Case Study Competition 2009

Ready for take off!

The future of air traffic control is in your hands

Preliminary round exercises

75 Years of Driving Innovation

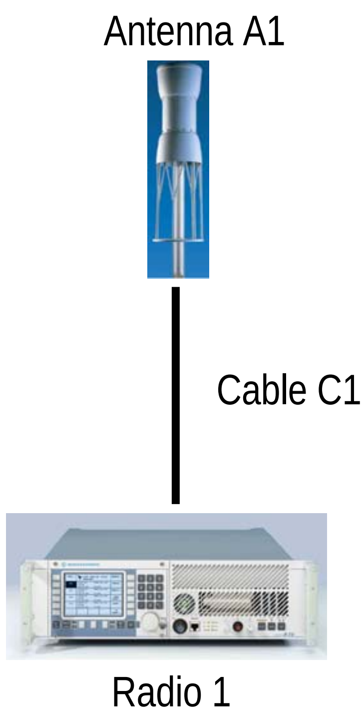
ROHDE&SCHWARZ

Scenario

- You are a designer of radiocommunications systems for civil air traffic control.
- You are part of a team that is analyzing an existing radio system and developing proposals for expanding it.
- You submit your proposal for expansion to the customer in the form of a bid presentation.

A typical small system for air traffic control

A typical single radio line consists of the following components:



Antenna A1:		gain 0 dB (referenced to λ/2 dipole)
Cable C1:		50 Ω, loss 1 dB
Radio 1:		
	Receiver:	sensitivity:
		(S+N)/N = 10 dB: -103 dBm for AM, m = 0.3
		Input IP3: +10 dBm at 100 kHz offset
		Audio bandwidth: 300 Hz to 3400 Hz
	Transmitter:	output power 30 W AM carrier
		noise floor: -160 dBc/Hz at 10 MHz offset

Note: In RF engineering, power is usually calculated in dBm.

0 dBm corresponds to 0 dB referenced to 1 milliwatt.

The power of 30 watts specified in this example corresponds to 30000 milliwatts or 45 dBm. This makes things a lot simpler!

Typical radio equipment in a plane

Radio:

Transmitter: 10 W

Receiver: -103 dBm sensitivity for AM, m = 0.3

(S+N)/N = 10 dB

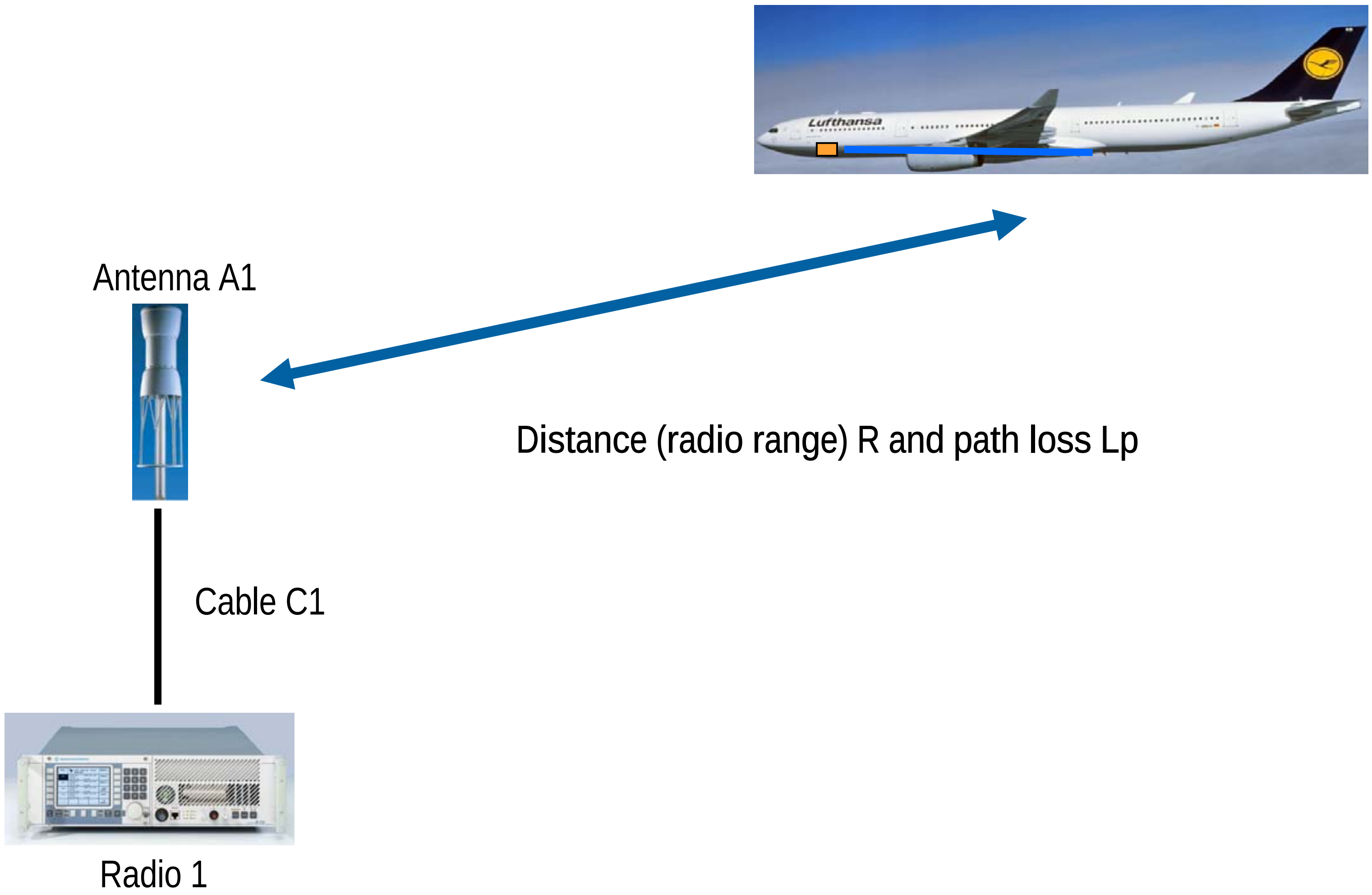
Cable:

Loss 1 dB

Antenna :

Gain -3 dB referenced to $\lambda/2$ dipole

Analysis of radio range



Analysis of radio range

Exercise 1 - Basic assumptions

The configuration is as shown in the previous figures:

- A ground system including a typical small system for air traffic control
- An aircraft with typical radio equipment

Operating mode:

- Modulation mode AM
- Modulation depth m = 0.3
- Frequency 130 MHz

Analysis of radio range

<u>Exercise 1 (6 points)</u>

Based on the radio system shown on the previous slides (basic assumptions):

- Calculate the maximum bridgeable path loss Lp in dB (<u>4 points</u>).
  Take into account the following criteria:
  - Parameters as specified in the preceding figures
  - A signal-to-noise ratio (S+N)/N of 10 dB is to be achieved
  - Allow for a margin of 7 dB
  - Calculate the path loss for both directions
- What is the theoretical range R in kilometers to which this path loss Lp corresponds, assuming that the aircraft is flying high enough and there is a direct unobstructed line of sight between the aircraft and the ground station (<u>for each direction 1 point</u>)?

Use the approximate formula:

Loss between two <u>*λ/2 dipoles*</u>: $Lp\,[dB] = 28.15 + 20\log f + 20\log d$

f : Frequency in MHz

d : Distance in km

Determination of system requirements

Exercise 2 (5 points)

To be able to correctly configure a ground system, it is important to know the minimum received signal field strength, as well as the minimum radiated transmit power in order to be able to attain a predetermined range.

- Calculate the free-space loss between two λ/2 dipoles for the criteria indicated below (1 point).
- Calculate the maximum signal strength S arriving at the ground system at an antenna with 0 dBd gain (referenced to a λ/2 dipole) (2 points).
- Calculate the minimum required transmit power P on the ground at an antenna with 0 dBd gain (referenced to a λ/2 dipole) (2 points).

For both calculations, the criteria are as follows:

- The aeronautical radio system described earlier is used.
- The (S+N)/N ratio should be 10 dB with a margin of 7 dB.
- There is an unobstructed line-of-sight link between the ground station and the aircraft, i.e. the aircraft is flying at an appropriate height.
- The distance to the aircraft is 400 km.
- The operating frequency is 130 MHz.

Estimation of expansion options (transmitter coupler)

<u>Exercise 3 – Introduction</u>

The small system used in Exercise 1 is to be expanded by additional radio lines.
Basically, there are several different ways to do this.

The following factors must be taken into account, for example:

- The specifications that can be achieved
  - Examine in particular whether all the radio lines can be operated simultaneously and independently of each other.
- The complexity of the system solution and the resulting costs
- Energy efficiency

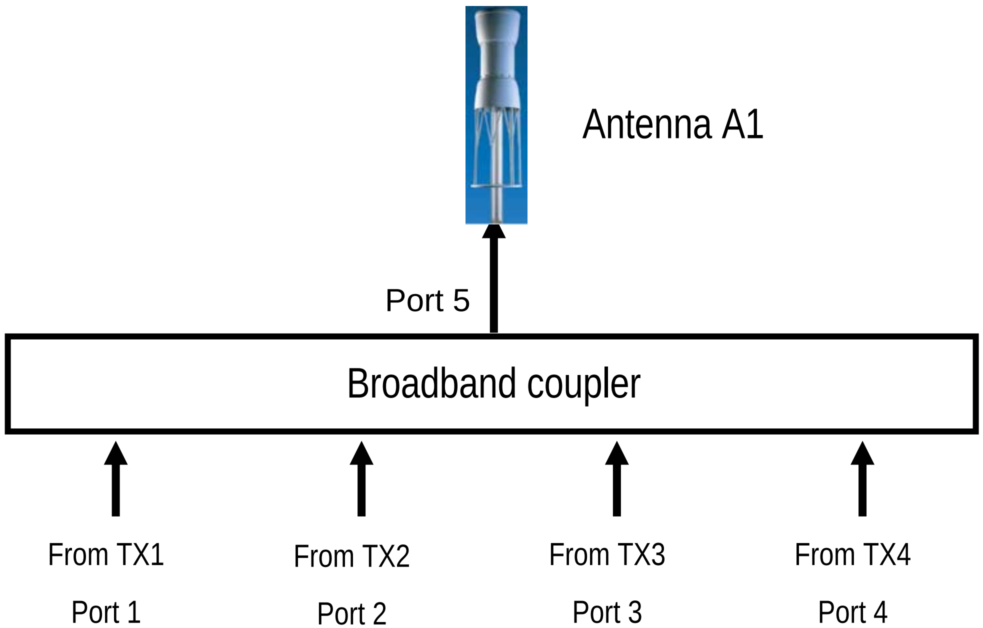
The following exercises will examine more closely the various basic principles and required building blocks for the expansion of radio systems.

Using this knowledge, a specific expansion to the radio system has to be proposed on the basis of predefined key criteria.

Estimation of expansion options (transmitter coupler)

<u>Exercise 3 (total of 15 points) - Basic assumptions, transmitter coupler</u>

To interconnect several transmitters, it is possible to use a broadband coupler. In the following example, the signals from up to 4 transmitters can be fed to a single antenna.



Parameters of antenna A1:

- Impedance: 50 Ω
- VSWR: ≤ 2 : 1

VSWR = voltage standing wave ratio

The transfer characteristic of the coupler alone in the 50 Ω system is as follows:

$|S_{5n}| = 0.5$ (n = 1 to 4) $|S_{mn}| = 0$ (m = 1 to 4) (n = 1 to 4)

Estimation of expansion options (transmitter coupler)

Exercise 3.1 (4 points)

The antenna is the load for the broadband coupler.

- Calculate the reflection coefficient S_{11} of antenna A1, both in linear terms and in dB (2 points).

The decoupling values specified for the coupler between ports 1 to 4 are only valid if an ideal impedance of 50 Ω is connected to port 5.

- Calculate the decoupling $|S_{mn}|$ between the inputs in dB if antenna A1 is connected to the coupler. The antenna cable loss is negligible (2 points).

Estimation of expansion options (transmitter coupler)

Exercise 3.2 (7 points)

The following equipment is connected to the system consisting of coupler and antenna:

Four transmitters, each with the following characteristics:

- Modulation mode: AM
- Transmit power: 30 W (carrier power)
- Modulation depth: 100 %

- Calculate the RMS carrier power per transmitter signal which is output to the antenna at the output of the coupler (2 points).
- Calculate the peak envelope power (PEP) per transmitter signal which is output as forward power to the antenna at the output of the coupler (2 points).
- Calculate the RMS total power that is dissipated in the coupler and must be eliminated, for example, via a heat sink (3 points).

Estimation of expansion options (transmitter coupler)

Exercise 3.3 (4 points)

For the system consisting of coupler and antenna, the necessary loading capacity of the antenna must be calculated. For this purpose, the four signals from Exercise 3.3 are connected once again.

The signals that the coupler outputs to the antenna have 4 different frequencies. Superposition of the four signals may create short-time high peak currents and voltages.

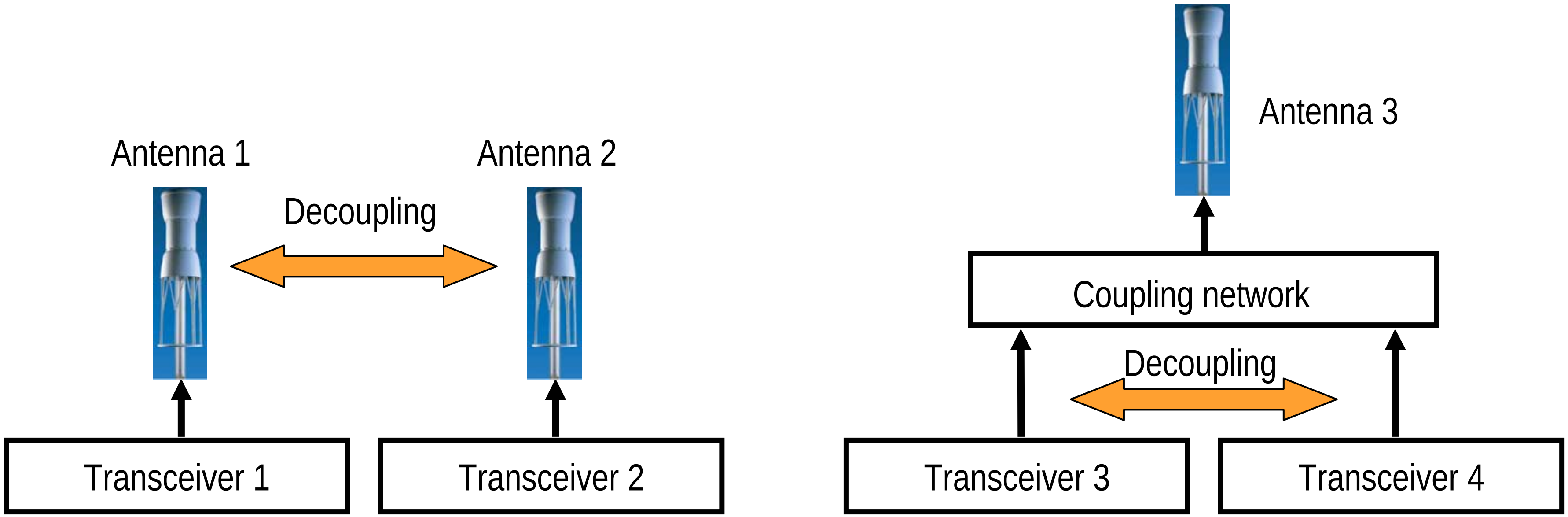
For this exercise, the antenna itself should be regarded as an ideal 50 Ω resistance.

- Calculate the short-time peak voltage that may occur at the antenna (2 points).
- Calculate the short-time peak current that may occur at the antenna (2 points).

Estimation of expansion options (decoupling)

Exercise 4 - Basic assumptions

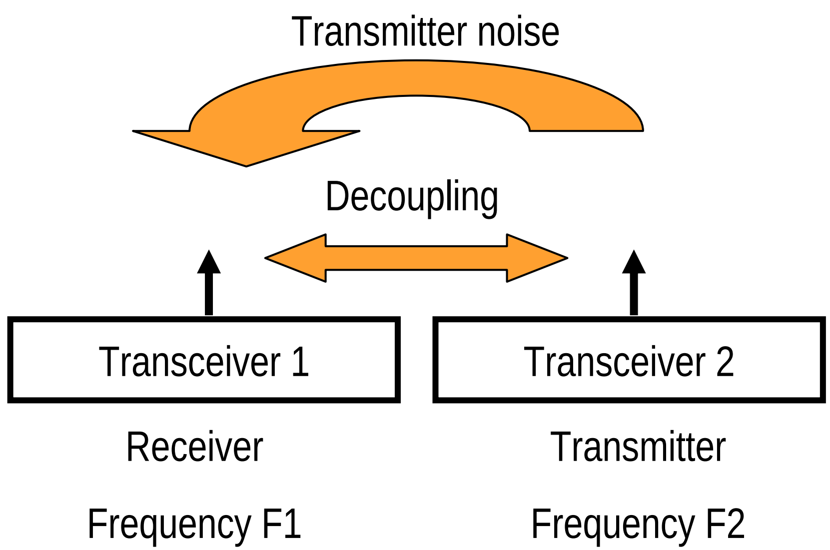
In order that all the radio equipment in a radio system can be operated independently of each other, there must be a minimum decoupling between a transmitter and a receiver. It does not matter whether this decoupling is achieved, for example, by the distance between the antennas or by the coupling networks used for combining radio lines.



Estimation of expansion options (decoupling)

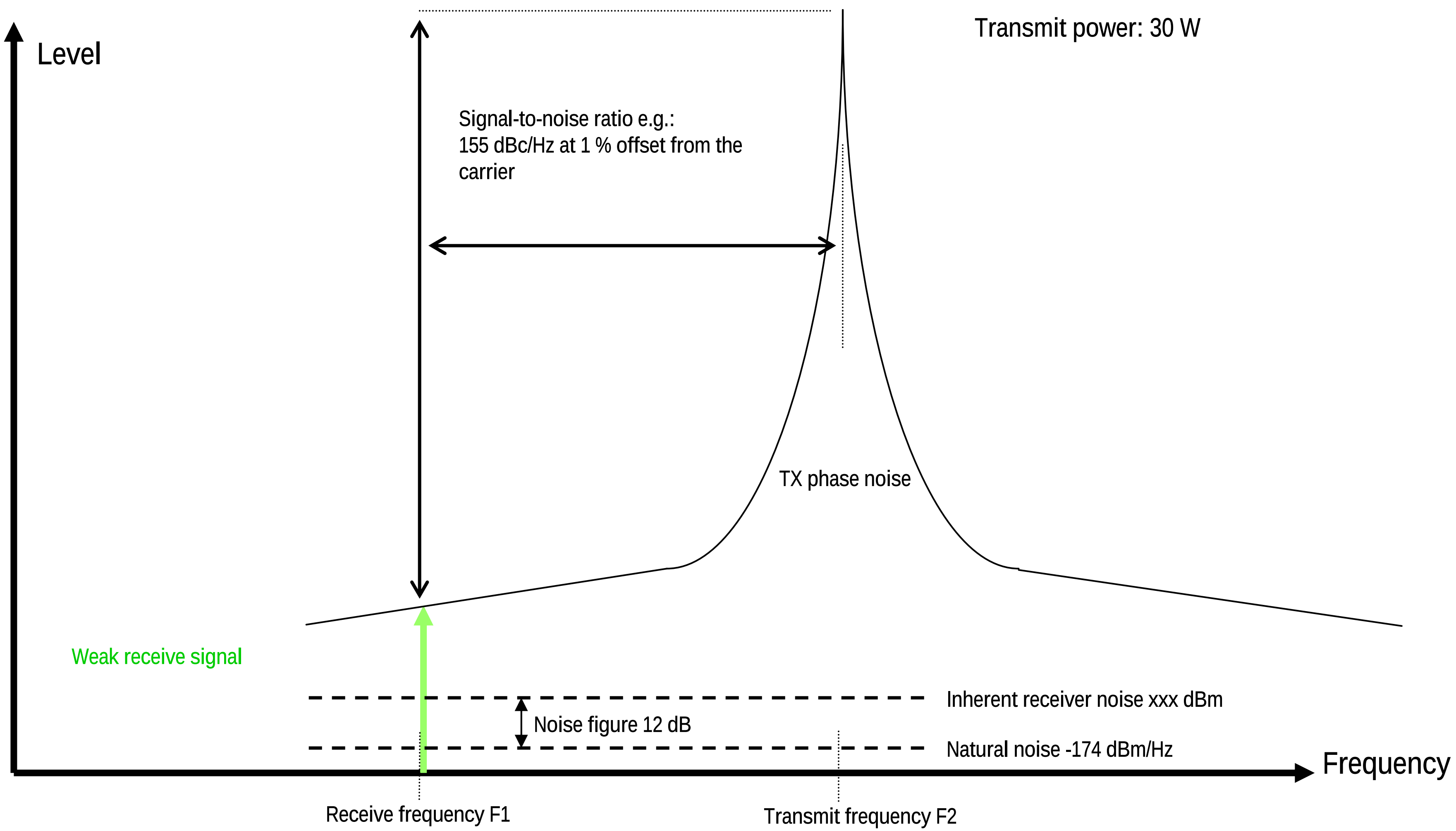
Exercise 4 - Basic assumptions

- A receiver receives at frequency F1.
- A transmitter transmits at frequency F2.
- The transmitter noise may at times obscure the receive signal, because due to limited decoupling between transmitter and receiver a high level of transmitter noise may be present in the receive channel (see diagram below).
- The diagram on the next slide shows the relationship in detail.



Estimation of expansion options (decoupling)

Exercise 4 - Basic assumptions



Estimation of expansion options (decoupling)

Exercise 4 (6 points)

The radio system described on the previous slides has the following parameters:

- A receiver receives at frequency F1, e.g. 128.7 MHz.
- A transmitter transmits at frequency F2 with an offset of 1 %, e.g. 130 MHz.
- The transmitter signal-to-noise ratio at 1 % offset is 155 dBc/Hz.
- The transmit power is 30 W.
- The noise figure of the receiver is 12 dB.

- Calculate the minimum required decoupling between transmitter and receiver such that the receiver does not lose more than 3 dB sensitivity (4 points).

- How can the system be improved so that even with smaller decoupling there will be no interference at the receiver (1 point)?
- What must be considered in the process (1 point)?

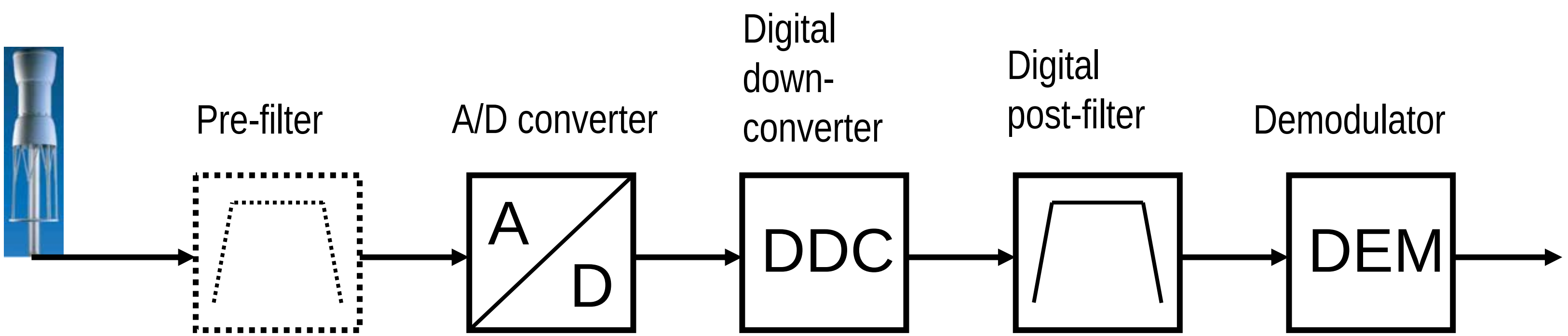
Estimation of expansion options (receiver engineering)

<u>Exercise 5 (total of 9 points) - Basic assumptions</u>

In order to operate a receiver in a radio system even under critical conditions, the receiver must be able to achieve its specified sensitivity despite a high level of interference at the input.

The trend in receiver engineering is to provide the antenna with an analog/digital converter if possible, so as to achieve the greatest possible operational flexibility.

The following block diagram of a receiver is the basis for the next exercise:



Estimation of expansion options (receiver engineering)

Exercise 5.1 (2 points)

The following parameters are valid for the block diagram of the receiver:

- The pre-filter is not always built in, but only provided as an option.
- Maximum level of interference caused by the antenna at the input: 0 dBm
- The receiver’s noise figure F should be 12 dB (= noise figure of the A/D converter F_{ADC})
- The A/D converter has the following specifications:
  - SNR_{ADC} = 68 dB
  - Nyquist frequency f_{nyq} = 200 MHz (= half the clock frequency)

- What is the maximum level of interference $S_{max,ADC}$ that may be present at the AD converter, such that reception is not disturbed (1 point)?

  Use the following formula: $S_{max,ADC} = F_{ADC} + SNR_{ADC} - 174\text{ dBm} + 10\log(f_{nyq})$

- Can the receiver be operated without the pre-filter (1 point)?

Estimation of expansion options (receiver engineering)

Exercise 5.2 (7 points)

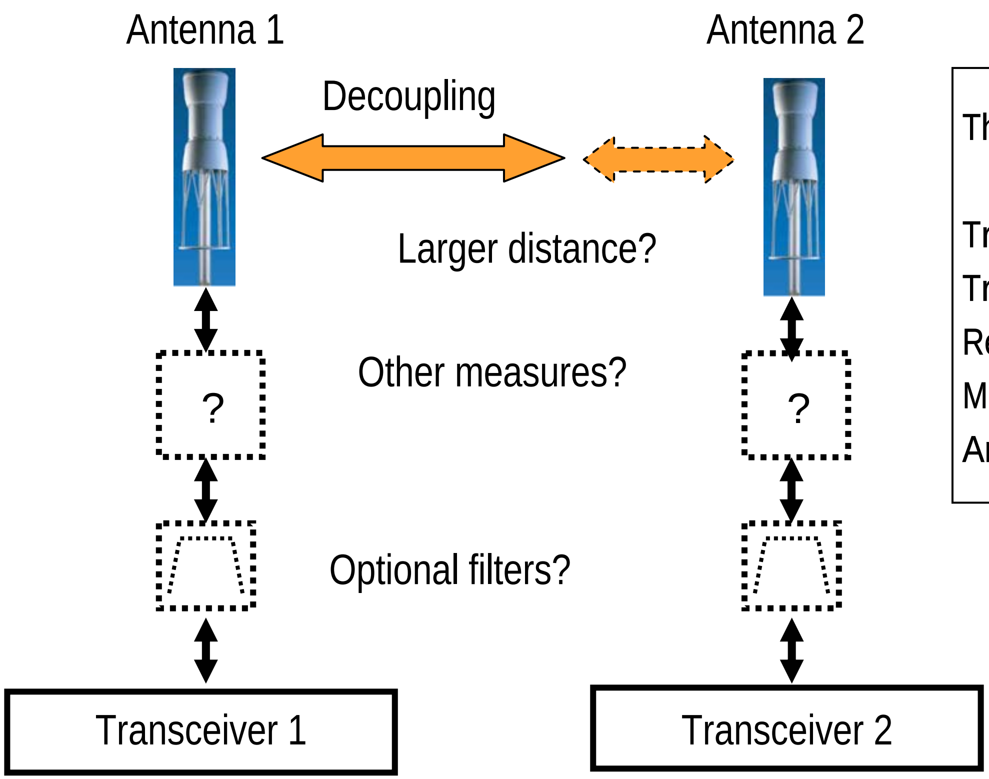
- How much attenuation must the pre-filter introduce if the permissible level of interference is max. +10 dBm (1 point)?
- Can the digital post-filter be of further help if the receiver is overdriven (1 point)?
- What basic task can be performed by the digital downconverter (5 points)?

Estimation of expansion options (system expansion)

Exercise 6 (total of 27 points) - Basic assumptions Part 1

A radio system consisting of transceiver 1 and antenna 1 is to be expanded by an additional radio line.

The following diagram shows the configuration. The areas marked by dotted lines indicate where a system can be optimized.



The devices have the following parameters:

Transmit power:	30 W
Transmitter signal-to-noise ratio:	-160 dBc/Hz
Receiver sensitivity:	-110 dBm
Max. interference level at receiver:	-10 dBm
Antenna gain:	0 dBd

Estimation of expansion options (system expansion)

Exercise 6 (total of 27 points) - Basic assumptions Part 2

It is permitted to make any kind of expansions or modifications, as long as the system achieves the following performance values:

Minimum receiver sensitivity at the antenna:	-100 dBm
Minimum transmit power at the antenna:	5 W
Maximum permissible transmitter noise at the receiver input:	-162 dBm/Hz

Further criteria:

- A separate antenna should be used for each radio line.
- The distances between the antennas clearly influence the decoupling between them.
- An increase in antenna decoupling and thus an increase in the distance between them is very costly to achieve. The costs incurred by varying the antenna decoupling, as well as for the required components, are specified in the table “Material list” (see slide 25).

Estimation of expansion options (system expansion)

Exercise 6.1 (14 points)

- Describe in qualitative terms what change takes place if a filter is inserted in the signal path.
  - In transmit direction (3 points)
  - In receive direction (3 points)
- Describe in qualitative terms what change takes place if antenna decoupling is increased.
  - In transmit direction (1 point)
  - In receive direction (1 point)
- Describe in qualitative terms what change takes place if an attenuator is inserted in the signal path.
  - In transmit direction (3 points)
  - In receive direction (3 points)

Estimation of expansion options (system expansion)

Exercise 6.2 (13 points)

- Create a proposal for a COST-OPTIMIZED system (11 points).
- What are the costs of your approach (2 points)?

The following requirements must be complied with:

The performance values specified on slide 22 are achieved or exceeded. Only the following components may be varied:

Material list:

Antenna decoupling:	Standard 40 dB Costs: € 20K	Optimized 50 dB Costs: € 30K	Ideal 60 dB Costs: € 40K
Filter:	Standard Selection 10 dB Costs: € 2K	Optimized Selection 20 dB Costs: € 4K	Ideal Selection 30 dB Costs: € 6K
Attenuator:	3 dB Costs: € 500	6 dB Costs: € 1K	10 dB Costs: € 2K

Get ready for take off, and the best of luck!

Each exercise can normally be solved independently.

Most of the exercises do not require complex calculations. The best approach is to think through each problem carefully.

We hope you enjoy solving these exercises and wish you good luck with them.