Karlsruhe Institute of Technology

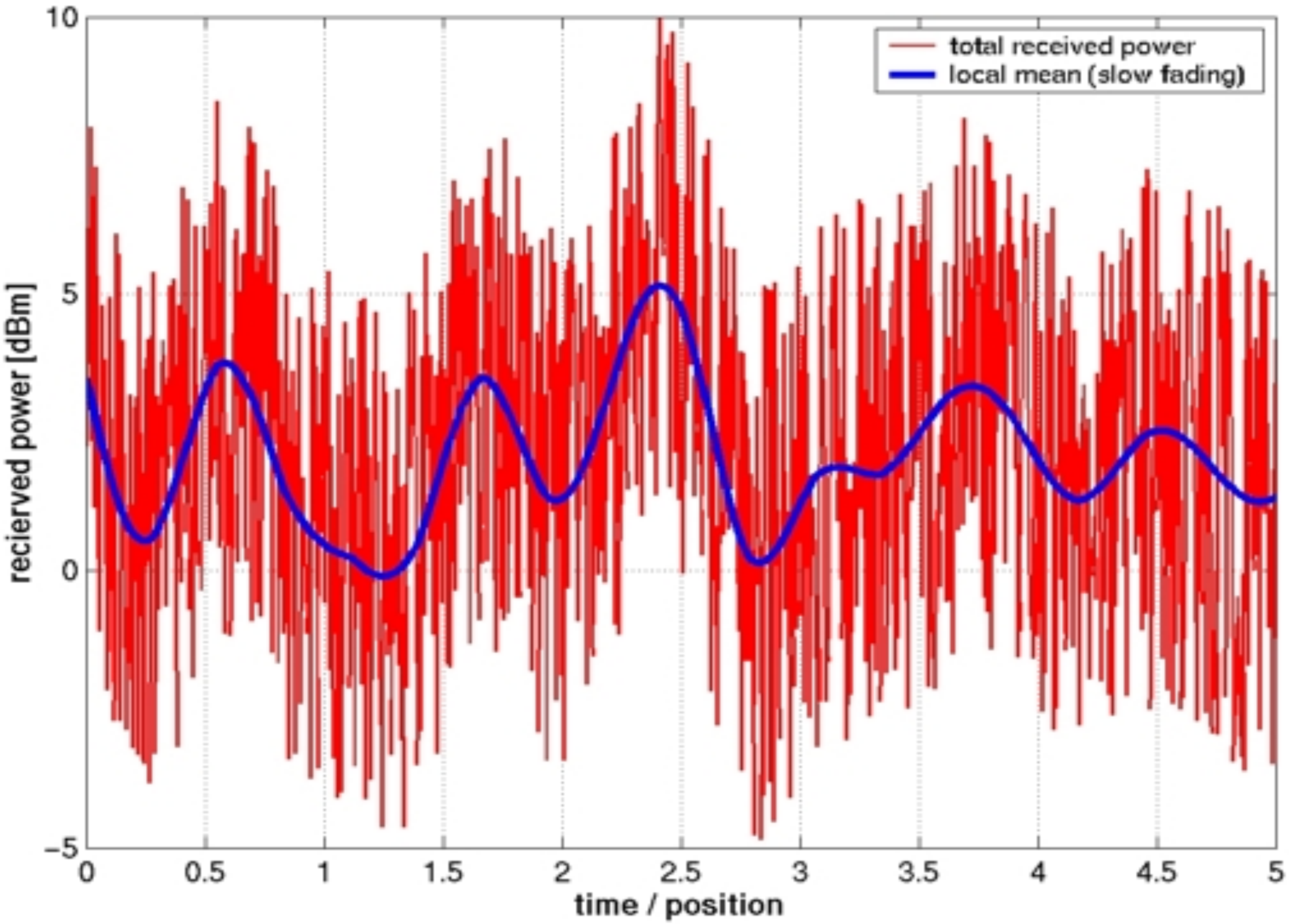
Time Varying and Frequency Selective Radio Channel

Advanced Radio Communication I

Prof. Dr.-Ing. Marwan Younis

INSTITUTE OF RADIO FREQUENCY ENGINEERING AND ELECTRONICS

Small-Scale Fading & Large-Scal Fading



small-scale fading: receiver moving through a spatial interference pattern.
large-scale fading: slow changes in the propagation environment.

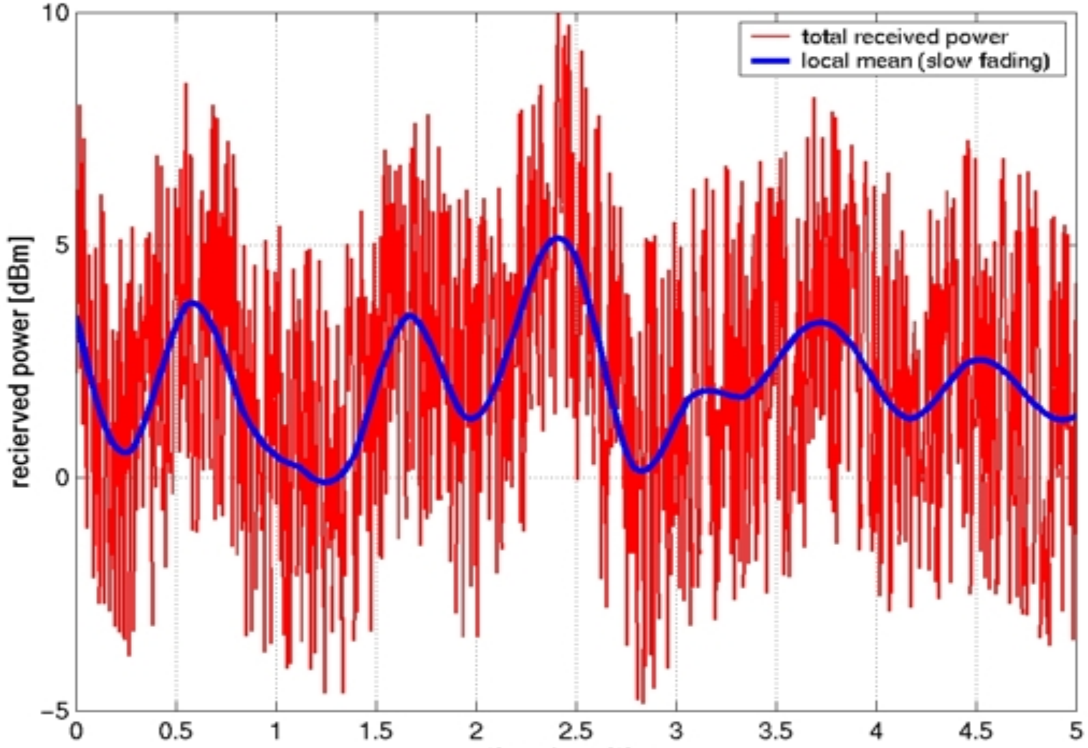
Multipath Effects

Multipath in the radio channel creates *small-scale fading* effects. This results in:

- rapid changes in signal strength over a small travel distance or time interval
- frequency selectivity caused by multipath propagation delays
- frequency modulation due to varying Doppler shifts on different multipath signals

Spatial and Temporal Variations

Consider a moving mobile station, a fixed base station and a static environment, i.e. only the mobile receiver is moving. Then, the *spatial variations* of the signal are seen as *temporal variations* by the receiver as it moves through the interference pattern



time or position

Factors Influencing Small-Scale Fading

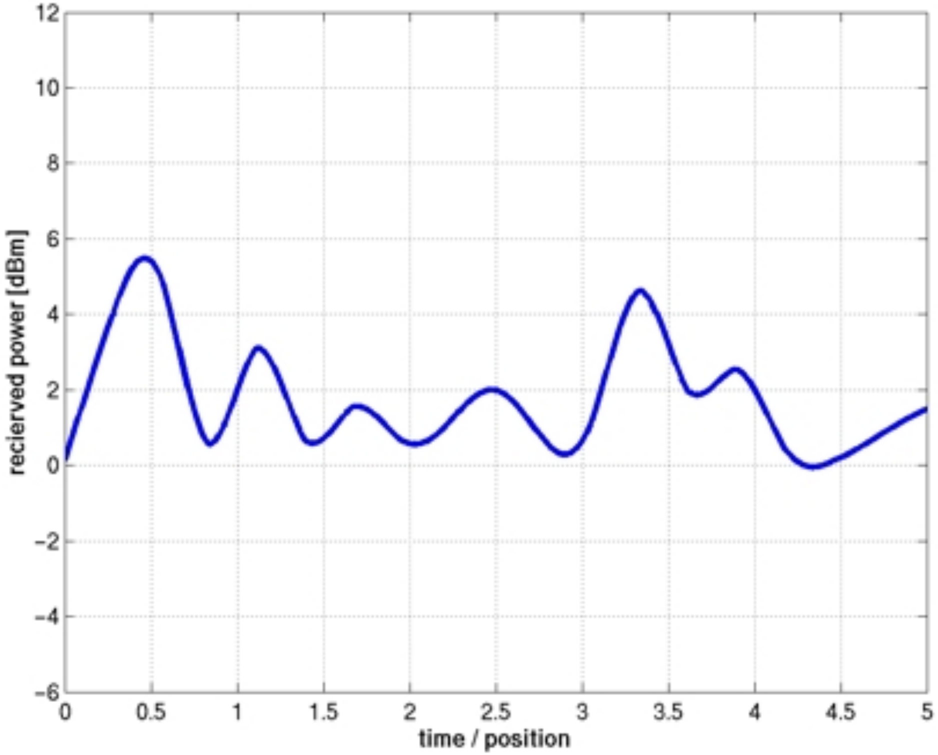
Channel Type:
- fixed-to-mobile
- line of sight (LOS) radio link
- satellite link
- stationary reception of TV/Radio
- …

Physical Factors:
- multipath propagation
- speed of the receiver
- speed of the surrounding objects
- signal bandwidth

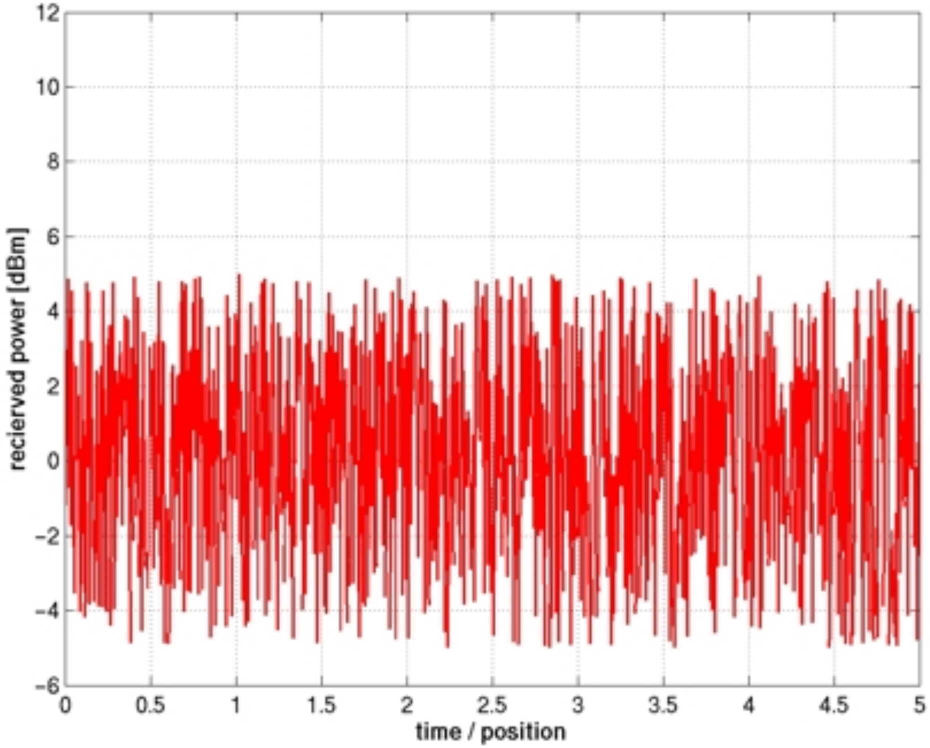
Small-Scale Fading

The Components of Fading

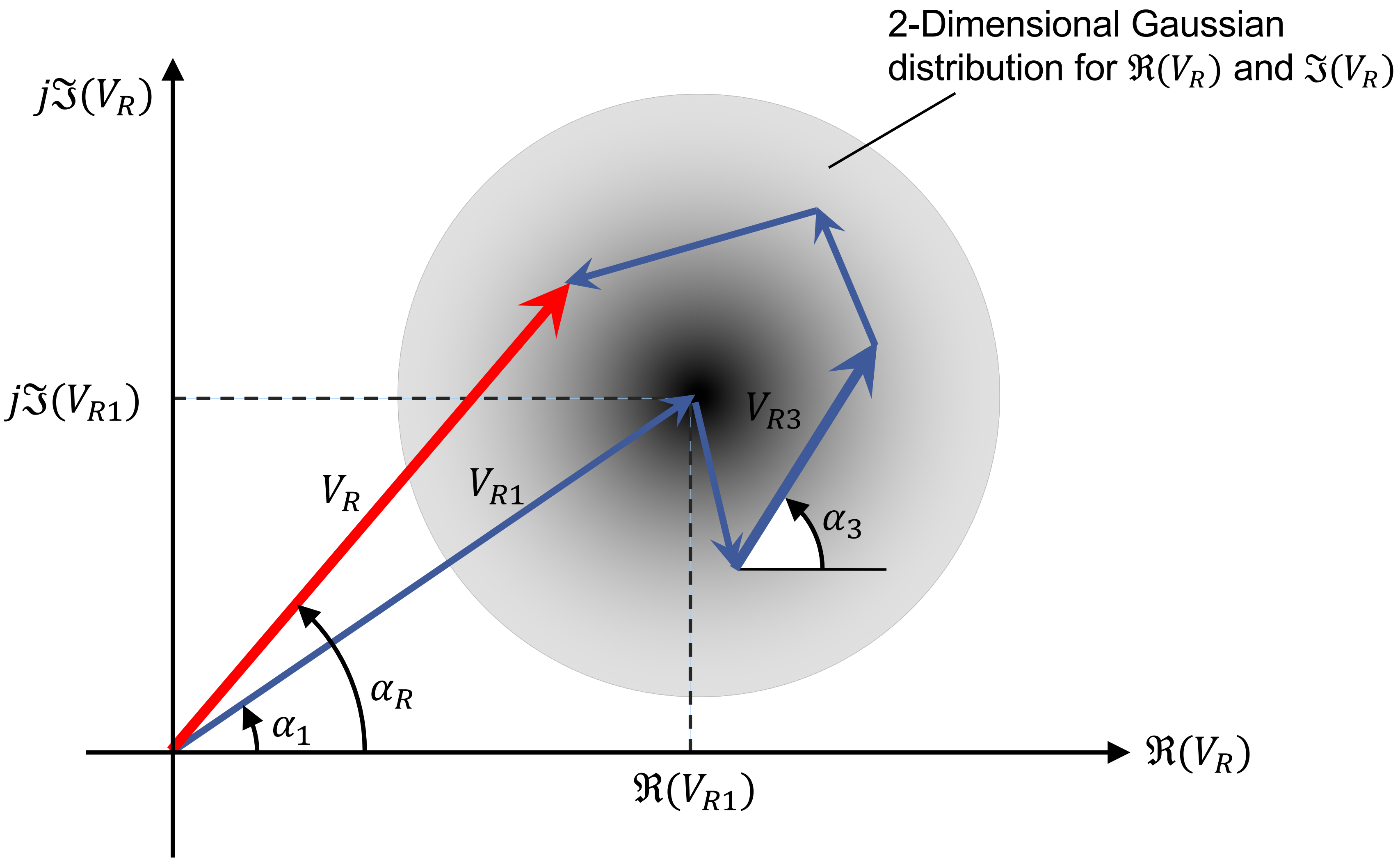
Larg-Scale Fading *m(t)*



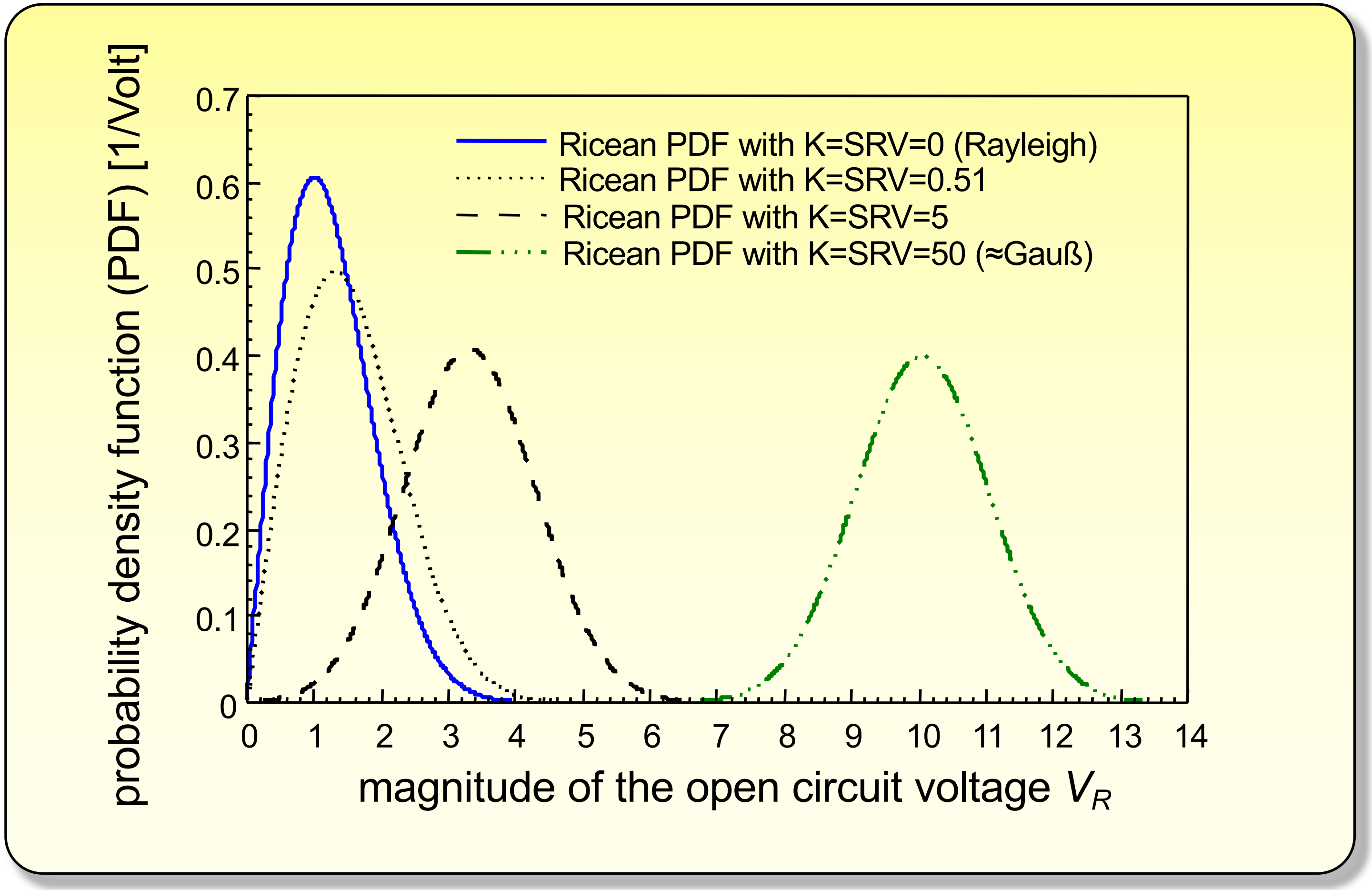
Small-Scale Fading *f(t)*



Superposition of Multipath Signals

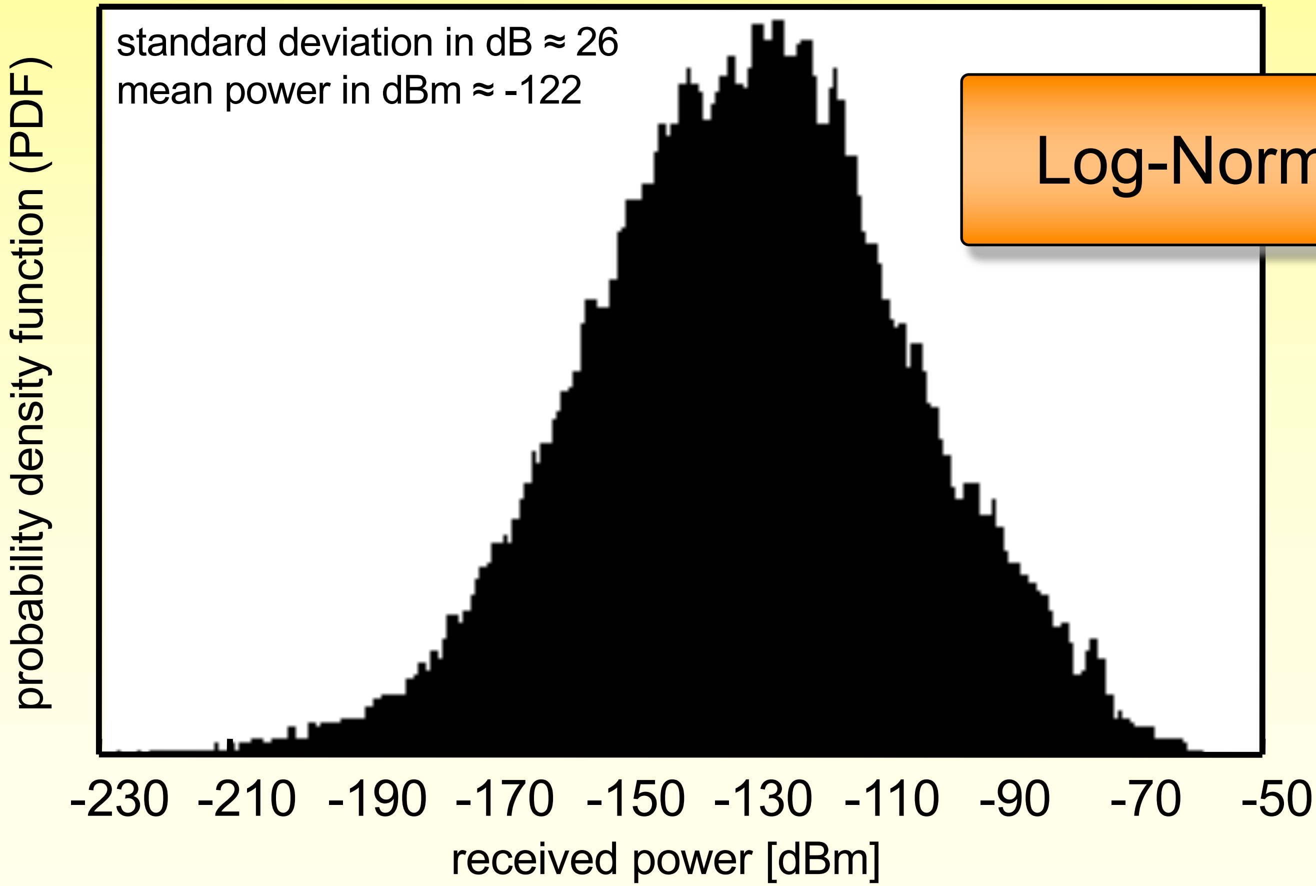


Probability Density Funciton



Large-Scale Fading
(Log-Normal Fading)

GSM1800 Coverage Simulation: Calculated Large-Scale PDF



Log-Normal Fading

Questions

Question 1:

Multi-Path creates small scale fading. What are the effects of fading?

Question 2:

Which physical factors (multipath, speed of Rx, movements of objects) are relevant for a satellite TV downlink?

Question 3:

What is the probability density function of the sum of a large number of independent random variables?

Question 4:

Which are the condition(s) to obtain a Rayleigh distribution for the magnitude of the Rx signal in a small-scale fading environment?

Question 5:

What does the Ricean factor *K* describe?

Question 6:

What probability density function describes large scale fading characterized

Channel Transfer Function and Impulse Response

Channel Transfer Function and Impulse Response

The channel, the input signal and the output signal are modeled as linear time variant. Then they are completely described in:

- Time Domain (time variable τ)
- Frequency Domain (frequency variable f)

In the time domain the channel, the input signal and the output signal are real quantities. Further, there DC component must be 0.

output — channel — input

$$r(\tau) = h(\tau) * s(\tau)$$

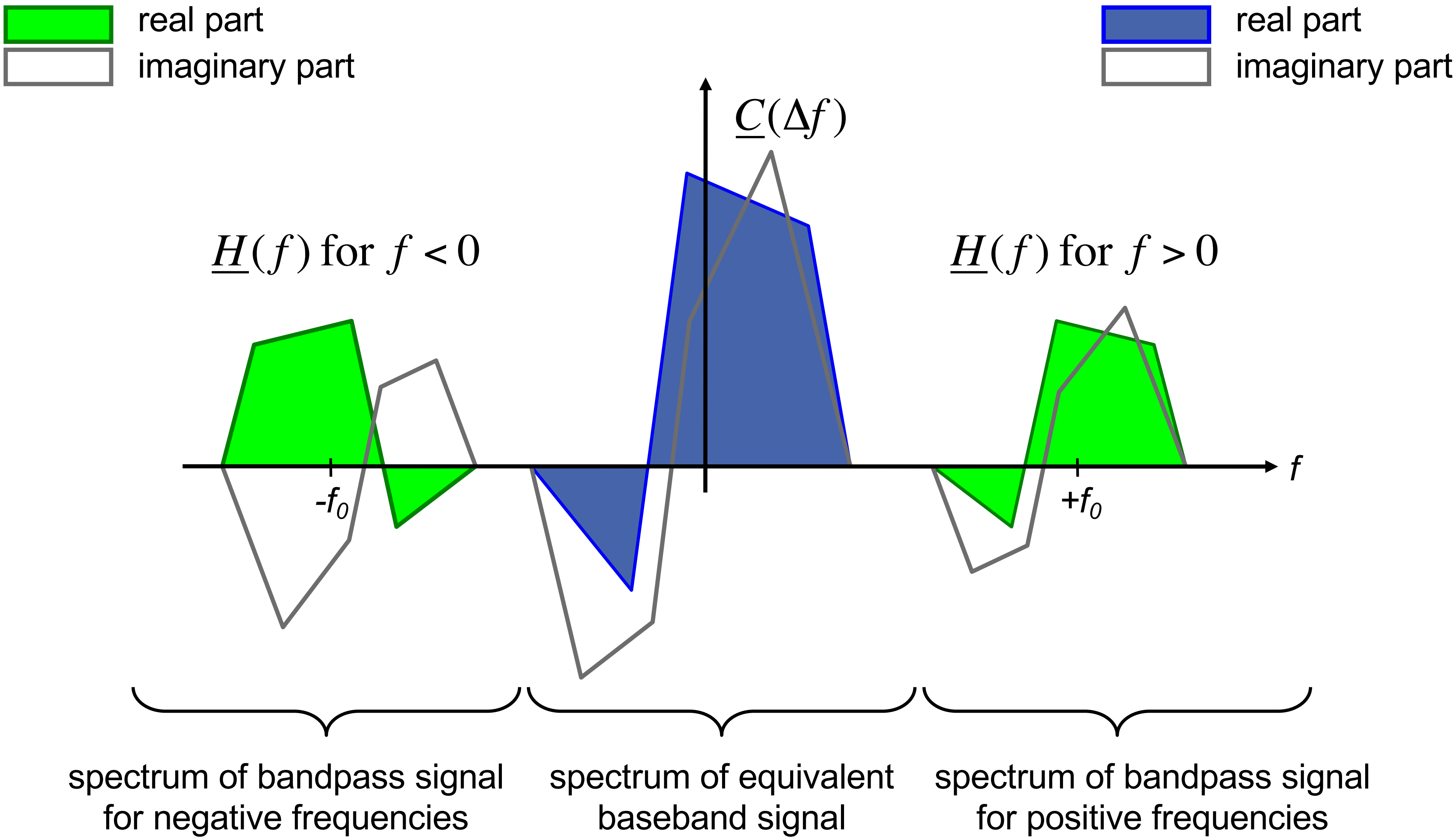
convolution

$$\circ\!\overset{\tau}{-}\!\bullet$$

output — channel — input

$$\underline{R}(f) = \underline{H}(f) \cdot \underline{S}(f)$$

Bandpass and Equivalent Baseband Signals



Channel Transfer Function and Impulse Response

Karlsruhe Institute of Technology

The channel, the input signal and the output signal are modeled as linear time variant. Then they are completely described in:

- Time Domain (time variable τ)
- Frequency Domain (frequency variable f)

Since all signals are band-limited (bandpass) the equivalent (complex) baseband representation can be used (known as low-pass or complex envelope)

Time domain (output, channel, input):

$$r(\tau) = h(\tau) * s(\tau) \quad \overset{\tau}{\circ\!-\!\bullet}$$

Frequency domain (output, channel, input):

$$\underline{R}(f) = \underline{H}(f) \cdot \underline{S}(f)$$

← bandpass

$$\underline{V}(\Delta f) = \frac{1}{2}\underline{C}(\Delta f) \cdot \underline{X}(\Delta f)$$

← equivalent baseband

Channel Transfer Function and Impulse Response

$$\underline{S}(f) \rightarrow \boxed{\underline{H}(f)} \rightarrow \underline{R}(f)$$

bandpass

$$\underline{X}(\Delta f) \rightarrow \boxed{\underline{C}(\Delta f)} \rightarrow \underline{V}(\Delta f)$$

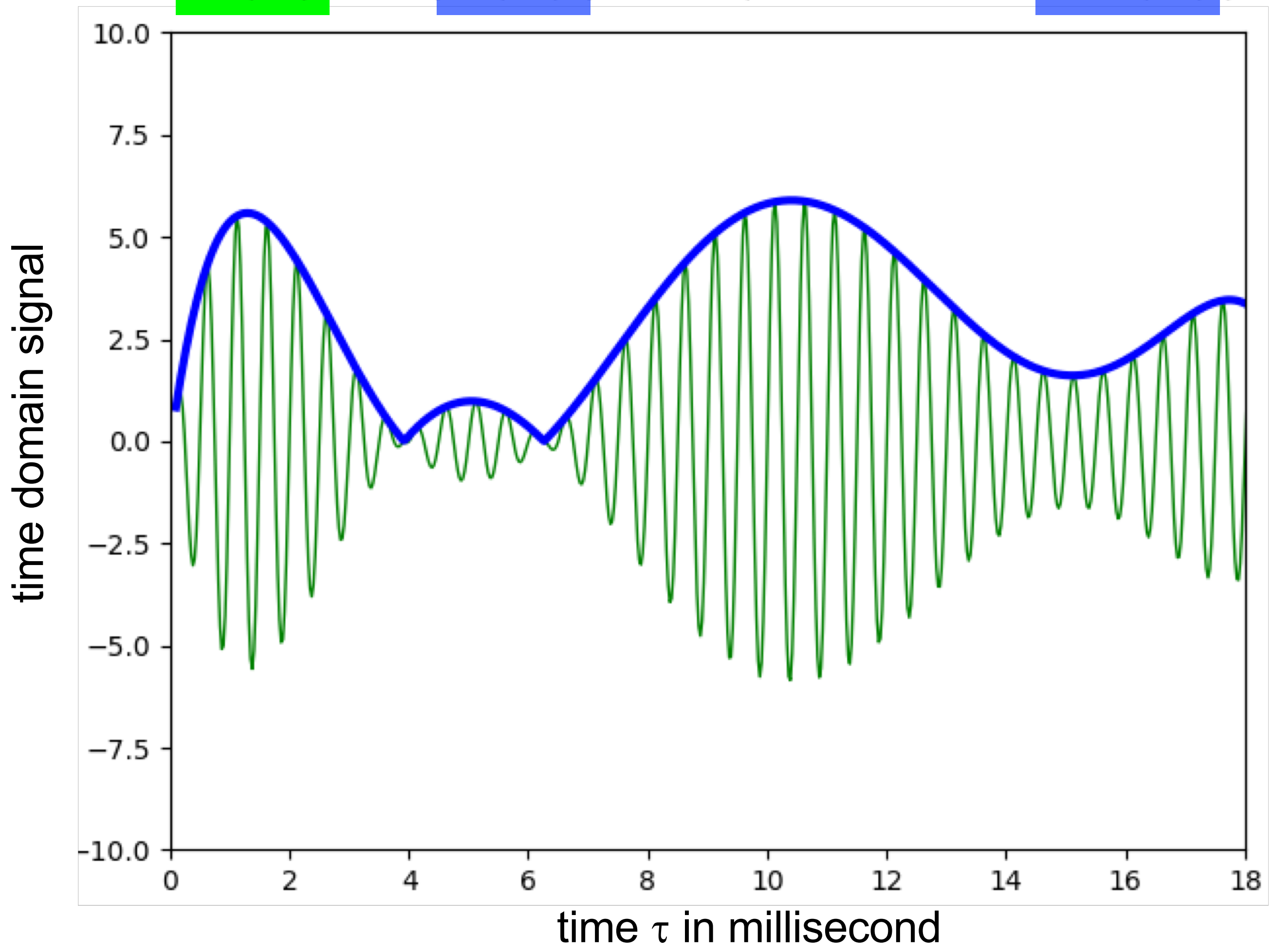
equivalent baseband

$$h(\tau) = |\underline{c}(\tau)| \cos\left(2\pi f_0 \tau + \angle \underline{c}(\tau)\right)$$

$$\underline{H}(f) = \frac{1}{2}\underline{C}(f - f_0) + \frac{1}{2}\underline{C}^*(-f - f_0)$$

Bandpass Signal and its Complex Envelope

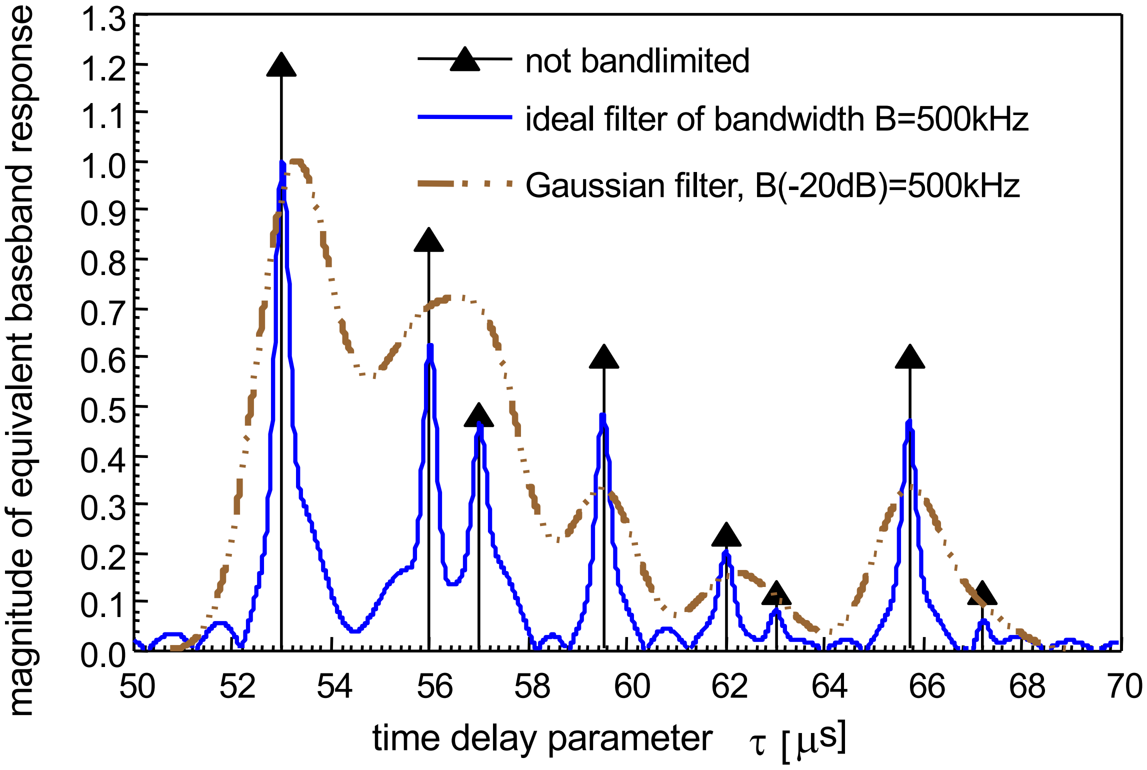
$$h(\tau) = |\underline{c}(\tau)| \cos\left(2\pi f_0 \tau + \angle \underline{c}(\tau)\right)$$



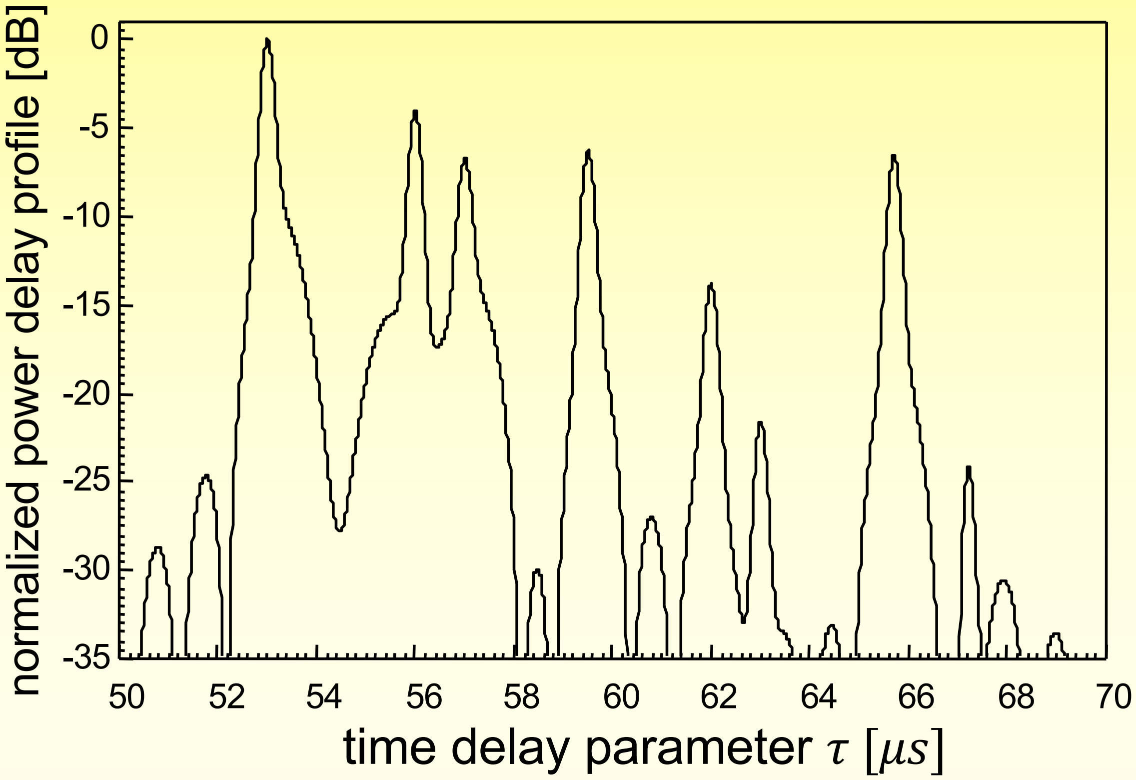
Characterization of the Frequency-Selective Channel

– Time Domain –

Band-Limited Impulse Response Function



Normalized Power Delay Profile



Frequency-Selective Channel

The radio channel can be characterized:

- in the time domain by the impulse response
- in the frequency domain by the channel transfer function

In the time domain, the characterization is based on the power delay profile (PDP) function which describes the relative received power as a function of the delay.

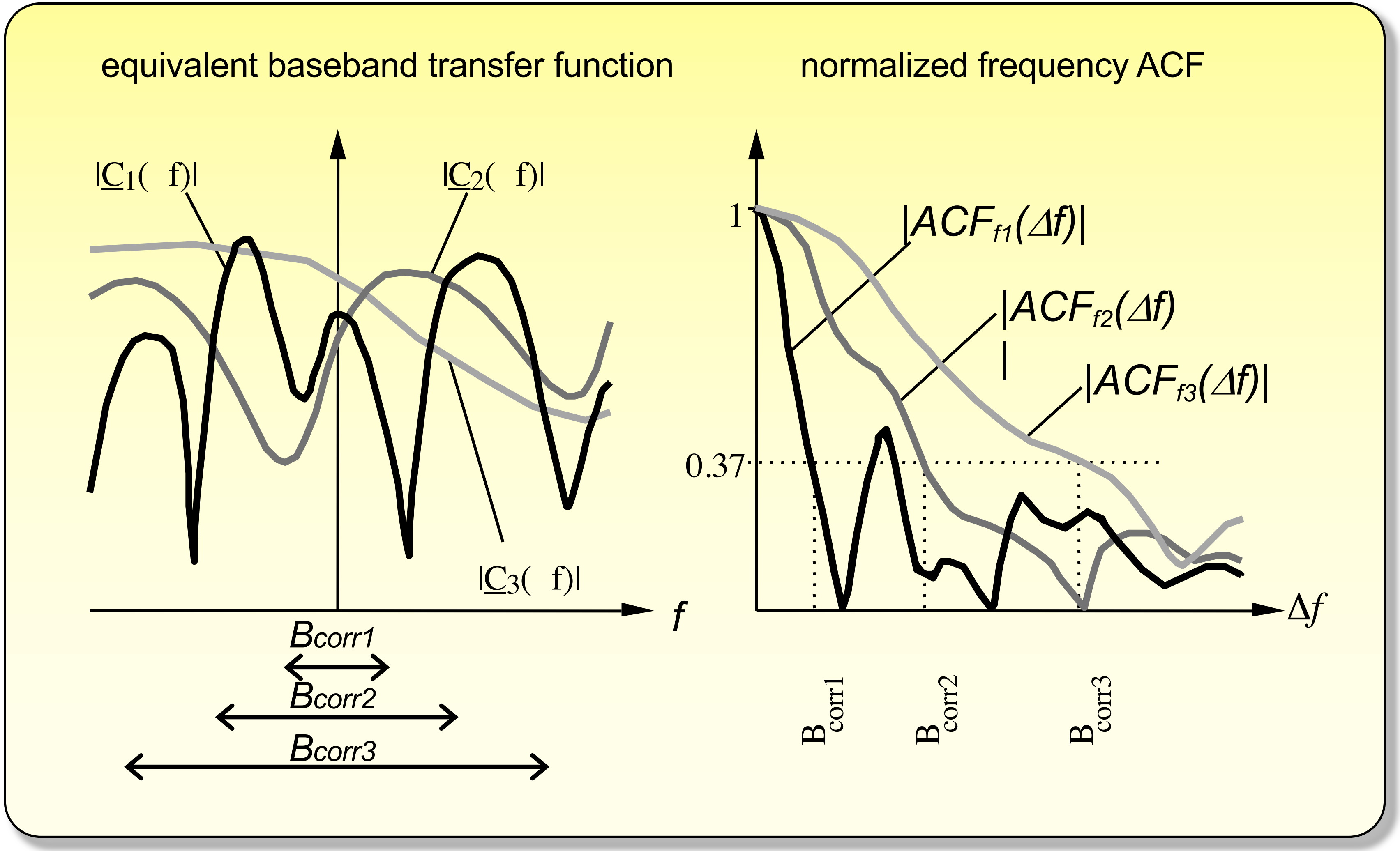
In order to compare different channels, parameters which quantify the channel are utilized. The mean excess delay and the RMS delay spread are parameters determined directly from the PDP

Characterization of the Frequency-Selective Channel

– Frequency Domain –

Institute of Radio Frequency Engineering
and Electronics

BB Transfer Function and Correlation Bandwidth

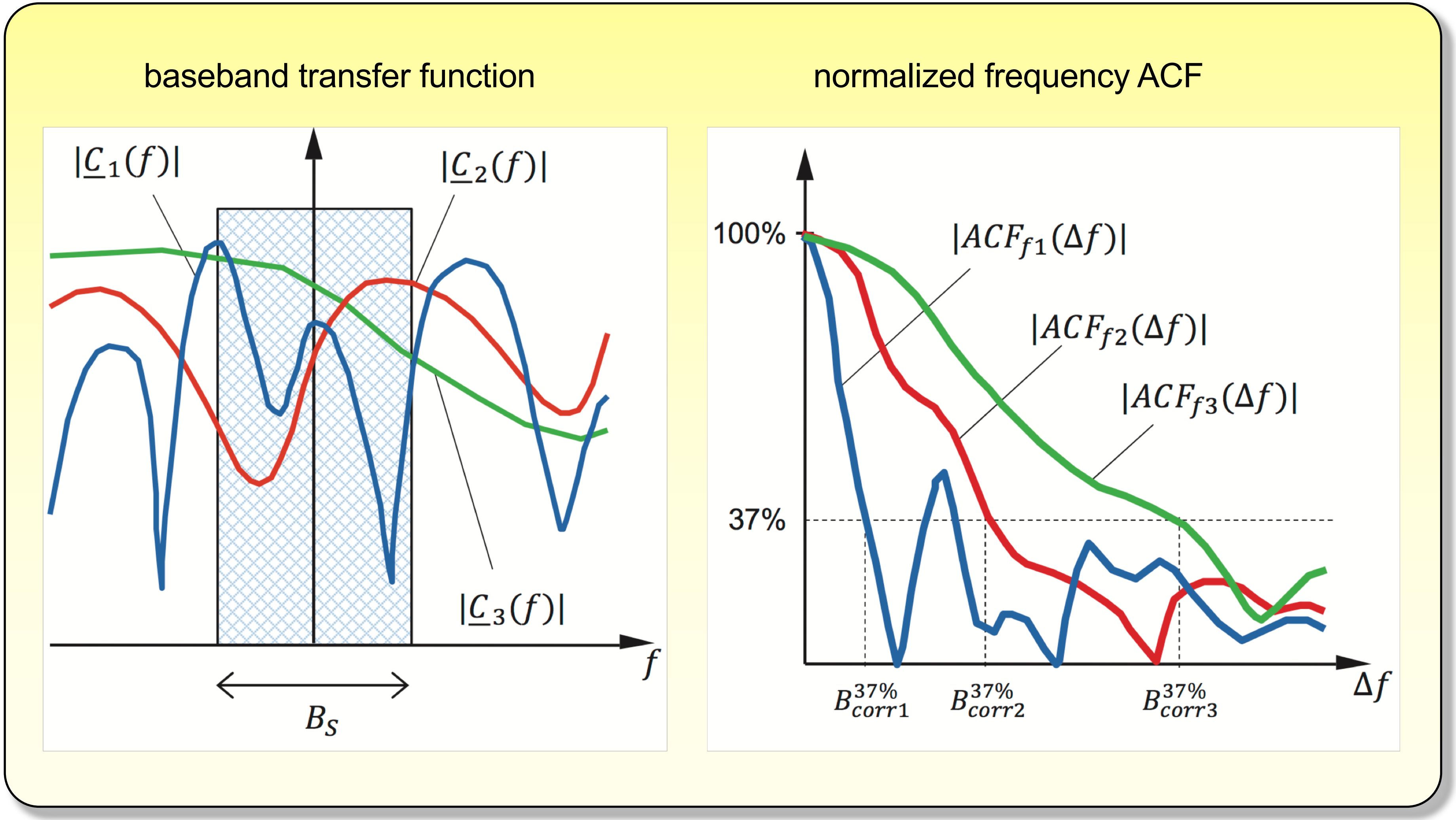


Frequency-Selective Channel

In the frequency domain, the characterization is based on the frequency autocorrelation function (ACF) which describes over which frequencies the channel is flat.

In order to compare different channels, parameters which quantify the channel are utilized. The coherence or correlation bandwidth is a parameters determined directly from the frequency ACF

Relating the Channel to the Signal

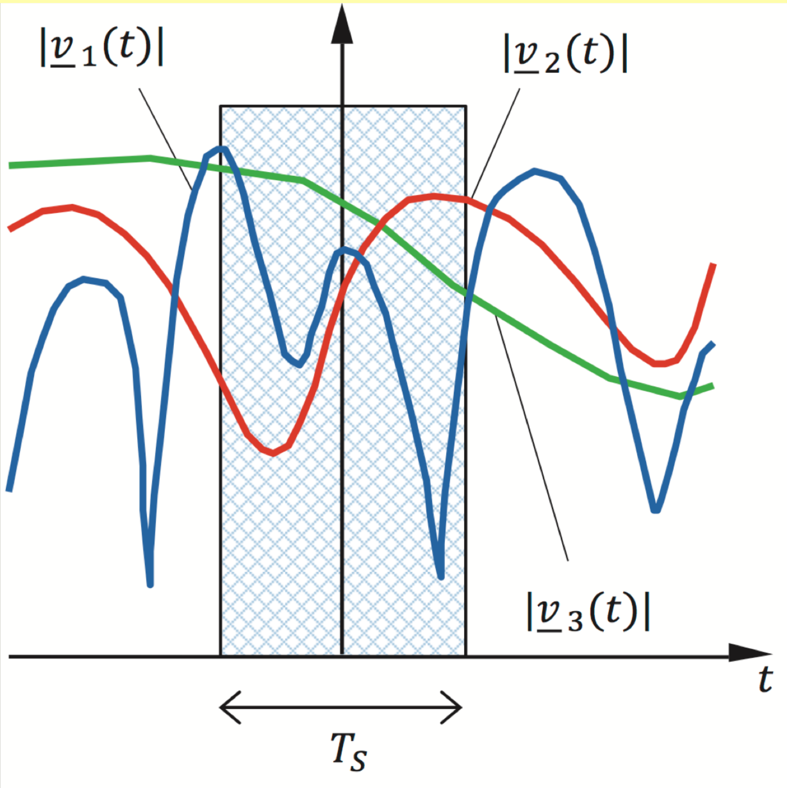


Characterization of the Time-Variant Channel

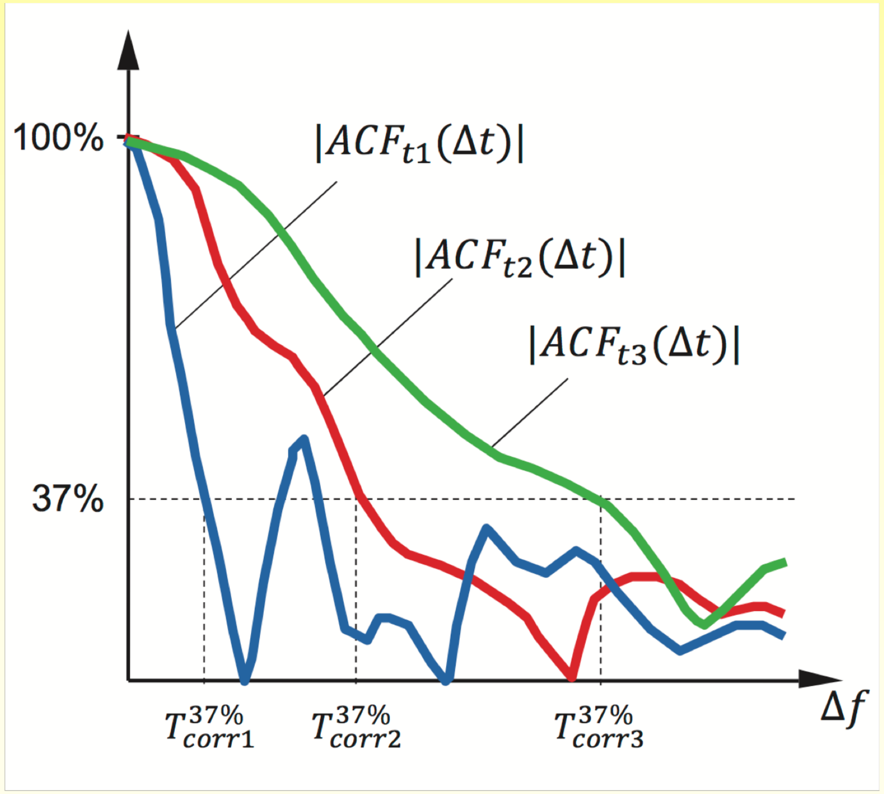
– Time Domain –

Signal Envelope and Coherence Time

time-varying envelope



normalized temporal ACF



Characterization of the Time-Variant Channel

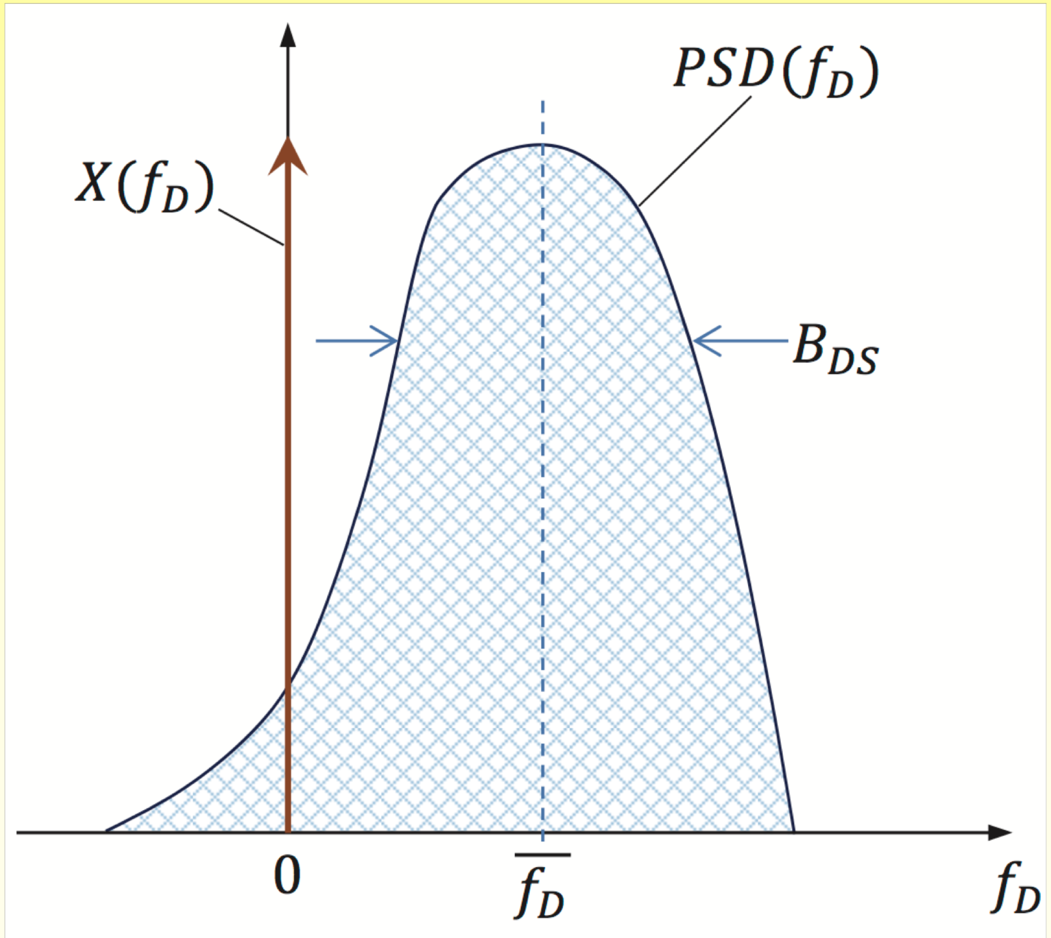
In the time domain, the characterization is based on the temporal autocorrelation function (ACF) which describes how fast the channel changes in time.

In order to compare different channels, parameters which quantify the channel are utilized. The coherence or correlation time is a parameters determined directly from the temporal ACF

Characterization of the Time-Variant Channel

– Frequency Domain –

Power Spectral Density (power Doppler Spectrum)



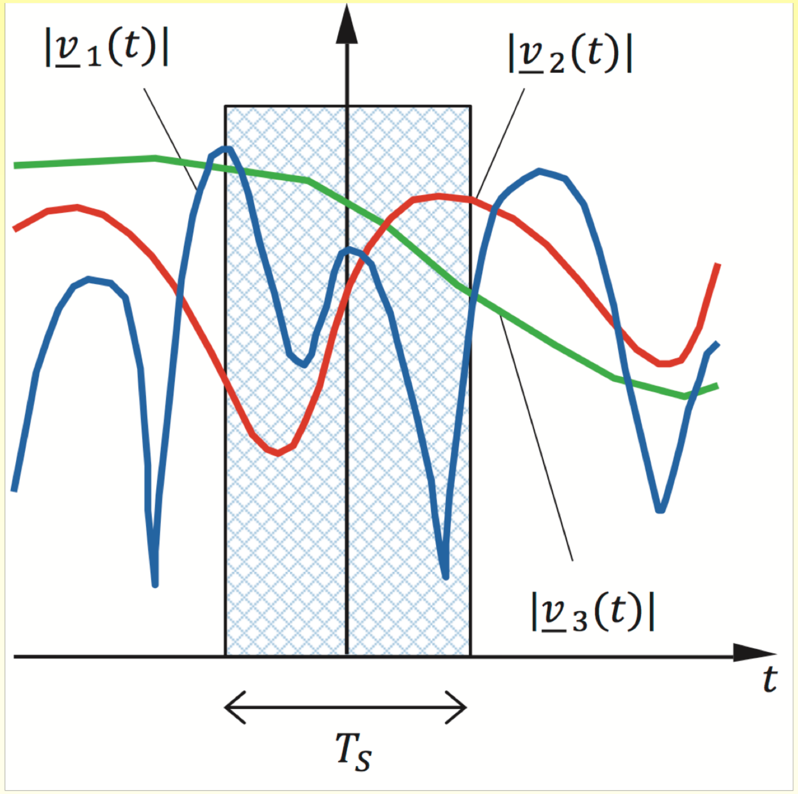
Characterization of the Time-Variant Channel

In the frequency domain, the characterization is based on the Power Spectral Density (PSD) or power Doppler spectrum (function) which is the received power spectrum for a pure sinusoidal transmitted signal.

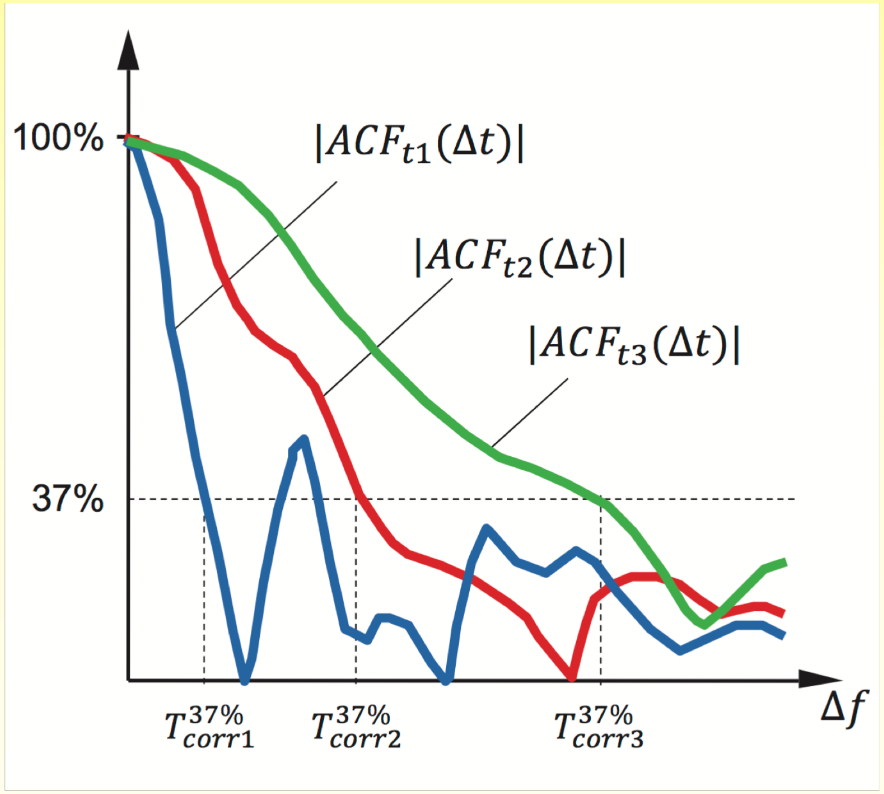
In order to compare different channels, parameters which quantify the channel are utilized. The Doppler spread is a measure of the spectral broadening.

Signal Envelope and Coherence Time

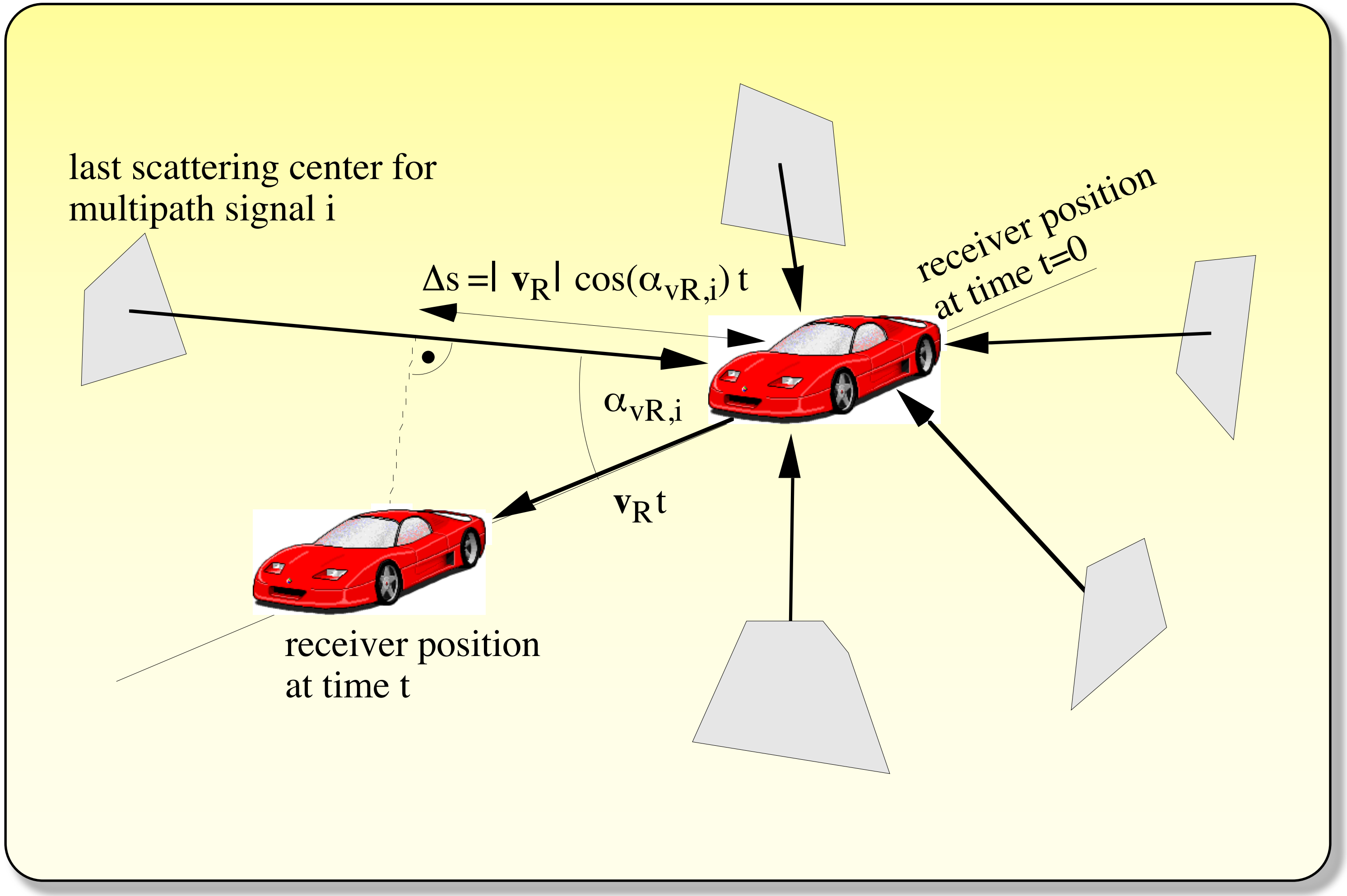
time-varying envelope



normalized temporal ACF



Geometry for Multipath Wave Propagation



Jakes Doppler Spectrum