Microwave engineering I

7 January – 8 March, 2018, 5 ECTS

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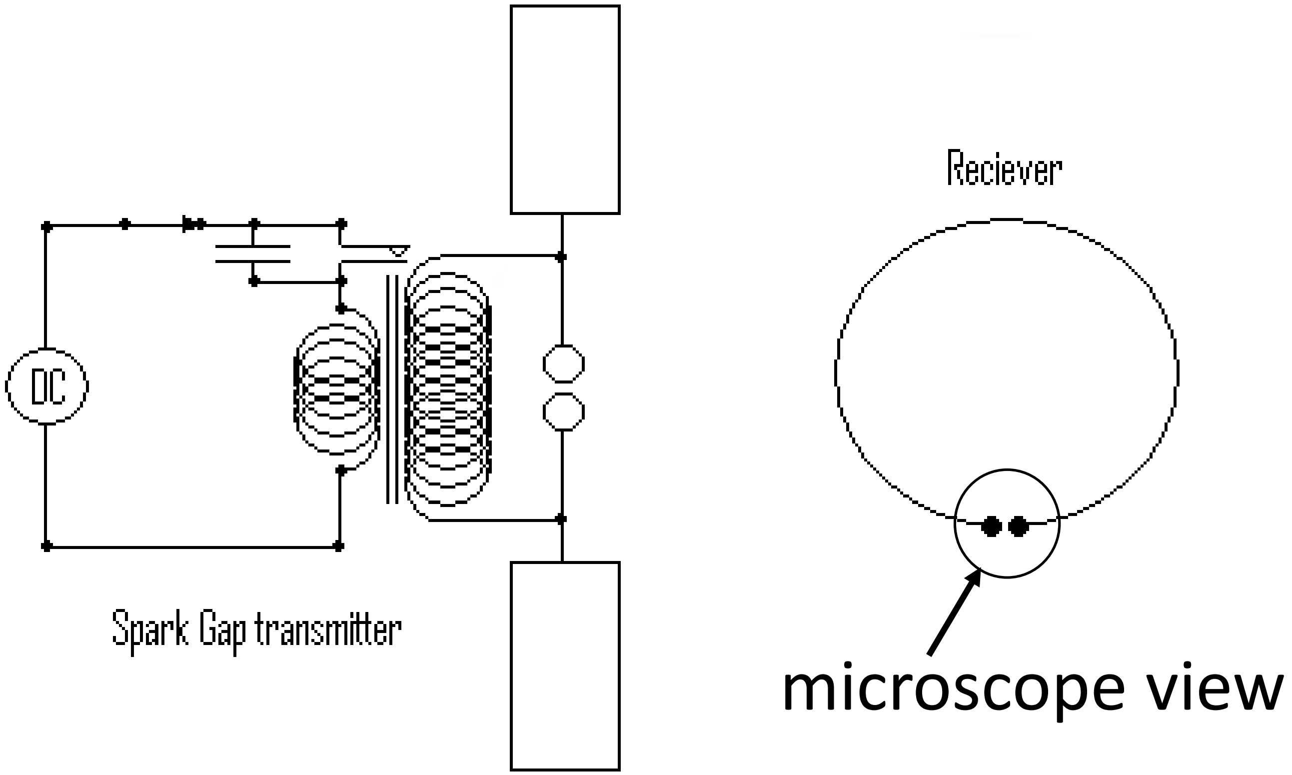
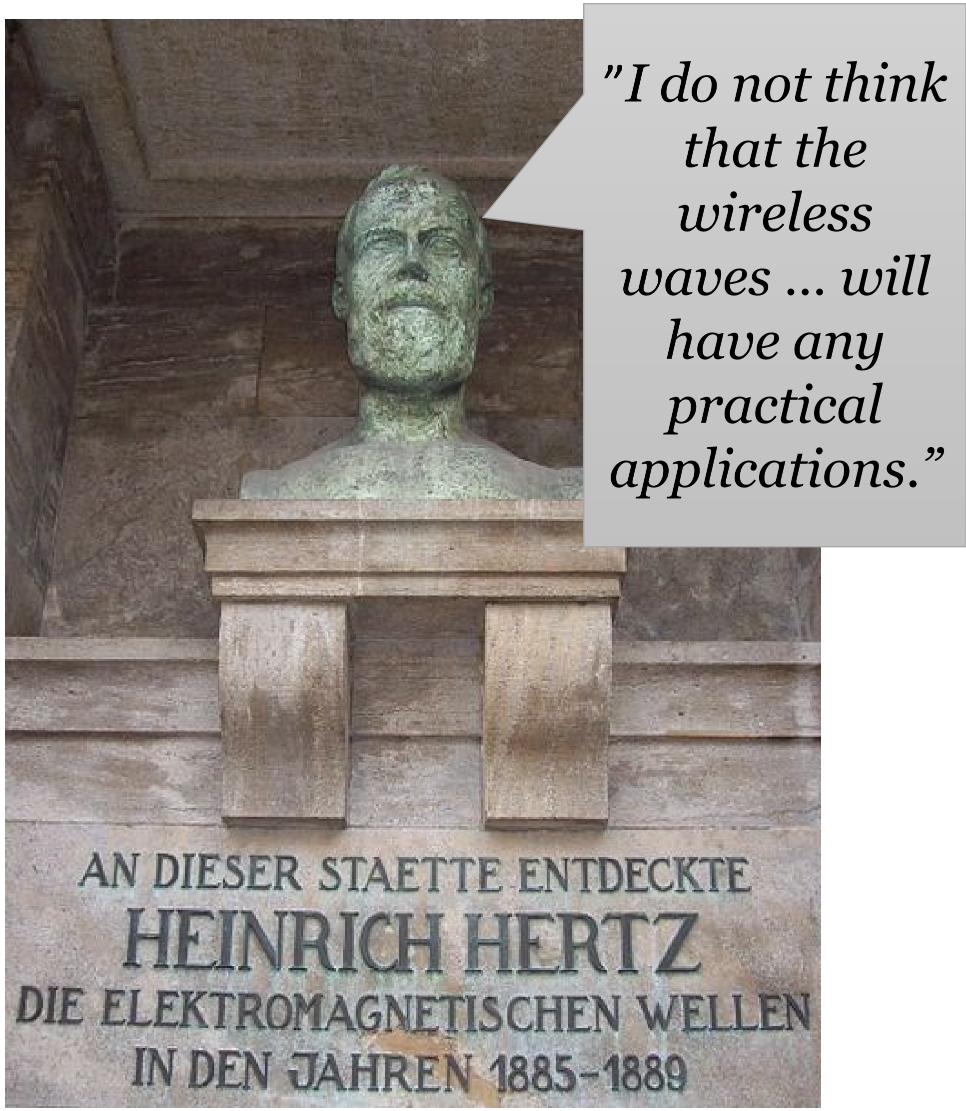
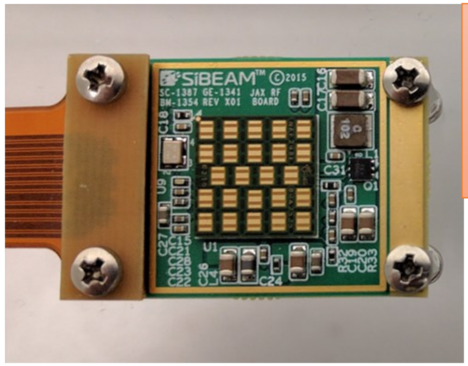
First step of microwave engineering

- H. Hertz proved the existence of the electromagnetic waves in Karlsruhe Institute of Technology in 1886

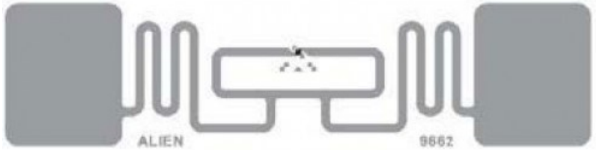


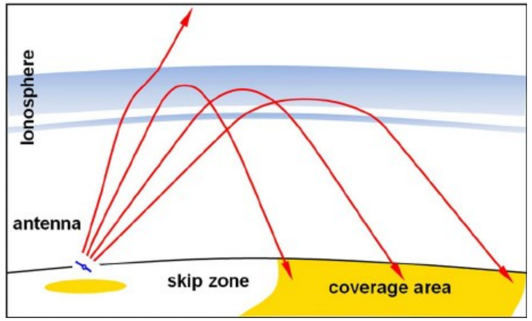


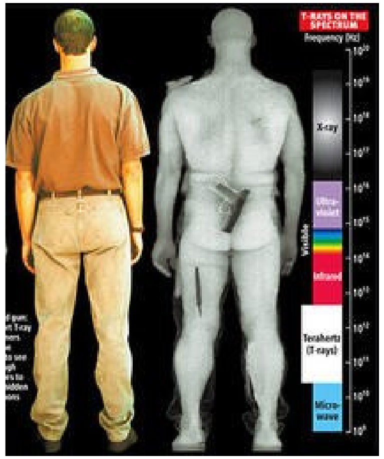
Application of radio waves

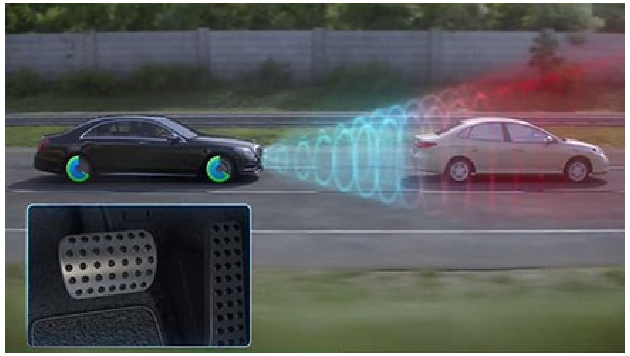


Very hot research topic today: Phased array for 5G communication









Partial ”flipped classroom” implementation

The course consists of Topics 1 – 5 → 4.5 rounds (Topic 5 only a half round)

Pre tasks 1 related to topic. Answering in MyCourses before Thursday clicker lecture. **First return on Thu, 10 Jan at 9.**

Clicker lecture 1 in the first hour of **Thursday** contact session. First on Thu, 10 Jan.

Thursday last hour and Mondays: Working and returning exercise problems. Individual return and teacher’s feedback and ”on demand” mini lectures in the contact sessions. (Topic 5 ends here!)

Pre tasks 2 related to the topic. Answering in MyCourses **before Thursday** clicker lecture.

Clicker lecture 2 in the **Thursday** contact session.

Thursday last hour and Mondays: Working and returning exercise problems. Individual return and teacher’s feedback and ”on demand” mini lectures in the contact sessions

Next Topic

Shared expertise and teachers’ support

Starting point: what do we teachers assume?

- 5 ECTS in 10 weeks (January 7 – March 14)
  - 5 x 27 h ↔ nominal **135 hours** of working
  - 5 hours weekly contact sessions ↔ 50 hours
  - 85 hours of independent working ↔ **8.5 hours weekly independent working**
  - The students with the grade goal higher than **"good" (3)** and/or the preknowledge lower than the average are assumed to work **more** than 135 working hours.

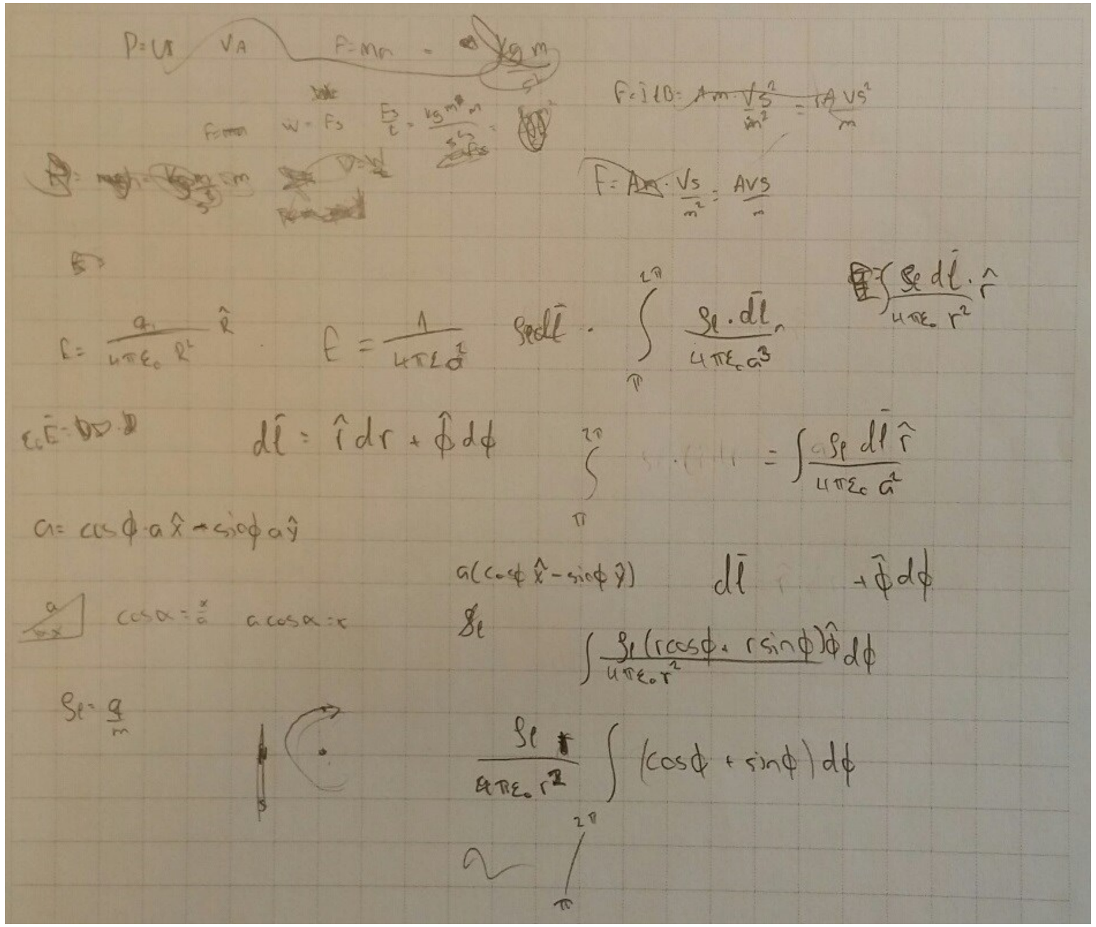
- The course has specified **preknowledge** that we assume you (more or less) to master before coming to the course. If not, you must work more!

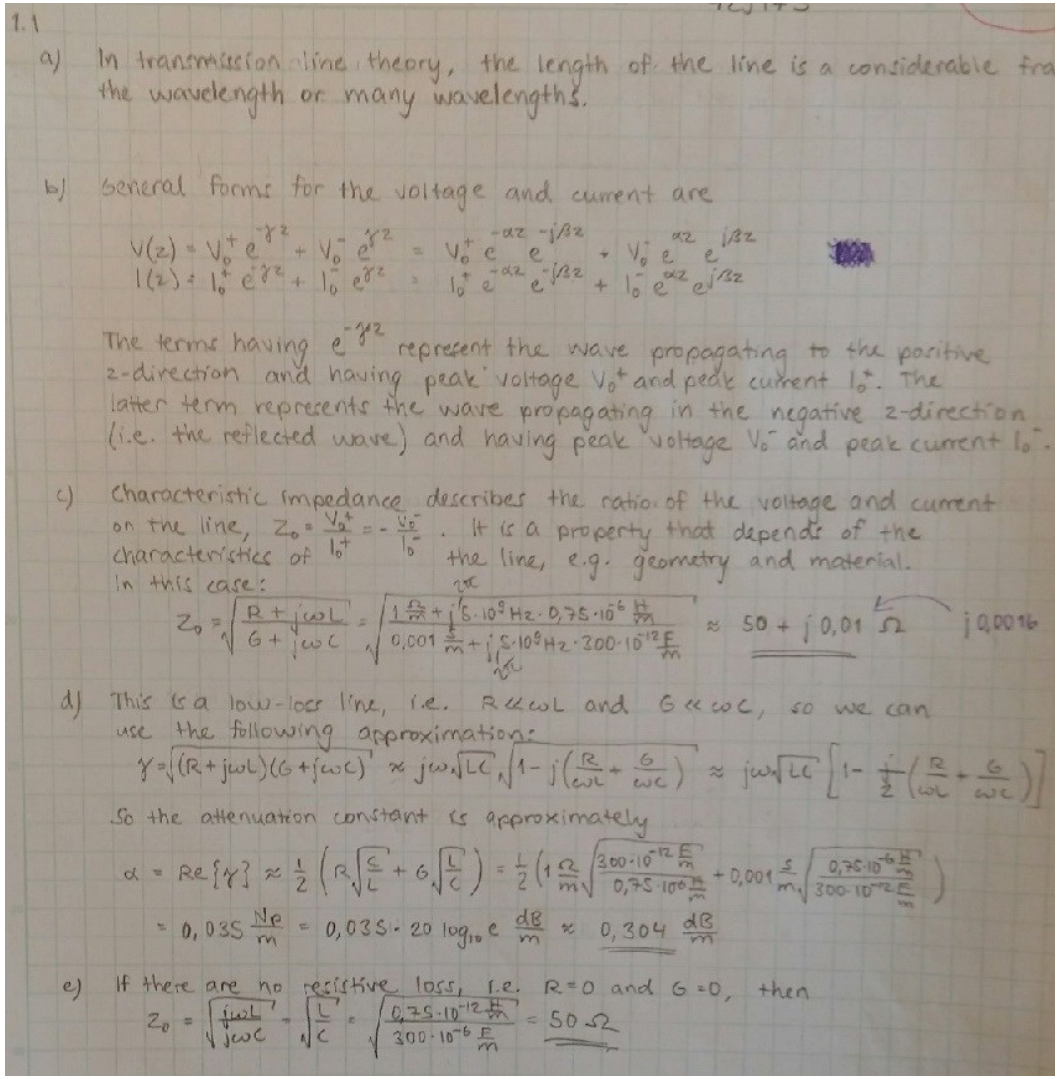
- This course is **cumulative**, meaning that the next problem or topic is (at least) to some extent based on the previous lectures, exercises and topics.

- You have an ability to approach problems and think **systematically** based on the taught theories.

Ability for systematic problem solving

Which student got better points for the exercise answer?





1.1

a) In transmission line theory, the length of the line is a considerable fra[ction of] the wavelength or many wavelengths.

b) General forms for the voltage and current are

$$V(z) = V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z} = V_0^+ e^{-\alpha z} e^{-j\beta z} + V_0^- e^{\alpha z} e^{j\beta z}$$
$$I(z) = I_0^+ e^{-\gamma z} + I_0^- e^{\gamma z} = I_0^+ e^{-\alpha z} e^{-j\beta z} + I_0^- e^{\alpha z} e^{j\beta z}$$

The terms having $e^{-\gamma z}$ represent the wave propagating to the positive z-direction and having peak voltage V_0^+ and peak current I_0^+. The latter term represents the wave propagating in the negative z-direction (i.e. the reflected wave) and having peak voltage V_0^- and peak current I_0^-.

c) Characteristic impedance describes the ratio of the voltage and current on the line, $Z_0 = \frac{V_0^+}{I_0^+} = -\frac{V_0^-}{I_0^-}$. It is a property that depends of the characteristics of the line, e.g. geometry and material.
In this case:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = \sqrt{\frac{1\,\frac{\Omega}{m} + j\,5\cdot10^9\,\mathrm{Hz}\cdot 0{,}75\cdot10^{-6}\,\frac{H}{m}}{0{,}001\,\frac{S}{m} + j\,5\cdot10^9\,\mathrm{Hz}\cdot 300\cdot10^{-12}\,\frac{F}{m}}} \approx \underline{\underline{50 + j\,0{,}01\ \Omega}} \quad j\,0{,}0016$$

d) This is a low-loss line, i.e. $R \ll \omega L$ and $G \ll \omega C$, so we can use the following approximation:

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \approx j\omega\sqrt{LC}\sqrt{1 - j\left(\frac{R}{\omega L} + \frac{G}{\omega C}\right)} \approx j\omega\sqrt{LC}\left[1 - \frac{j}{2}\left(\frac{R}{\omega L} + \frac{G}{\omega C}\right)\right]$$

So the attenuation constant is approximately

$$\alpha = \mathrm{Re}\{\gamma\} \approx \frac{1}{2}\left(R\sqrt{\frac{C}{L}} + G\sqrt{\frac{L}{C}}\right) = \frac{1}{2}\left(1\,\frac{\Omega}{m}\sqrt{\frac{300\cdot10^{-12}\,\frac{F}{m}}{0{,}75\cdot10^{-6}\,\frac{H}{m}}} + 0{,}001\,\frac{S}{m}\sqrt{\frac{0{,}75\cdot10^{-6}\,\frac{H}{m}}{300\cdot10^{-12}\,\frac{F}{m}}}\right)$$
$$= 0{,}035\,\frac{Np}{m} = 0{,}035\cdot 20\log_{10} e\,\frac{dB}{m} \approx \underline{\underline{0{,}304\,\frac{dB}{m}}}$$

e) If there are no resistive loss, i.e. $R = 0$ and $G = 0$, then

$$Z_0 = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}} = \sqrt{\frac{0{,}75\cdot10^{-12}\,\frac{H}{m}}{300\cdot10^{-6}\,\frac{F}{m}}} = \underline{\underline{50\ \Omega}}$$

Ability for systematic problem solving

This is what we assume in practice:

- ✓ Explain the used variables and give their units, e.g., ***E*** = electric field, unit V/m
- ✓ Sketch a clear figure of the situation, mark the variables, dimensions, vectors etc. to the figure
- ✓ Justify the applied principle or theory physically and explain how they relate to the given problem
- ✓ Give a source of information, especially if it is other than the course book
- ✓ Let your solution to proceed systematically and explain the main principles (this helps especially when solving complex problems)
- ✓ Write all the intermediate steps of a mathematical solution clearly. Give assumptions you use.
- ✓ Give the final answer in the same number of significant digits than the most inaccurate starting value
- ✓ Ponder whether your final answer makes sense. Justify the answer based on physical understanding of the problem (typical problems have a simplified connection to the real world).

Learning outcomes

- After successful completion of the course the student is able to **identify** the types of radio waves and **discuss** usage of radio spectrum and typical applications in microwave engineering.
- The student can **discuss** the biological effects and safety issues of radio waves.
- The student is able to **explain** the behaviour of a radio signal in typical transmission lines, **calculate** and **simulate** related circuit parameters, and **design** transmission lines.
- The student can **design** impedance matching circuits and **explain** the design principles.
- The student is able to **model** basic microwave circuits and resonators with suitable circuit parameters and **analyze** their operation based on calculations and simulations.
- The student can **explain** the operational principles of basic microwave systems and **calculate** relevant system parameters.
- The student can **explain** the radio wave propagation. He/she is able to **calculate** basic characteristics of radio links based on propagation models.

Topics and material

Course book: Pozar – Microwave engineering

- all editions ok, but we refer to the chapters of Edition 4

- Today's session: introduction of microwave engineering (Chapters 1 and 14)
- Topic 1: transmission line theory and waveguides (Chapters 2 and 3)
- Topic 2: Smith chart and impedance matching (Chapters 2 and 5)
- Topic 3: analysis of microwave circuits (Chapters 4 and 6)
- Topic 4: radio systems (Chapters 10 and 14)
- Topic 5: radiowave propagation (Chapter 14 + other given material)

Chapters 6-13 – i.e., design of microwave circuits – will be handled in the course Microwave engineering II which starts after this course on Mon, March 18.

Total points and grading

- **Pre tasks** before Thursday clicker lectures 9 x 3 p = **27 points**
  - each graded 0-3 p
- **Thursday clicker lectures** 9 x 2 p = **18 points**
  - participation = 1 p, ”sufficiently good” answers = 2 p
- **Exercise problems** 26 x 3 p + 6 p = **84 points**
  - each graded 0-3 p and single bigger problem related to radiowave safety 0-6 p)
- **Total points = 129 points**
  - Smallish changes possible before the Thursday session

- Tentative grading plan: 50 % of the points (63 p) → 1, 60% → 2, 70% → 3, 80% → 4, 90 % → 5

Miscellaneous instructions

- We use **partial** ”*flipped classroom*” principle: the theories are partly studied at home and the exercise problems are worked and returned in the class.
- The preliminary tasks, clicker lectures and exercise problems cover all the essential course learning outcomes and they all affect the grading
- The course consists of five **successive** topics (Topics 1-5)
  - Study the topics one by one and solve problems starting from Problem 1.
- Progress with your individual speed but notice that minimum of two (2) problems must be returned weekly.
  - Detaileed instructions for the problem returning will be given on next Thursday
  - The optimal returning speed would be to return about **three** problems per week.
  - Each topic 1-5 must be covered by Thursday, March 14, 2018.
- The teachers can provide mini lectures and examples on selected topics on demand → ask them (pro)actively

Students' feedback from the previous years

"My only negative comment about the course is the fact that we have to discuss **all** our answers, which takes a lot of time between waiting for someone to be free and narrating our answer to them."

Action: A systematic and detailled written answer is asssumed → then all the details do not need to be explained face-to-face → the returning process will be faster. You may also return when a teacher is free; not everyone should try to return simultanenously in the end of the session.

"Plan the homework's deadlines in order to prevent that there will be a lot of exercises pending to the end of the course."

Action: minimum of 2 weekly returned answer. Also, plan your individual schedules so that you do not return your exercise answers in the end of the course. Also, prepare your answer so that a short discussion is enough → no rush

"The emphasis of receiving assistance of others can not be emphasized too much, as otherwise one will most likely run out of time and energy."

Action: We recommend that you cooperate as much as possible, but returning exercises is individual.

Students' feedback from the previous years

Great course! I hope that clicker lectures do stay the same. That is: they do affect too much the course grade. As there was no traditional exam, I had significantly less stress during the course. That really helped me to concentrate on the actual learning.

I really like this teaching methodology by solving the exercise problems related to the topic and then when you return the answer to the teacher and do the discussion is the best learning point.

The teaching methods were excellent. I learnt a lot more from this course than any other. It is great that the teachers are always available for help, and the mini lectures are also very useful.

The teachers really care about everyone and you feel that they want you to understand.

Go with your mobile phone to **presemo.aalto.fi/mwe1**

(If you do **not** have a mobile phone, ask teachers to give a laptop)