Wireless Communications Channels
Lecture 1: Introduction

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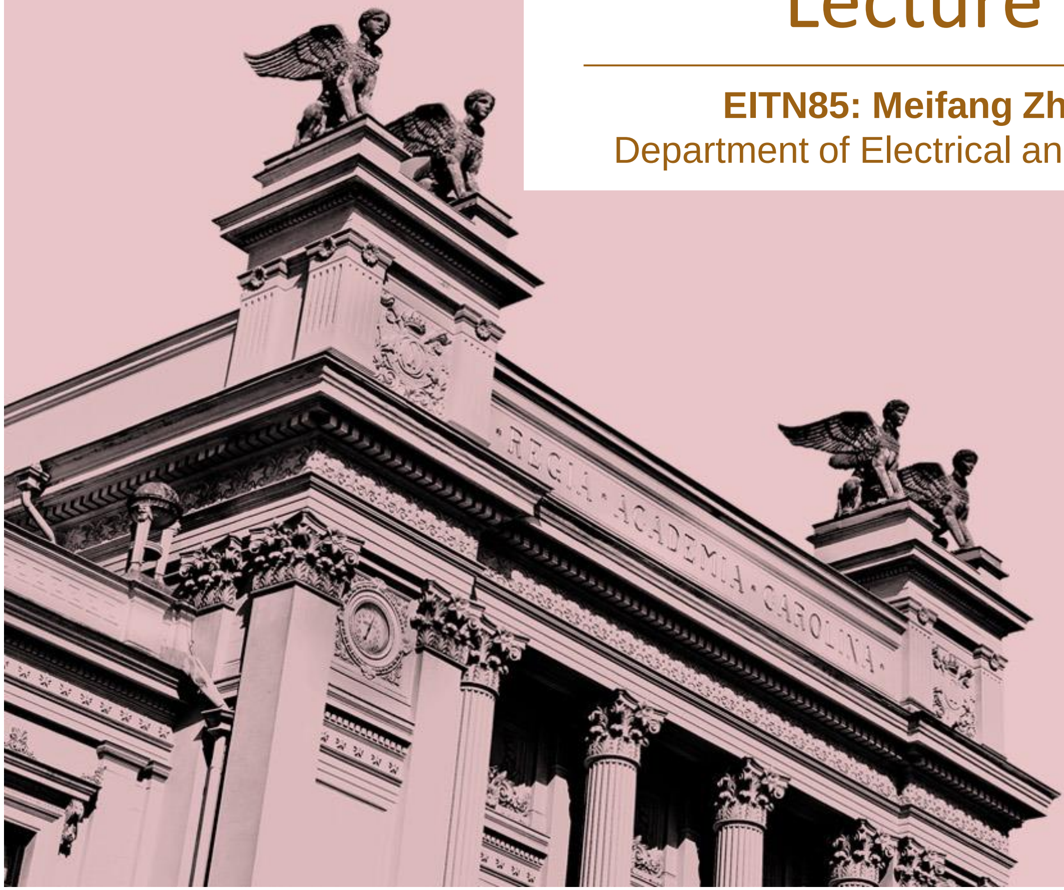

Lecture contents

- Course information and introduction
- Why care about wireless propagation channels?
- Review of concepts and techniques

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Course website

- All course information is available at:

  http://www.eit.lth.se/course/EITN85

(or www.eit.lth.se, -Education, -Courses, -Wireless Prop.)

- Most important:
  - Continuously updated schedule
  - Lecture handouts (available before each lecture)
  - Any additional material

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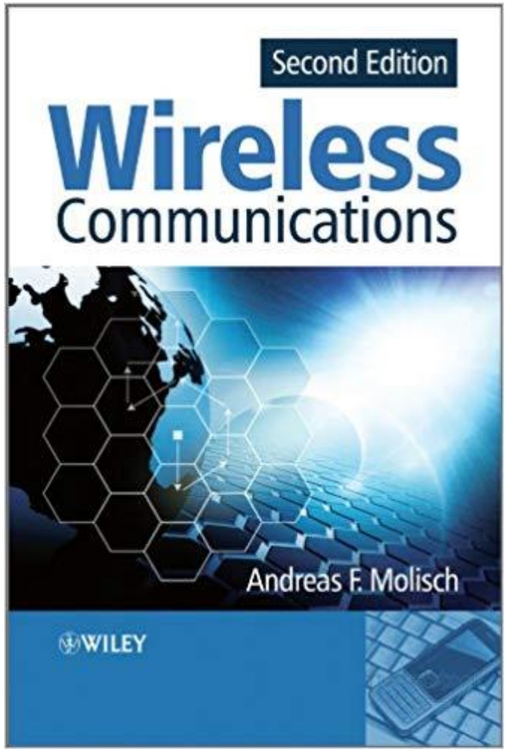
Course textbook



Andreas F. Molisch

Wireless Communications, 2^{nd} ed

ISBN: 978-0-470-74186-3

Wiley/IEEE press

The second edition will be used!

- Available, e.g., through:
  - Lexis, www.lexis.se
  - Amazon U.K., www.amazon.co.uk
  - Wiley, eu.wiley.com
  - etc.
- Authored by Andreas F. Molisch, former professor of Radio Systems at Lund University/LTH.

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Schedule

- Recurring components (with some exceptions)
  - **Lectures: Meifang Zhu**
    Mondays (13-15, E:3139)
    Tuesdays (10-12, E:3139) **(first two weeks only)**
    Fridays (10-12, V:S1)
  - **Exercise classes: Guoda Tian**
    Wednesdays (8-10), E:4148
- **Two** special components:
  - **Assignments/Projects:**
    ***Three* assignments, where *reports* are handed in**
  - **Exam**: week 11: Details TBA

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Oral Exam + Written Exam

- **How?**
  - Approximately 3.5 hours long , Oral Exam (upto 2.5 hours), Written Exam (upto 1 hour)
  - Both conceptual questions and calculations
  - “A group discussion”, but also with individual questions
  - No assignments, no oral exam!
- **When?**
  March 14
- **Where?**
  Further information closer to the date

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Lectures

- Overview of the content in the textbook
- Important materials and explanations
- Chance to have a joint discussion about the principles learned
- Application examples

Exercise classes

- A selection of suitable exercises is listed on the course website

- During exercise classes, some of the exercises will be analysed in detail

- By working through the exercises beforehand, it becomes easier to ask questions about the parts You find difficult.

Assignments/Projects

- There are **three** compulsory assingments.
- Performed in groups of two students.
- You will receive measured channel data in MATLAB-format,
  - analysis
  - parameter extraction
  - conclusions
- Short reports are handed in within 7 days.
- You are **NOT** allowed to share results or code between groups!
- **THIS IS A COMPULSORY PART OF THE COURSE!**
- **You need to submit the assignments in order to take the oral exam.**

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Covid

1. **Stay at home if you have any symptom even it is really minor**
2. **Keep distance while entering and leaving the classroom**
3. **Try to come to the classroom as close as possible to the lecture time to avoid the crowd in the corridor outside the classroom. If waiting outside the classroom is needed, try to stand spread over the corridor.**
4. **Lecture can be changed into online while for example, the teacher has symptoms or more than half of the student cannot attend due to symptoms. It can be a last minute call depending on how the situation changes. (email)**
5. **Leture vedios from last year are avaliable, not 100% idential but can be good references.**

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Wireless Propagation – Let's begin!

But first....

What about Wired Channels?

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Why worry about propagation channels?

- The performance of a radio system is ultimately determined by the channel over which communication takes place
- The radio channel is the basis for:
  - system design, and field performance (bits/seconds)
  - architectures at both the transmitter and receiver
  - signal processing requirements/design at both link ends: channel estimation, power control, spatial beamforming, radio resource optimization
  - antenna design, the list goes on..
- Knowledge about system and channel interaction is vital

Without reliable channel models, it is difficult to design radio systems that work well in *real* environments.

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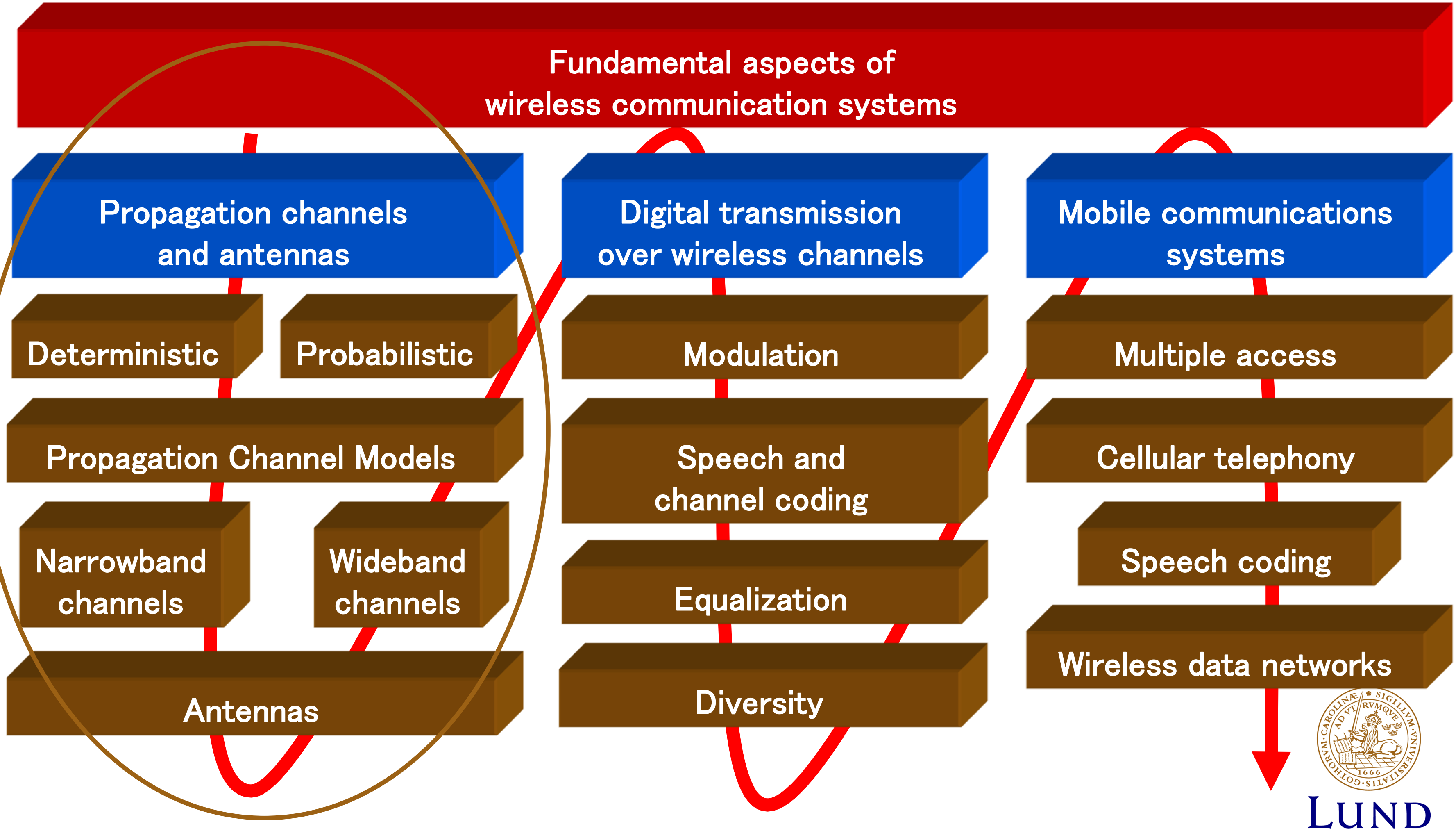
Different Aspects of Wireless Systems



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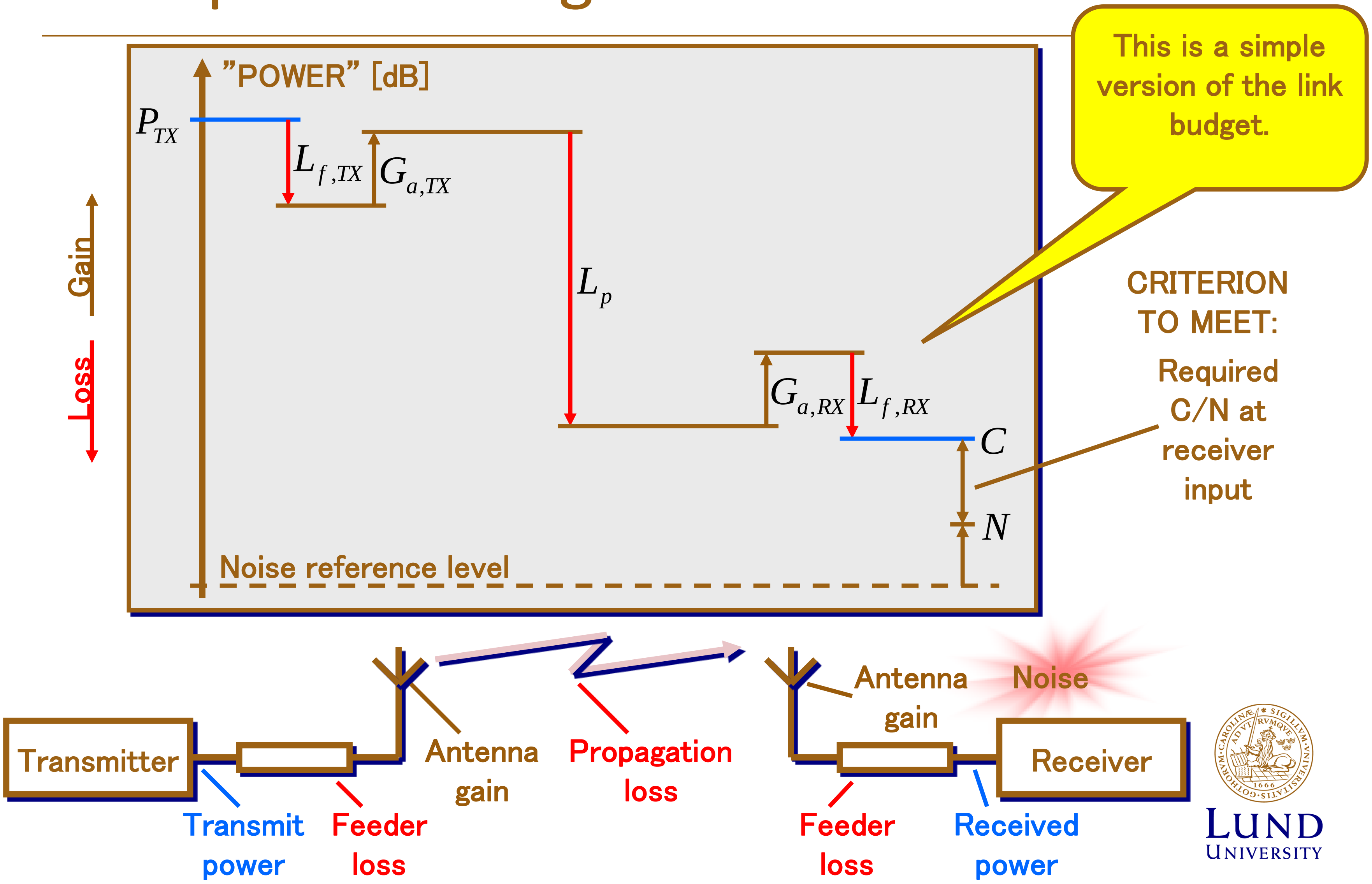
THE RADIO CHANNEL

A simple link budget



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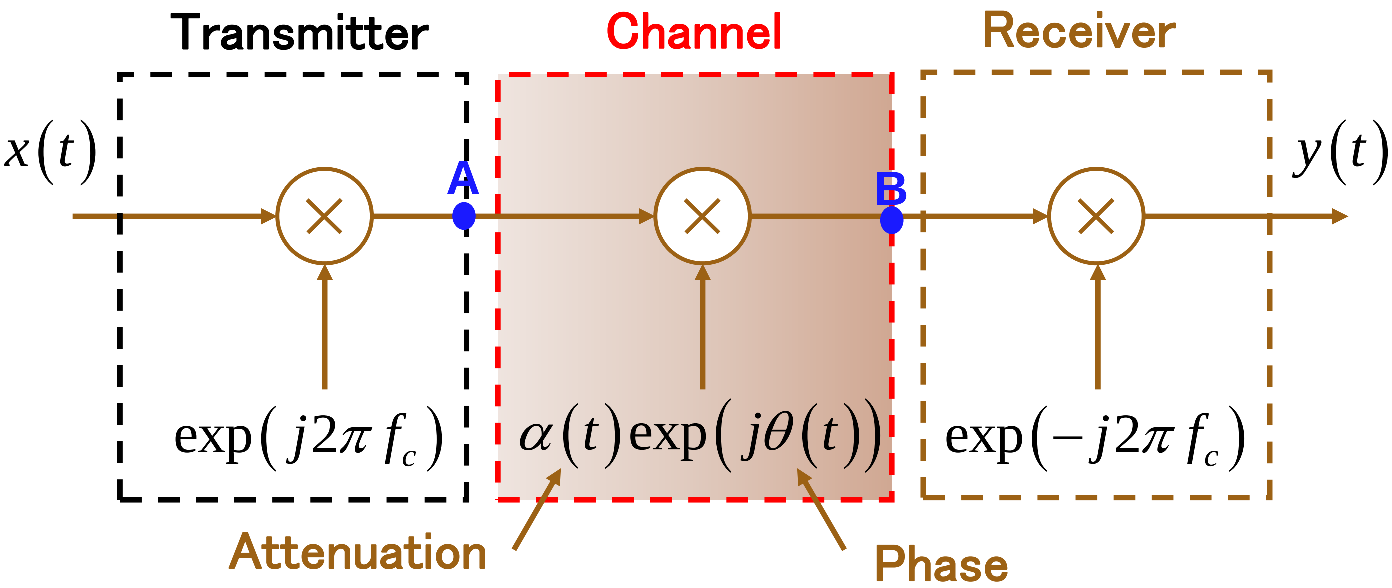
THE RADIO CHANNEL
It is more than just a loss

- Some examples:
  - behavior in time/space?
  - behavior in frequency?
  - directional properties?
  - bandwidth dependency?
  - behavior in delay?

A narrowband system described in complex notation



In: $x(t) = A(t)\exp(j\phi(t))$

Out: $y(t) = A(t)\exp(j\phi(t))\exp(j2\pi f_c t)\alpha(t)\exp(j\theta(t))\exp(-j2\pi f_c t)$

$$= A(t)\alpha(t)\exp\left(j\left(\phi(t)+\theta(t)\right)\right)$$

It is the behavior of channel attenuation and phase variations we will investigate throughout the course.

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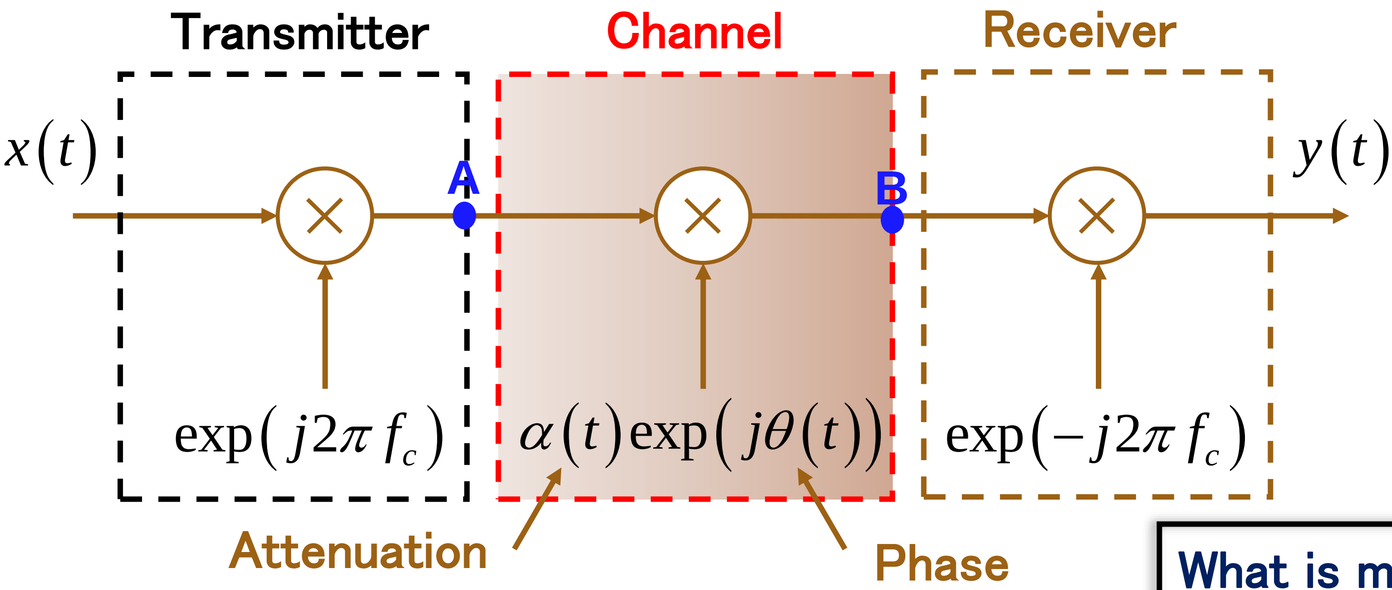
A narrowband system described in complex notation



What is missing?

In: $x(t) = A(t)\exp(j\phi(t))$

Out: $y(t) = A(t)\exp(j\phi(t))\cancel{\exp(j2\pi f_c t)}\alpha(t)\exp(j\theta(t))\cancel{\exp(-j2\pi f_c t)}$

$$= A(t)\alpha(t)\exp\left(j\left(\phi(t)+\theta(t)\right)\right)$$

It is the behavior of channel attenuation and phase variations we will investigate throughout the course.

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THE RADIO CHANNEL
Some properties

- **Path loss (a.k.a. geometric attenuation):**
  - Roughly speaking, received power decays exponentially with distance. Assuming there are no other impairments,

$$\text{Received power} \propto \text{Transmitted power} \times \text{Distance}^{-\text{Propagation exponent}}$$

- **Large-scale fading:**
  - Caused by interacting objects which are of a large size in comparison to the wavelength
  - Obstructs the travelling signal enroute to the receiver.
- **Small-scale fading**
  - Objects reflecting, diffracting or refracting the signal causing multipath propagation from transmitter to receiver -> constructive and destructive (self-)interference.

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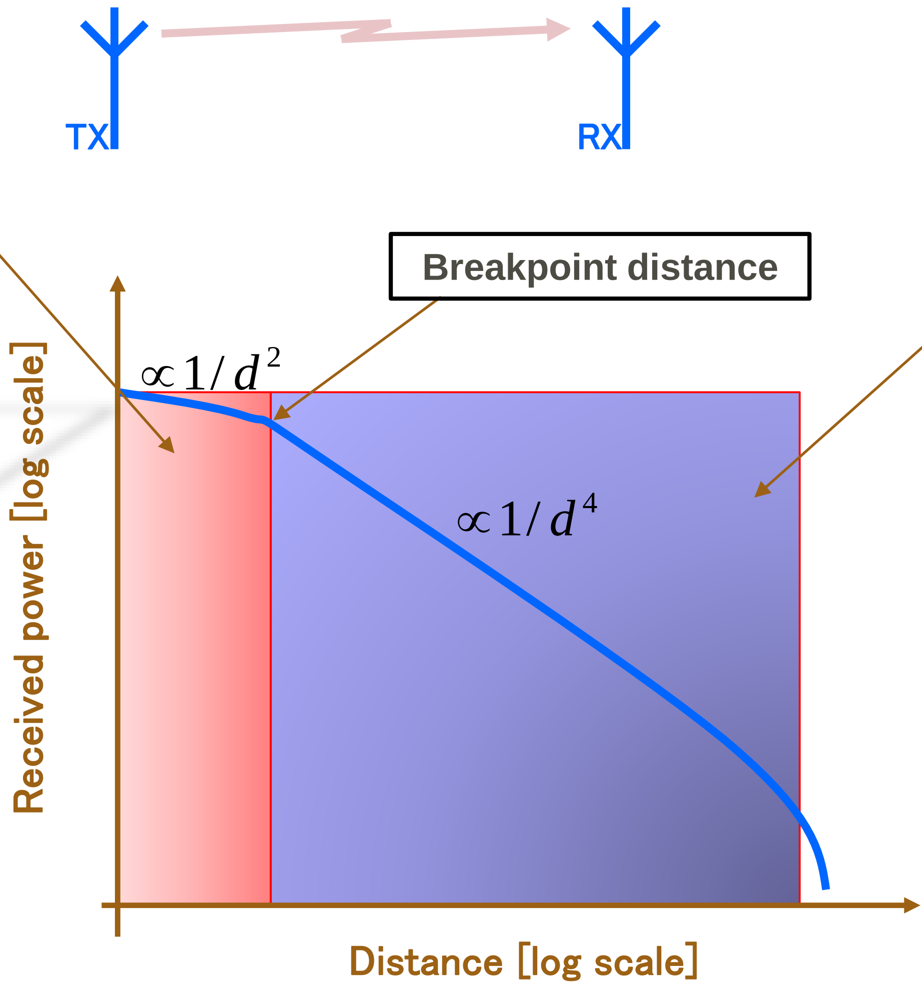
THE RADIO CHANNEL
Path loss – I

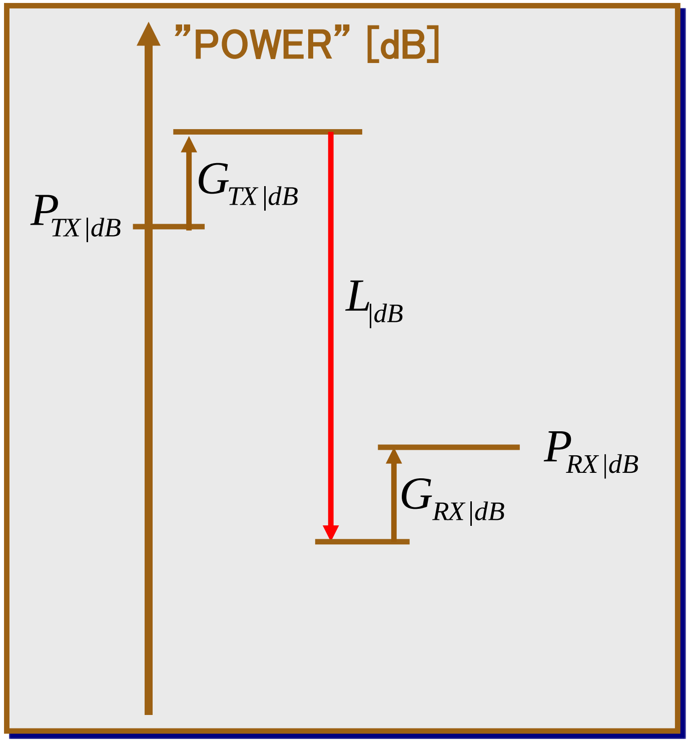
Fris equation zone: path loss a function of frequency, since received power a function of frequency.



d to the four region: received power is no longer a function of frequency, and hence path loss losses frequency dependency.

Typically only happens in scenarios with more than one multipath component.

THE RADIO CHANNEL
Path loss – II



Two theoretical expressions for the deterministic propagation loss as functions of distance:

$$L_{|dB}(d) = \begin{cases} 20\log_{10}\left(\dfrac{4\pi d}{\lambda}\right) & \text{, free space} \\ 20\log_{10}\left(\dfrac{d^2}{h_{TX} h_{RX}}\right) & \text{, ground plane} \end{cases}$$

There are other models, which we will discuss later.

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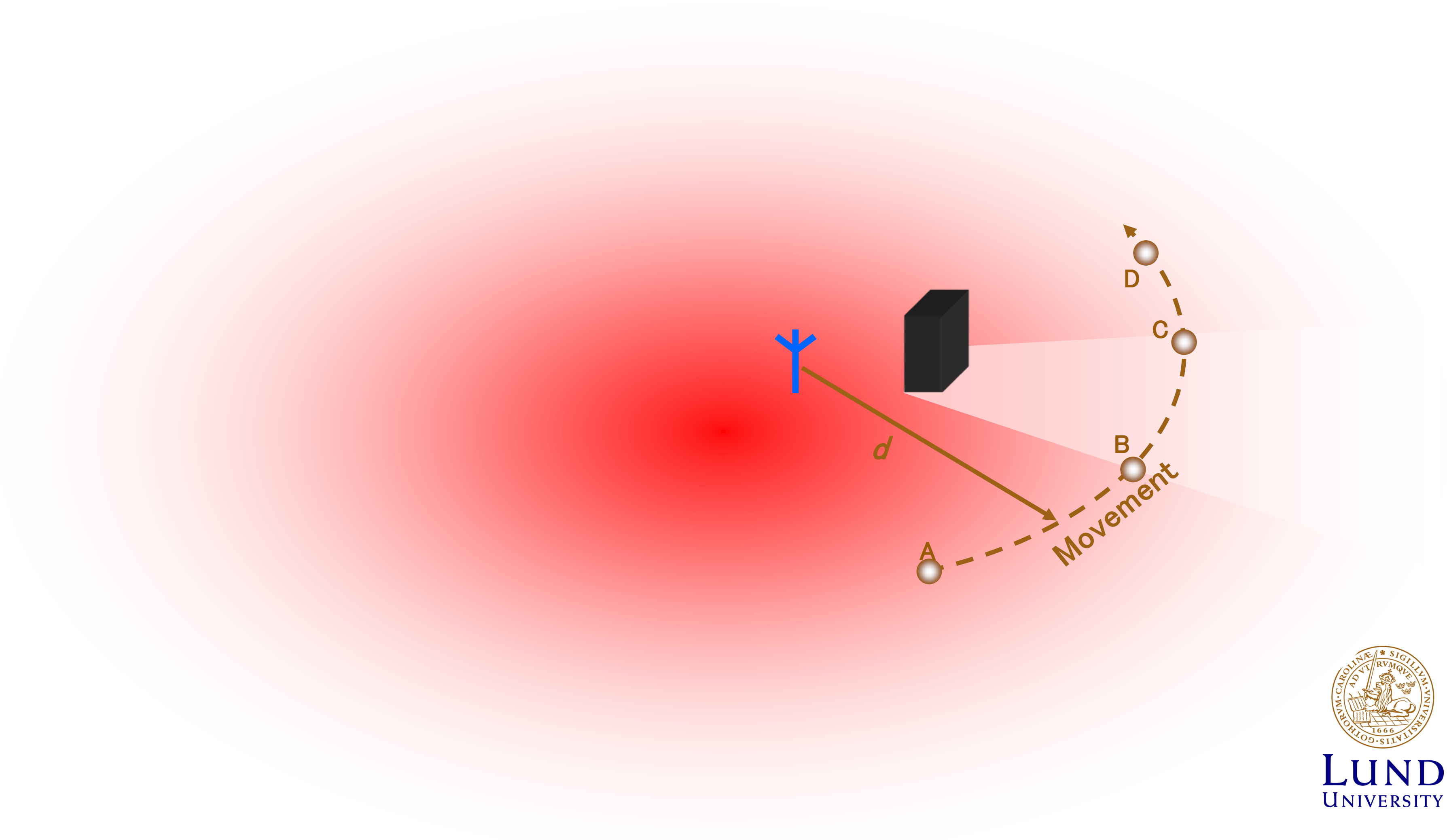
Large-scale fading (Shadow fading): The basic principle



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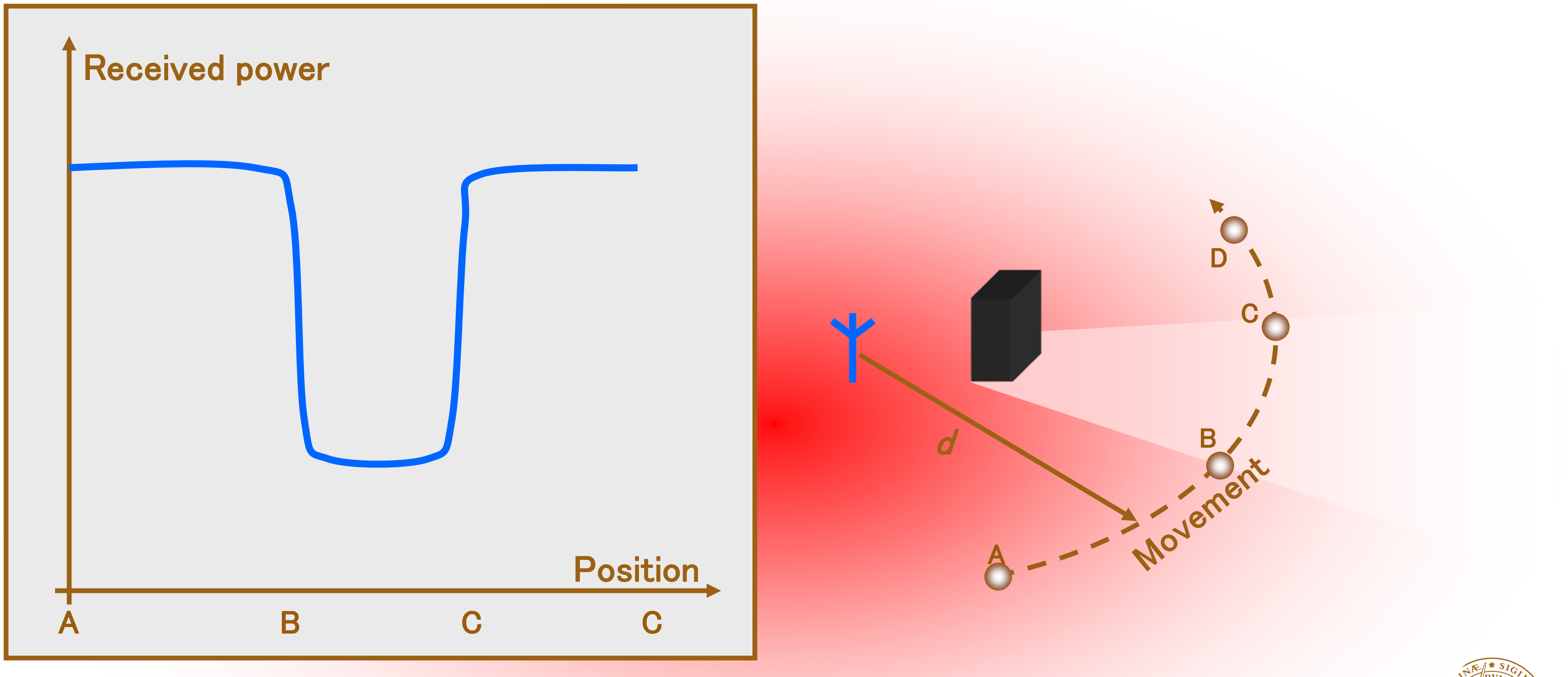
Shadow fading: The basic principle



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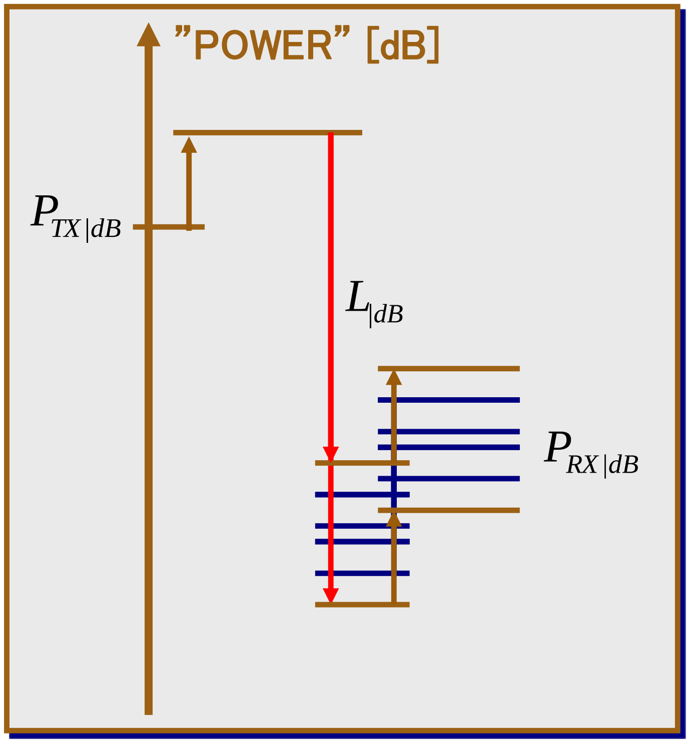
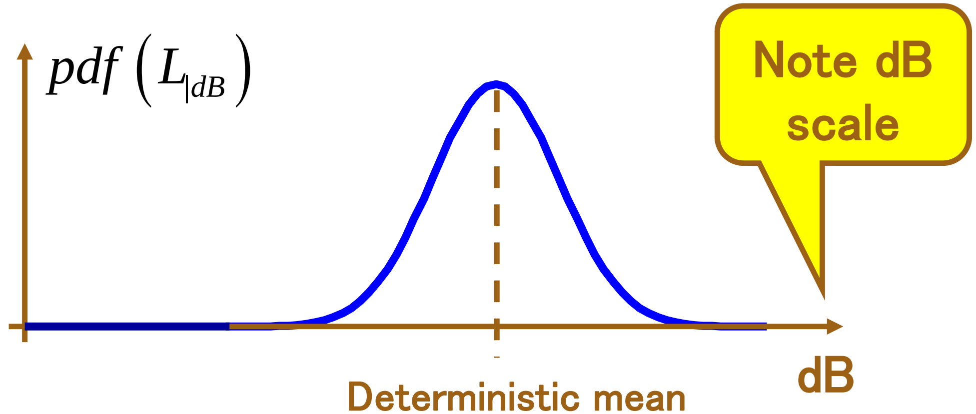
Shadow-fading Characterization: The Log-normal distribution

Measurements confirm that in many situations, the large–scale fading of the received signal strength has a normal distribution in the dB domain.





Deterministic mean value of path loss, $L_{0|dB}$

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

Standard deviation: $\sigma_{F|dB}$ is typically 3–10 dB.

Question!

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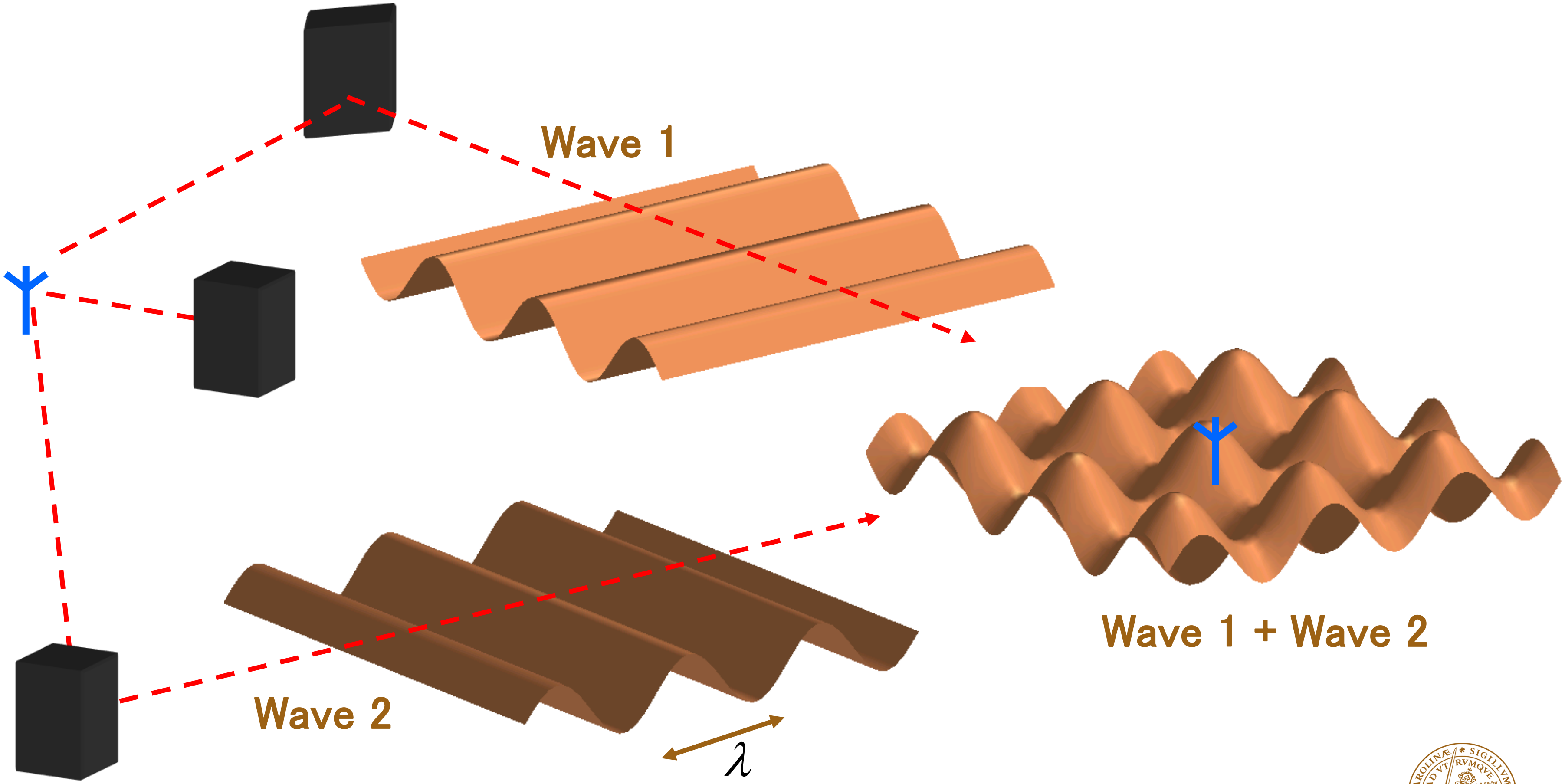
Small-scale fading: A two path illustration



At least in this case, we can see that the interference pattern changes on the wavelength scale.

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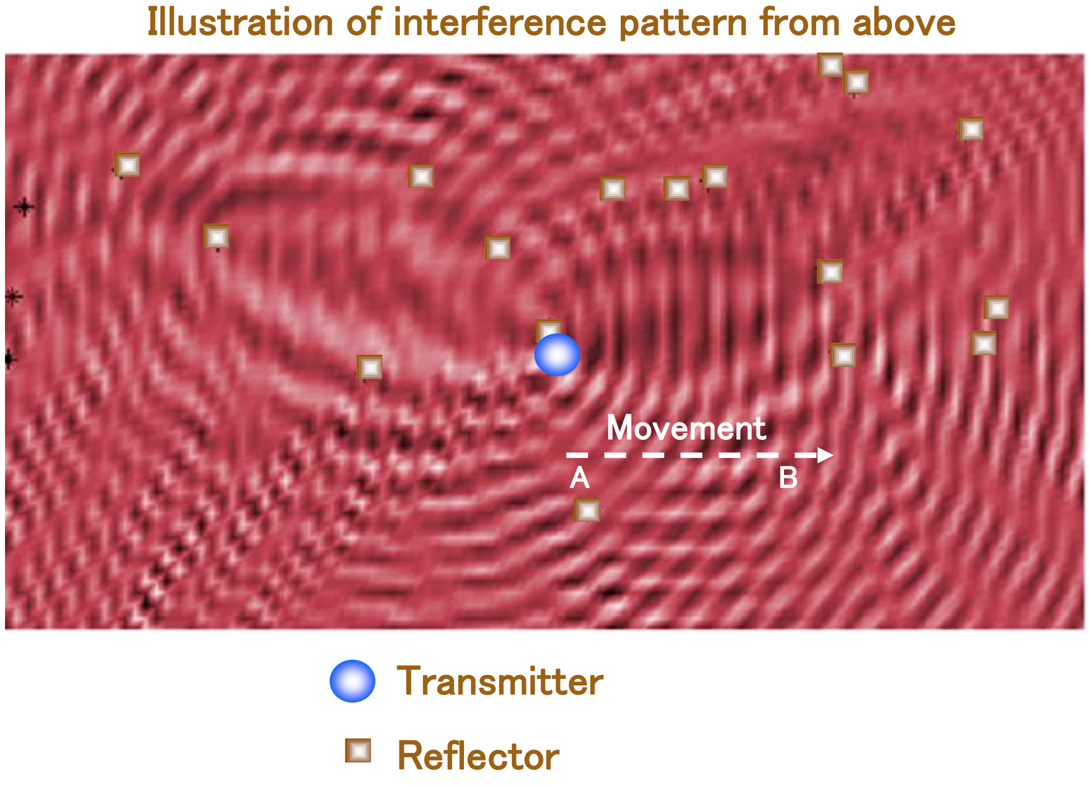
THE RADIO CHANNEL
Small-scale fading (cont.)



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Small-scale fading (cont.)

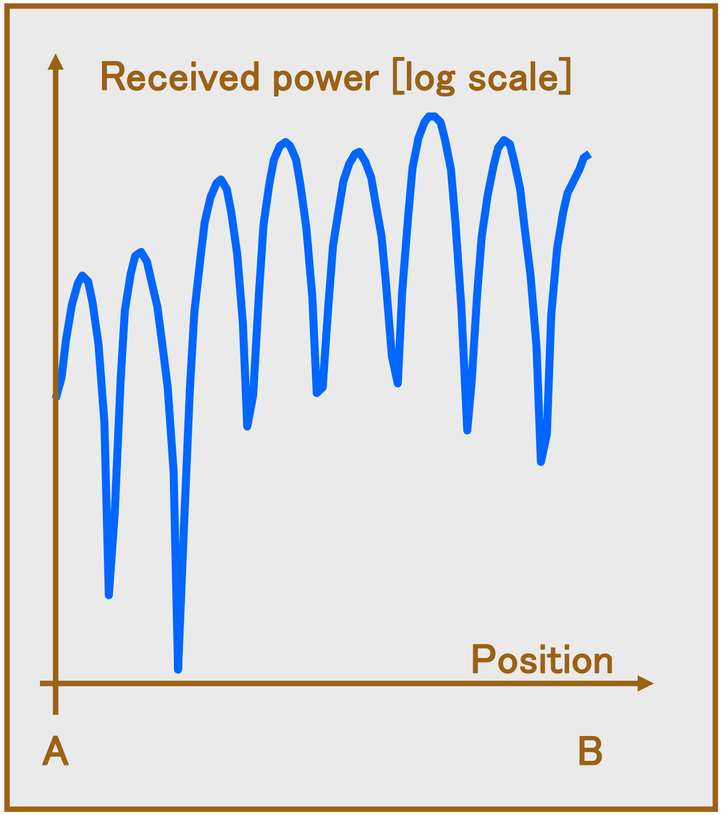
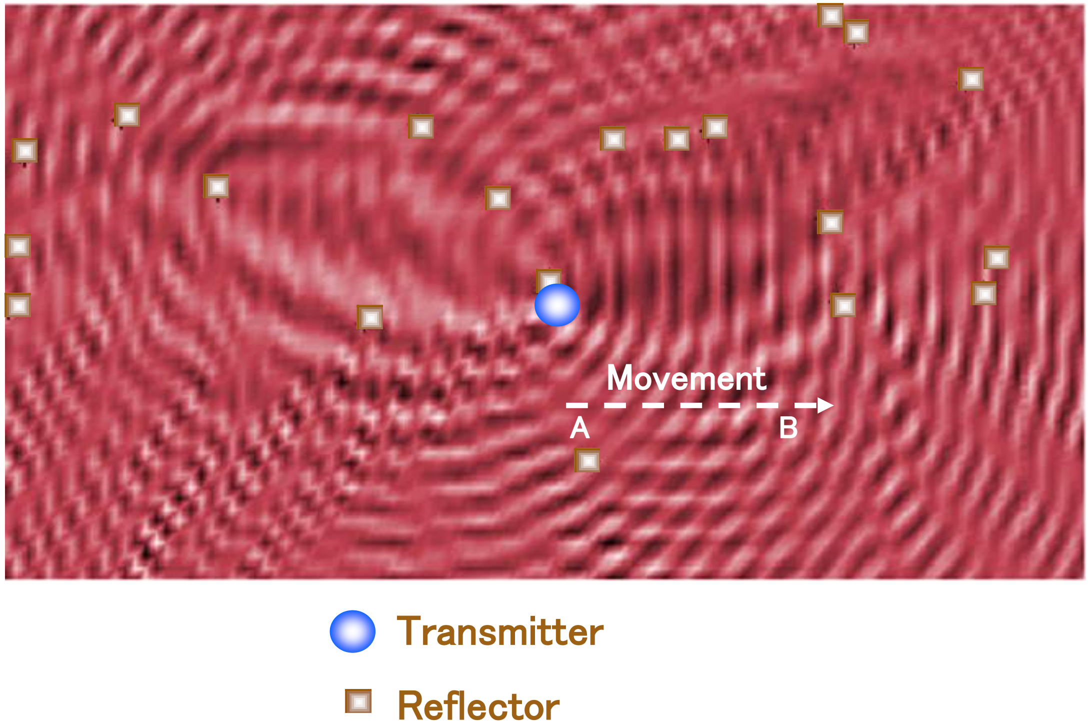


Illustration of interference pattern from above



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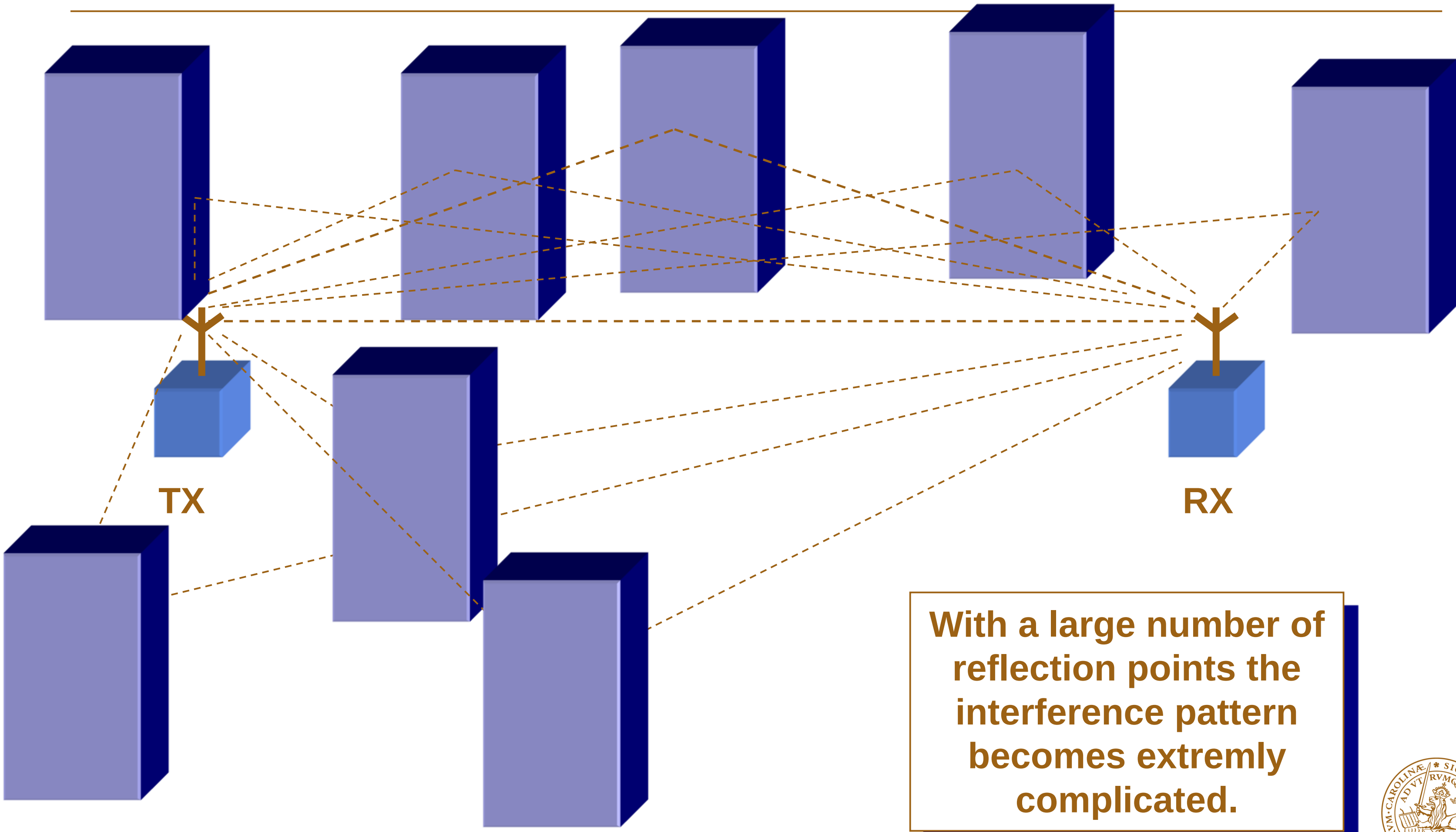
THE RADIO CHANNEL
Small-scale fading (cont.)



With a large number of reflection points the interference pattern becomes extremly complicated.

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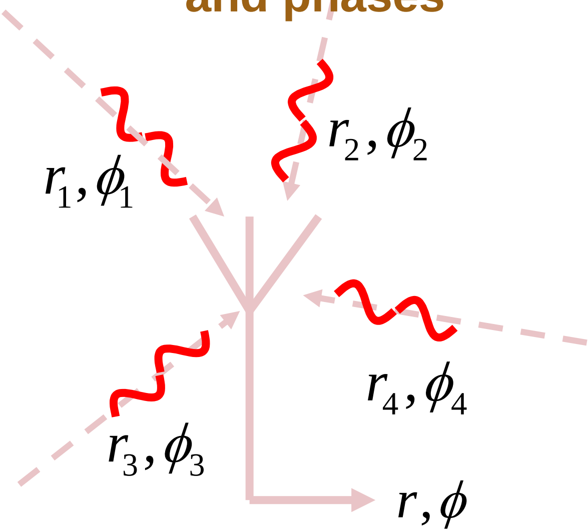
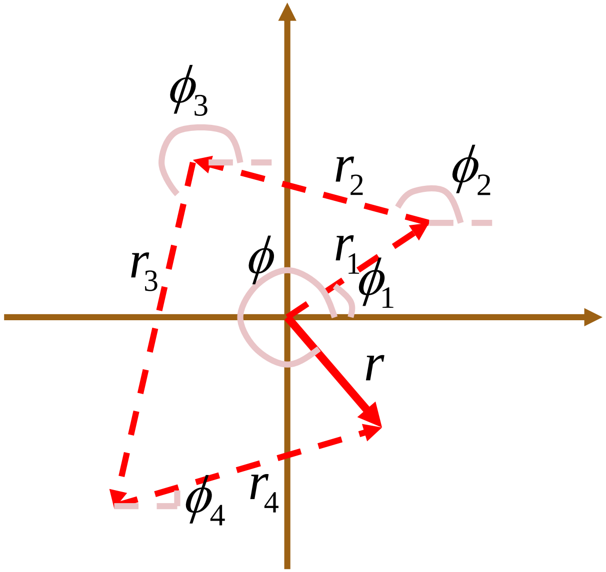
Small-scale fading: Many wavefronts Mathematical Treatment

Many incoming waves with independent amplitudes and phases



Add them up as phasors



$$r\exp(j\phi) = r_1\exp(j\phi_1) + r_2\exp(j\phi_2) + r_3\exp(j\phi_3) + r_4\exp(j\phi_4)$$

What do we really have? Random angles and magnitudes multiplying and adding, due to the different arriving multipath components, with their underlying propagation processes.

What does this mean regarding the distribution of the real and imaginary components?

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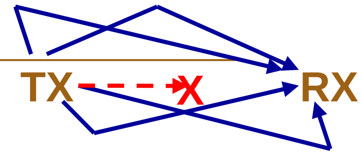
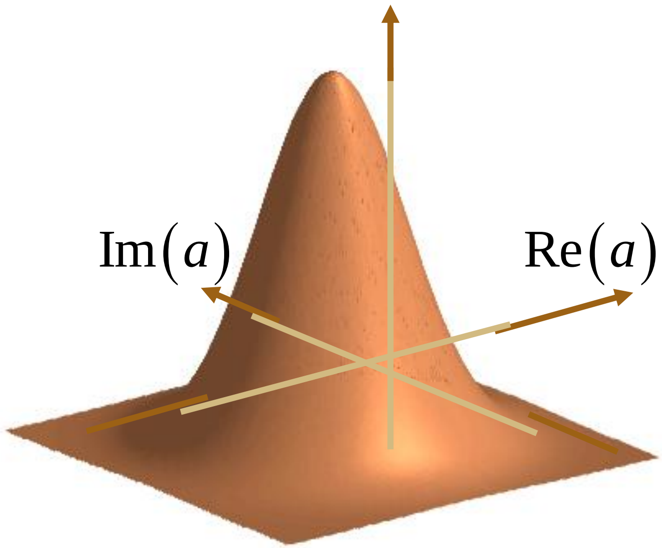
Small-scale fading
Rayleigh fading characterization



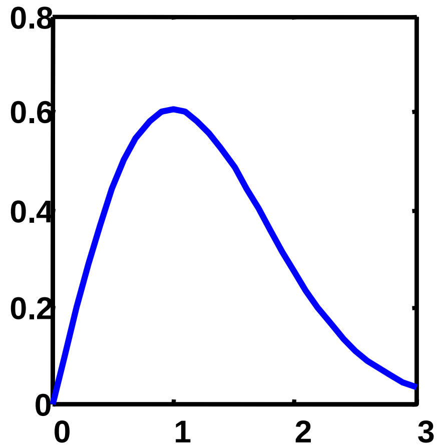
No dominant component
(no line-of-sight)

Tap distribution
2D Gaussian
(zero mean)



$$r = |a|$$

Amplitude distribution
Rayleigh



This is since the behaviour of most RXs is determined by the magnitude of the field strength phasors

$$pdf(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2} \right)$$

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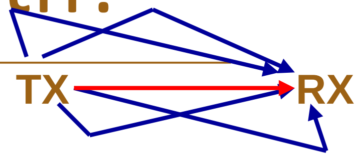
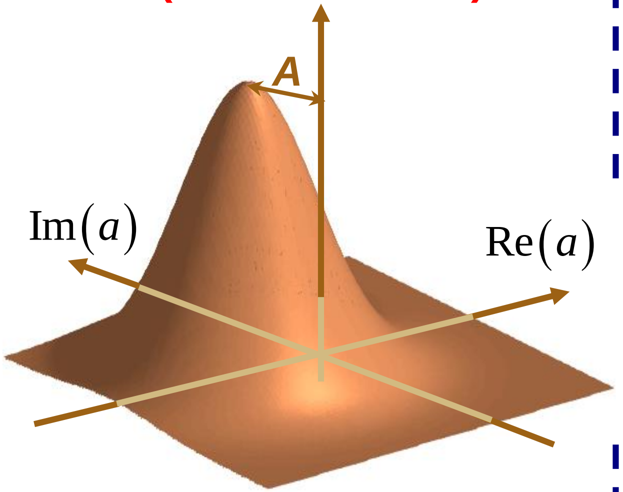
What happens with a dominant path?



Line-of-sight path plus diffuse paths

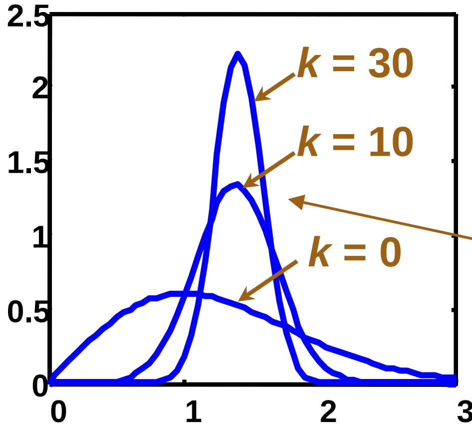
Tap distribution
2D Gaussian
(non-zero mean)



Line-of-sight (LOS) component with amplitude *A*.

$$r = |\alpha|$$

Amplitude distribution
Rice



Note the shift in the mean!

$$pdf(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2 + A^2}{2\sigma^2} \right) I_0\left(\frac{rA}{\sigma^2} \right)$$

$$k = \frac{\text{Power in LOS component}}{\text{Power in random components}} = \frac{A^2}{2\sigma^2}$$

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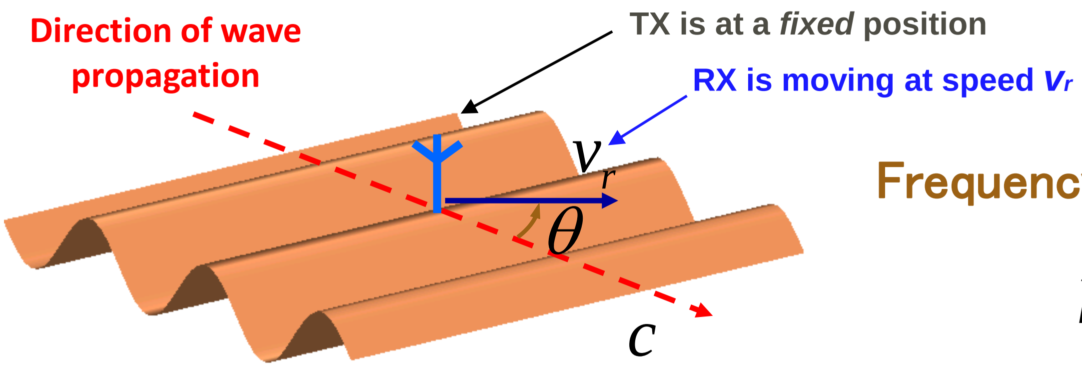
Small-scale fading: Doppler shifts



Receiving antenna moves with speed v_r at an angle Θ relative to the propagation direction of the incoming wave, which has frequency f_0

Question: What do we expect to happen to the **received signal** in such a scenario?

Frequency of received signal:

$$f = f_0 + \nu$$

Frequency offset Due to movement

where the Doppler shift is

$$\nu = -f_0 \frac{v_r}{c} \cos(\theta)$$

Speed of light

The maximal Doppler shift is

$$\nu_{\max} = f_0 \frac{v}{c}$$

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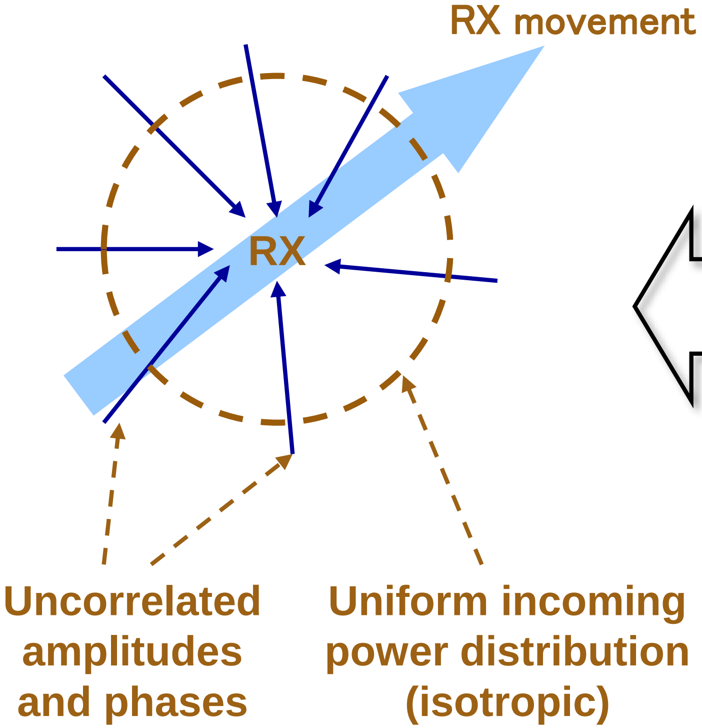
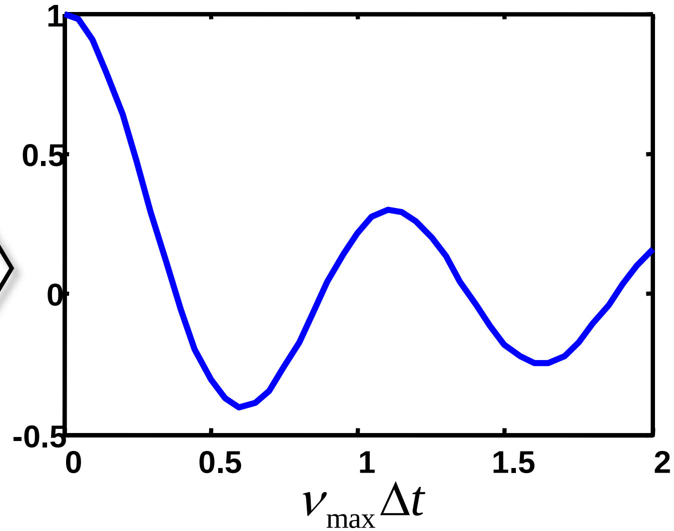
Small-scale fading: Doppler spectrum

Isotropic uncorrelated scattering



Time correlation



$$\rho(\Delta t) = E\{a(t)a^*(t+\Delta t)\} \propto J_0(2\pi\nu_{\max}\Delta t)$$

J_0 is the Bessel function of the first kind.

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