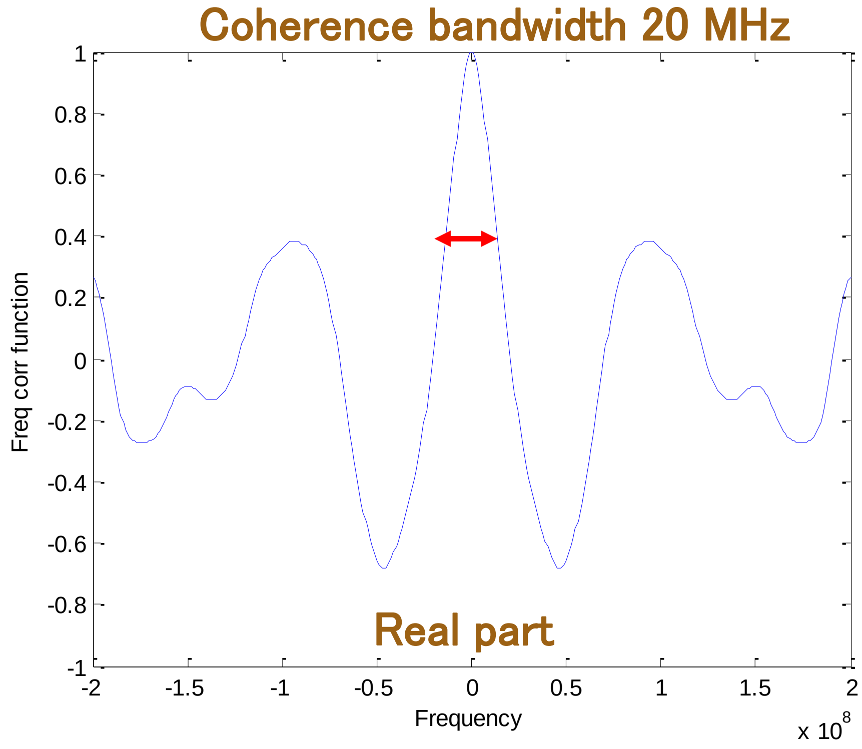


Coherence time 0.04 s



Measured Frequency correlation function





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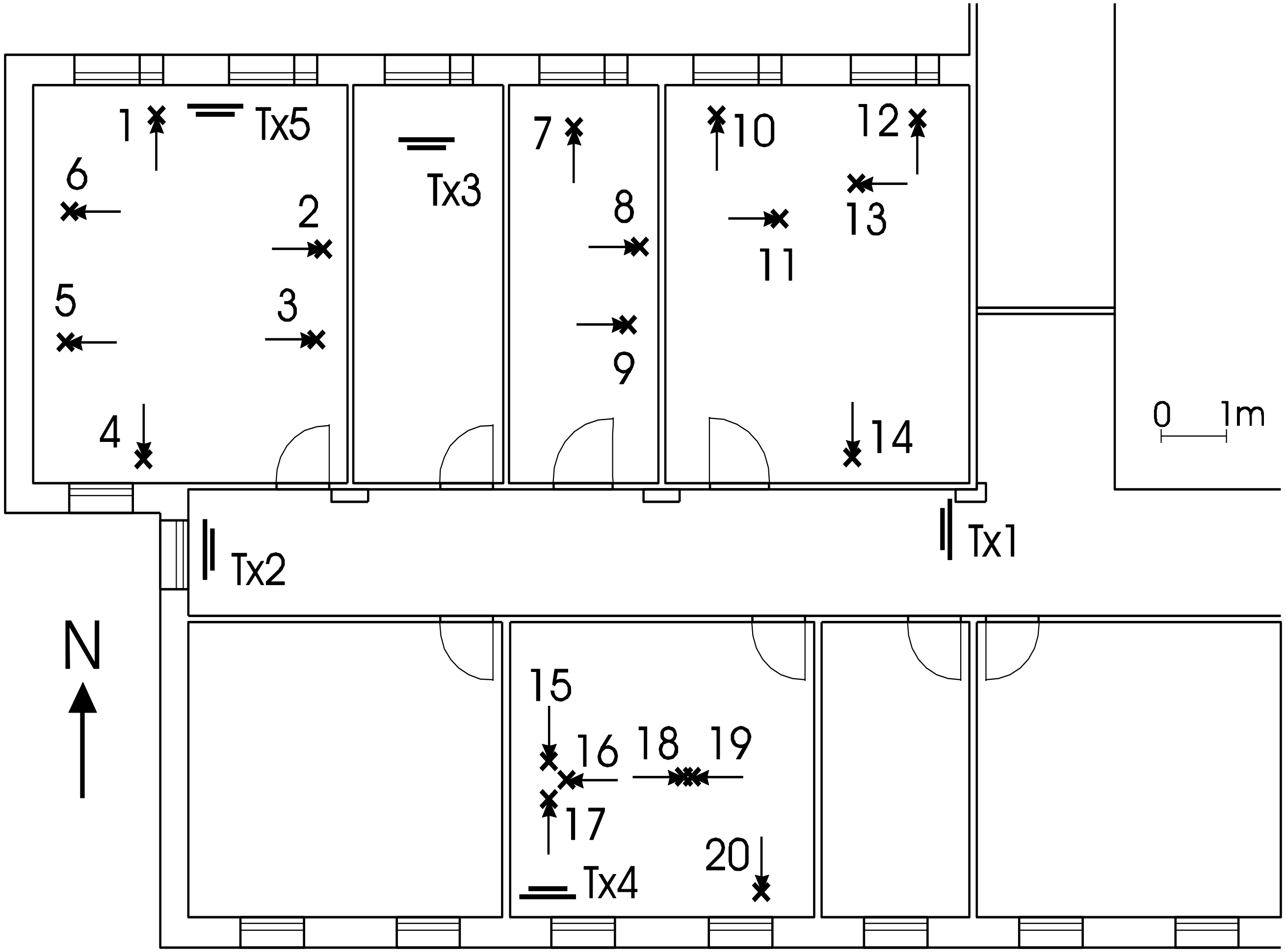
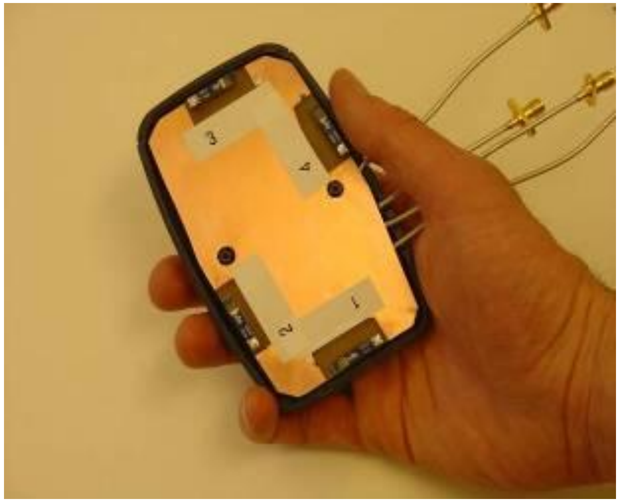
Measurements performed at typical work positions



2.6 GHz antennas

2 port hand held

PC



4 port hand held

Fixed device

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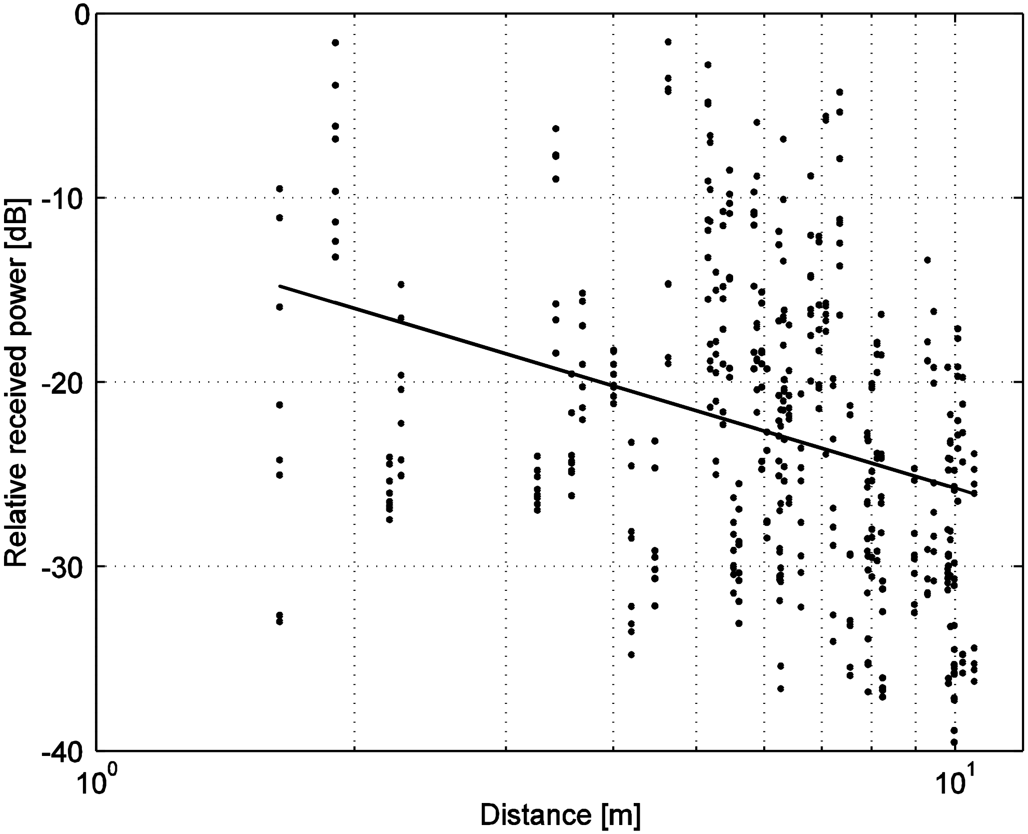
Total received power vs. link distance



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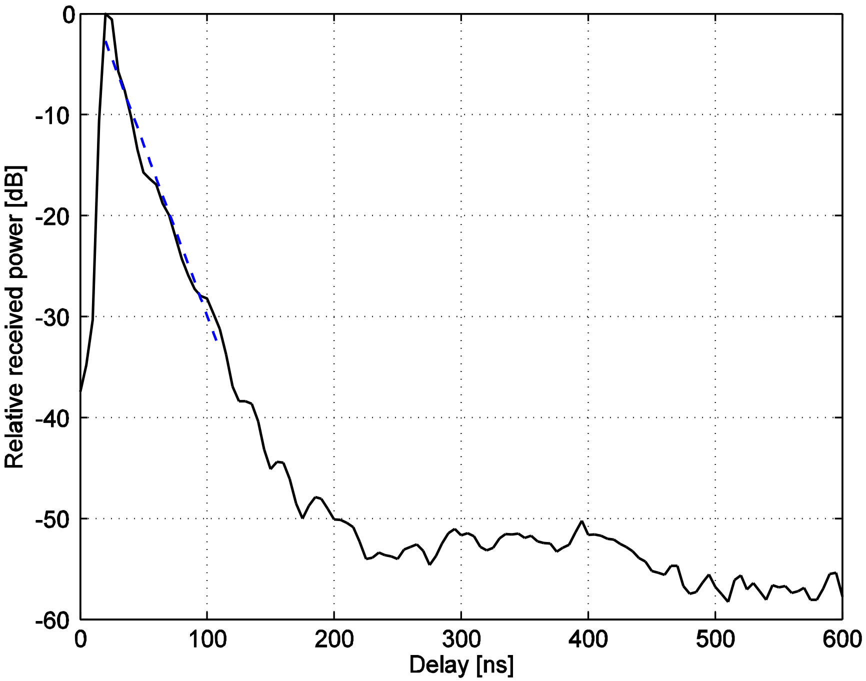
Power delay profile



- exponential decay

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

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

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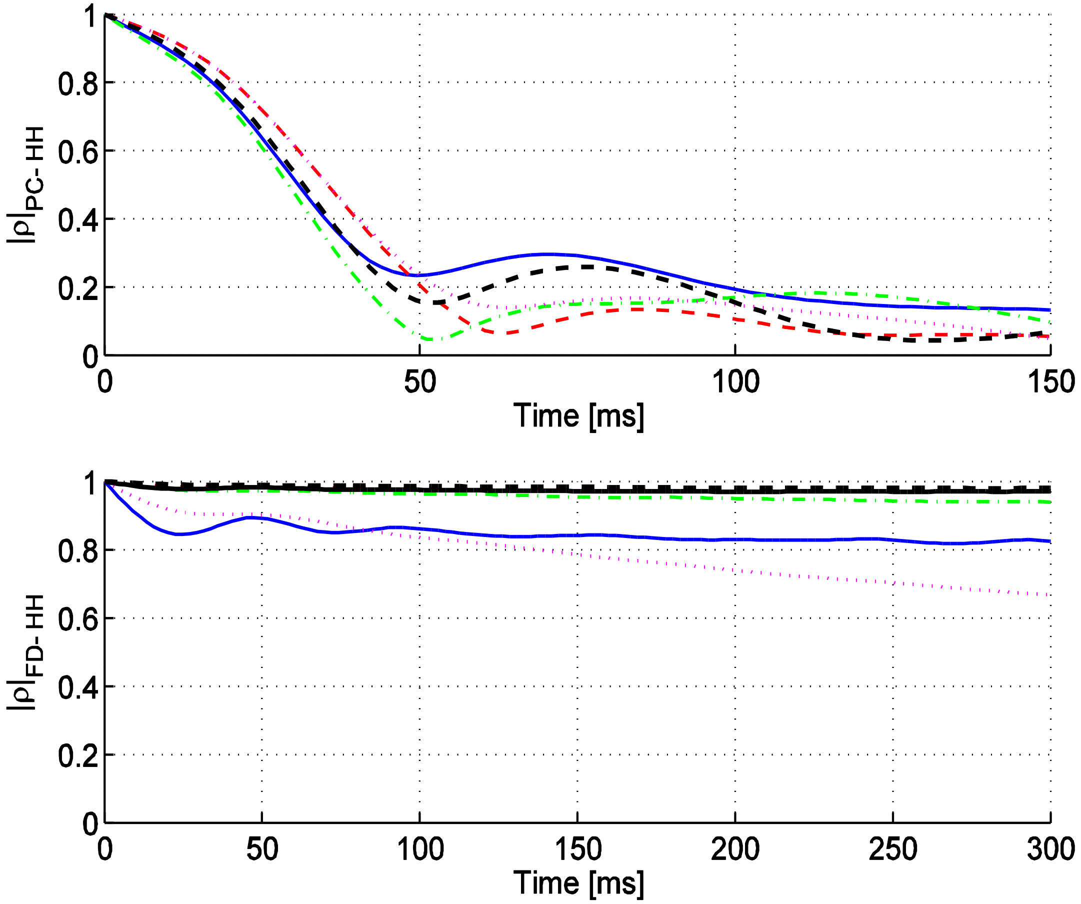
Variation of coherence time vs. measured environment



PC-HH

moving receiver

FD-HH

person moving in corridor

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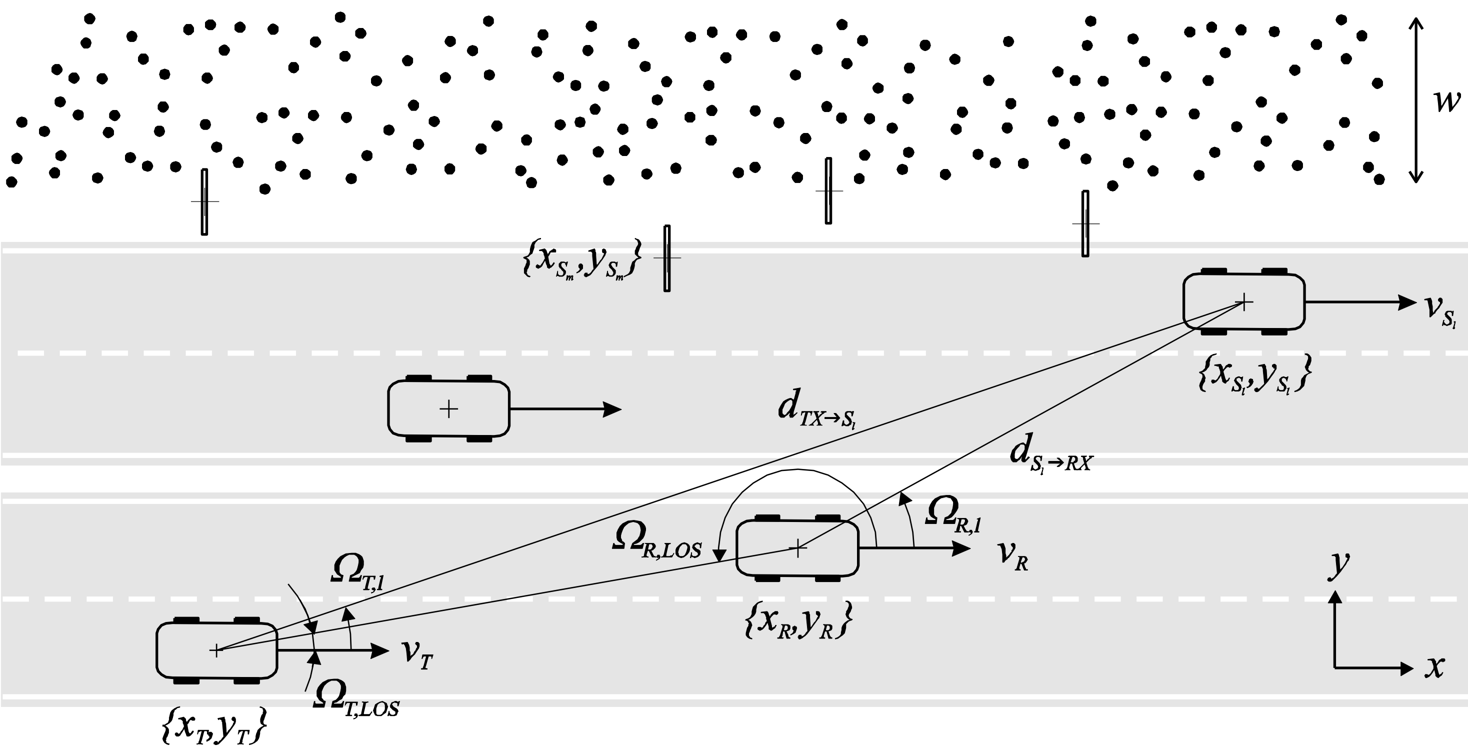
Car to car communication

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



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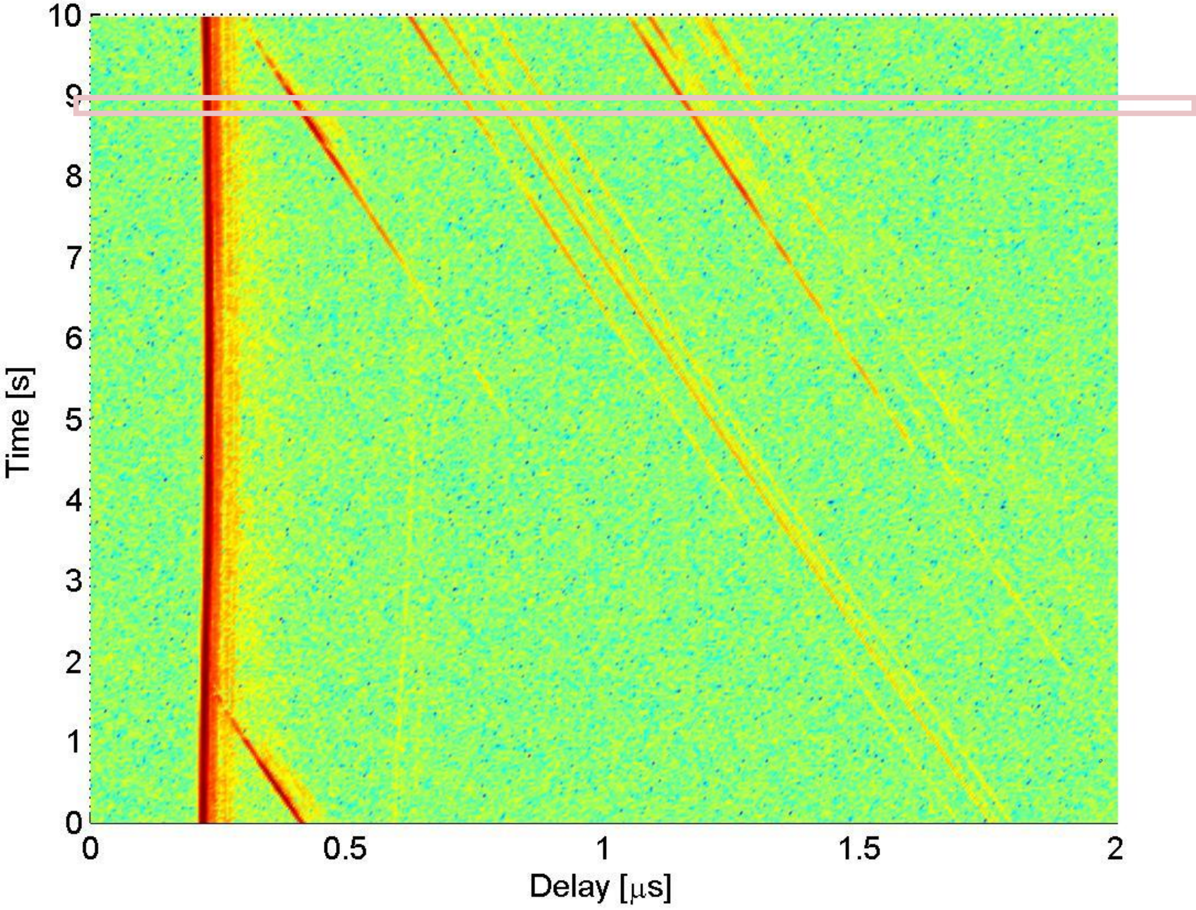
Time variant impulse response



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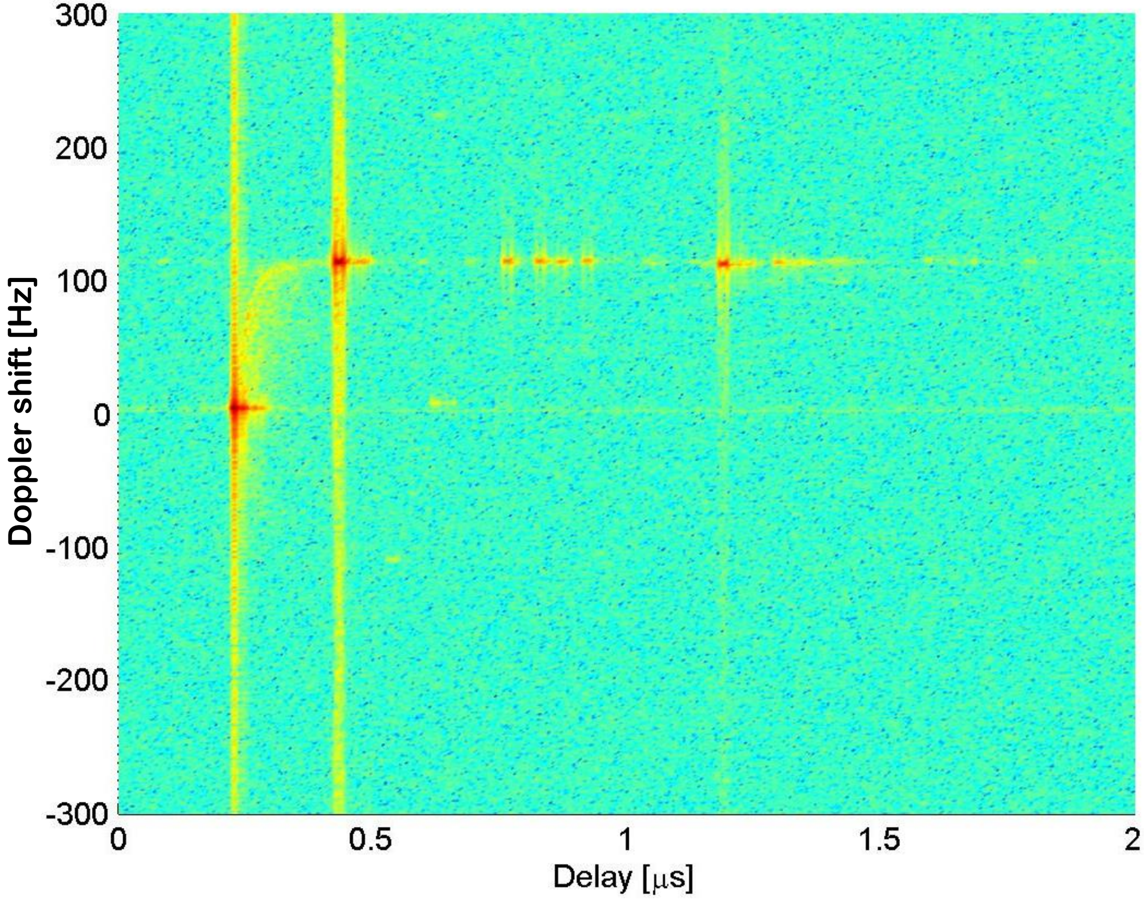
Scattering function, t=8.5-8.65 s



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UWB channel

- UWB bandwidth is relatively large compared to the carrier frequency
- Different frequency componnet see different propagation properties
- Statistical channel models are changed

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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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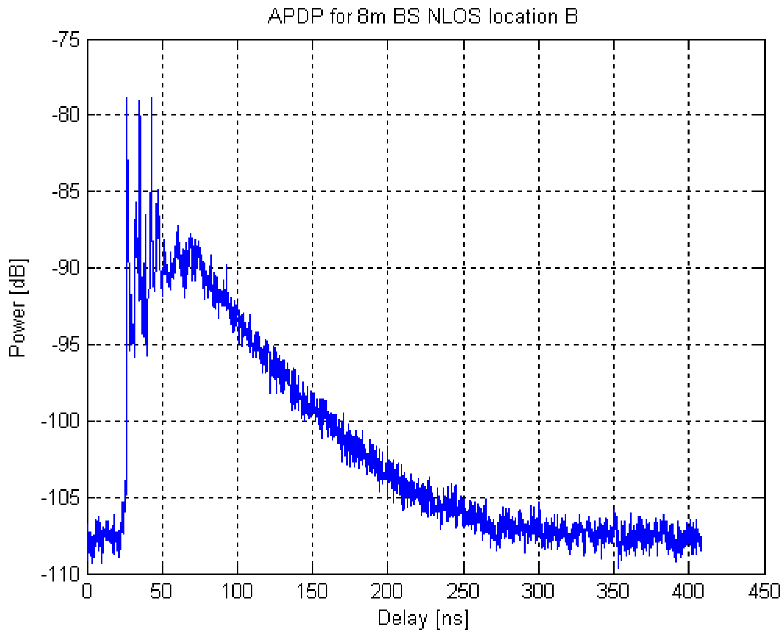
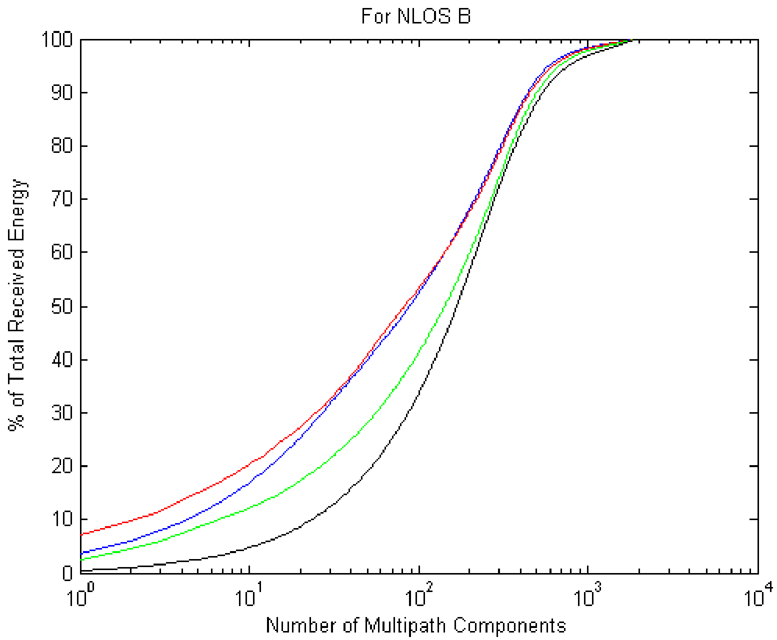
UWB channels – PDP





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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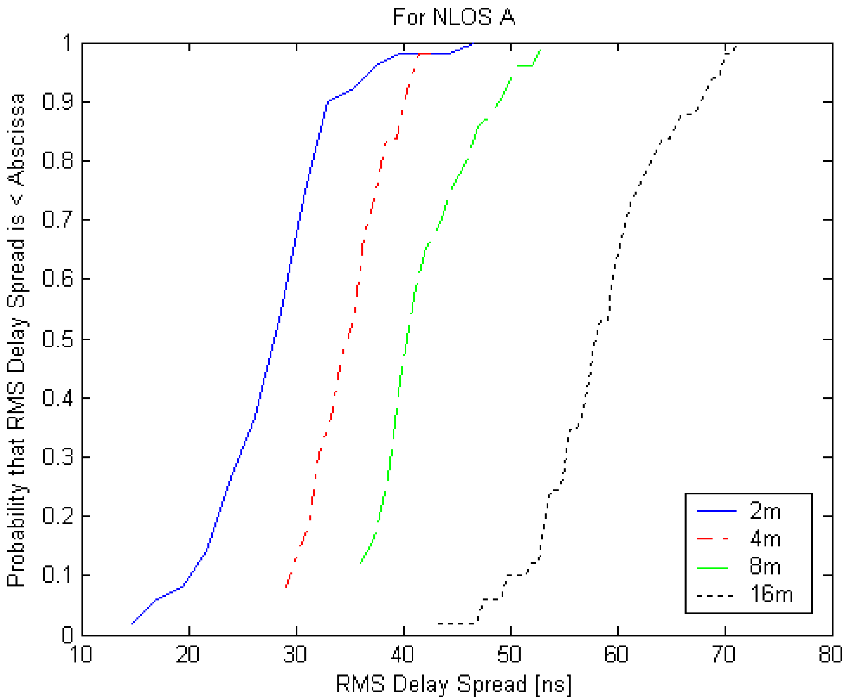
UWB channels

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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