Microwave engineering I

11 January – 18 March, 2021, 5 ECTS

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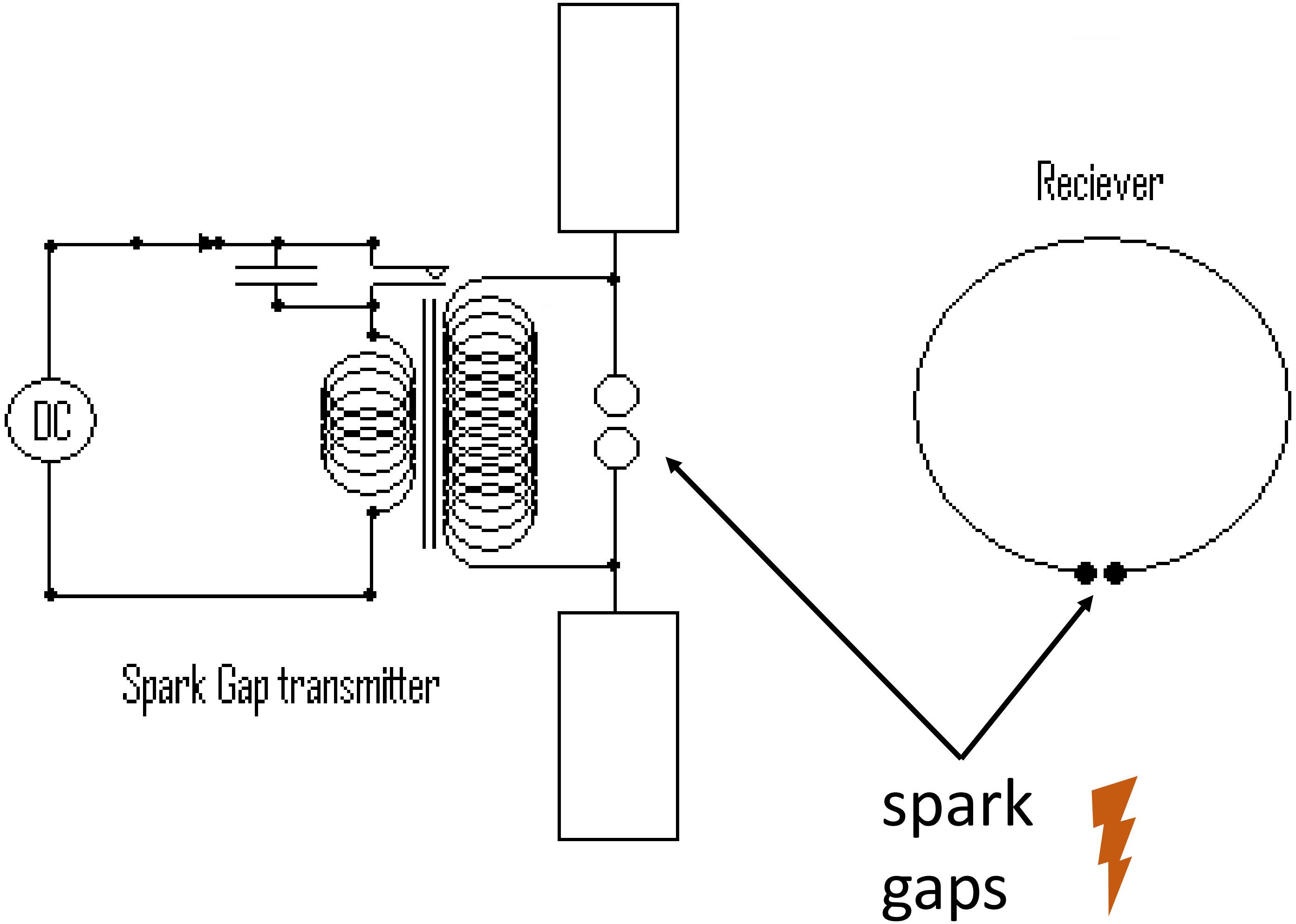
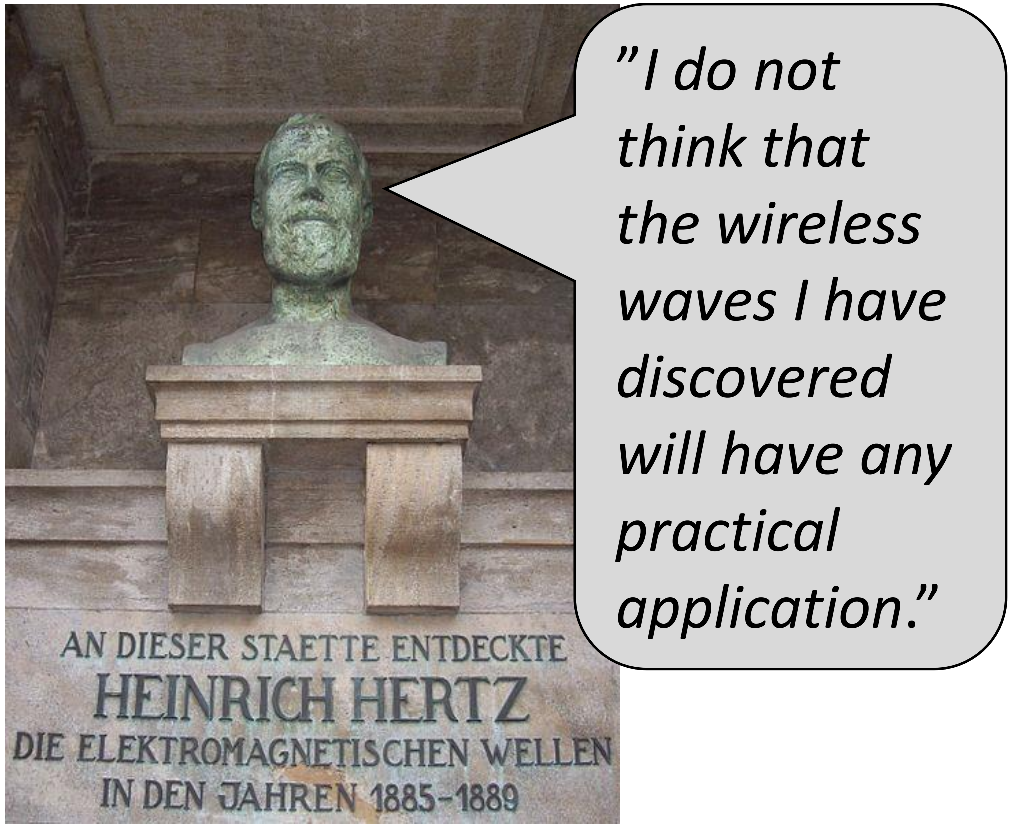
The first step of microwave engineering

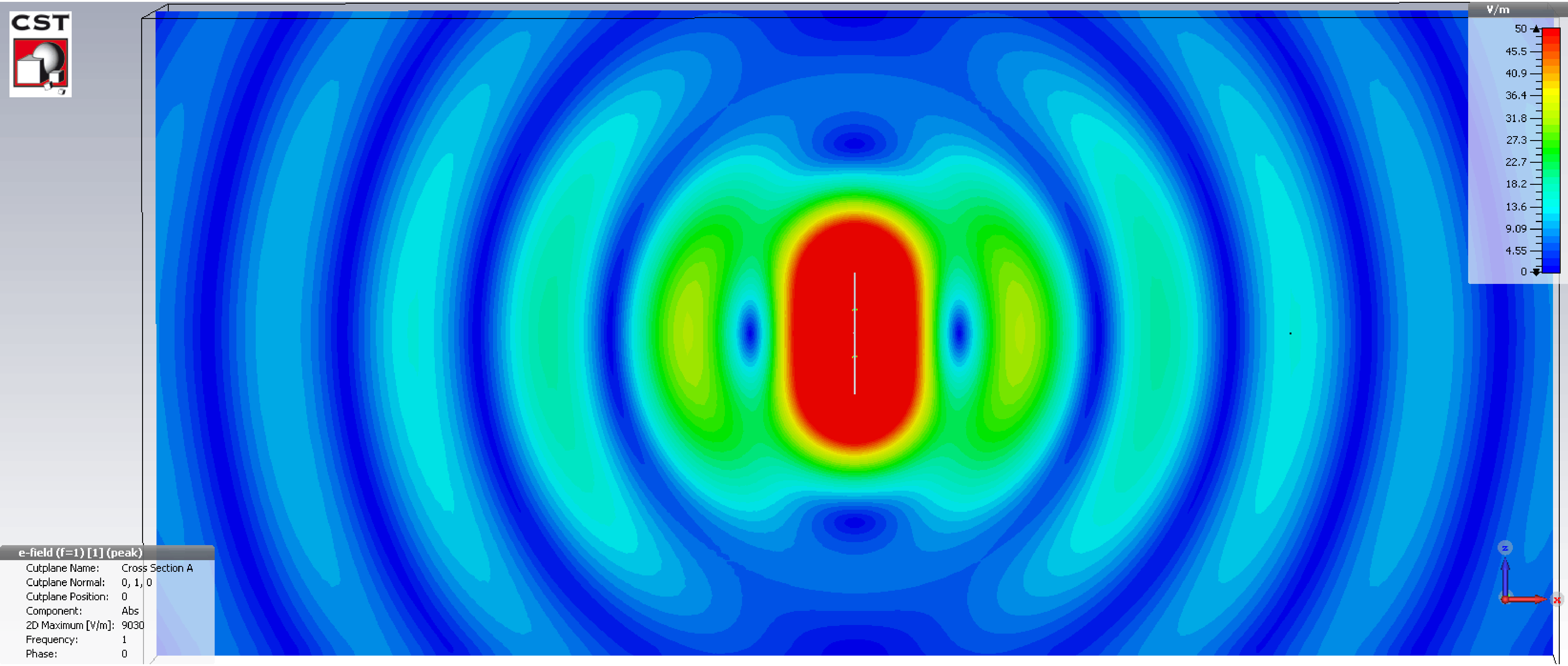
(Maxwell's equations in 1865 to predict the existance of electromagnetic waves.)



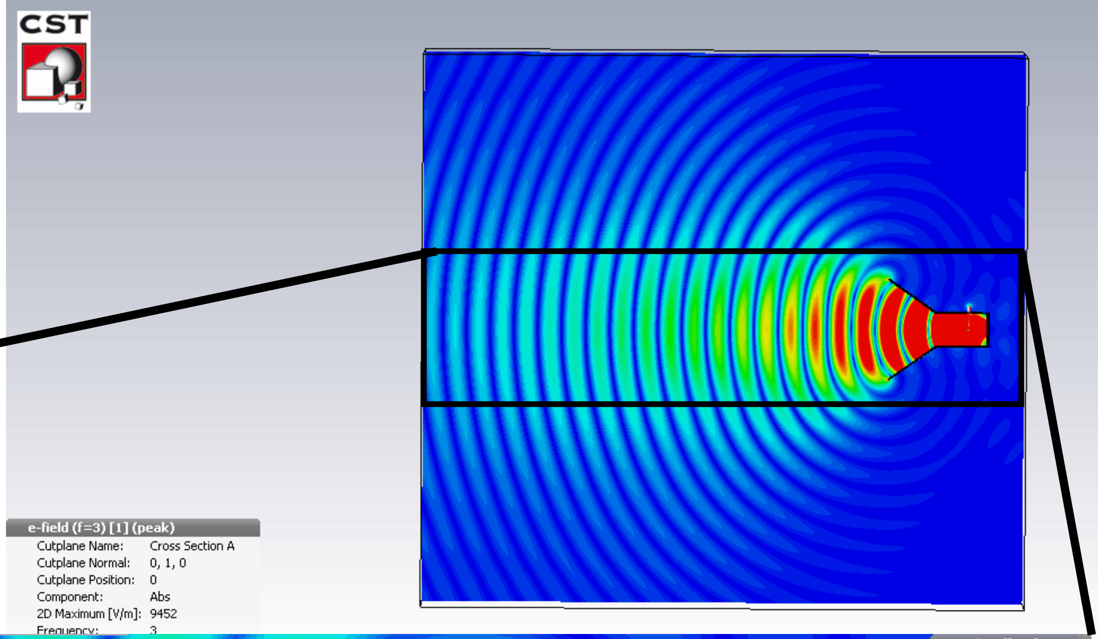


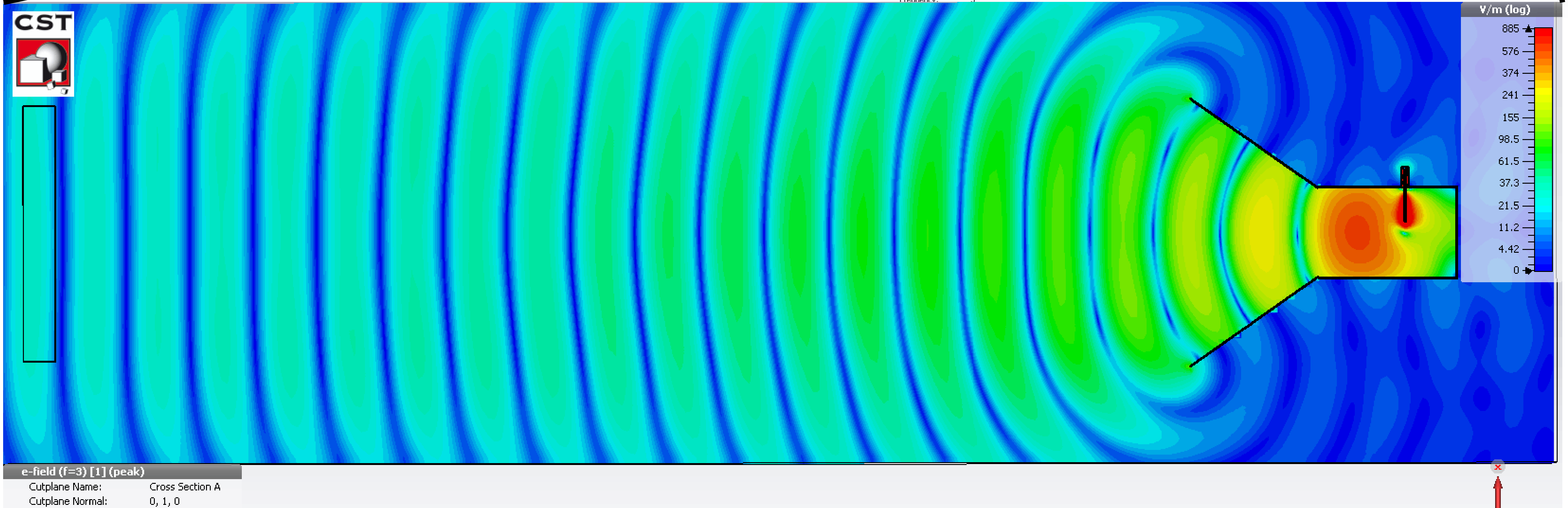
Source:
https://www.famousscientists.org/how-hertz-discovered-radio-waves/

Alternating current in a wire induces radio waves that propagate to the surrounding free space

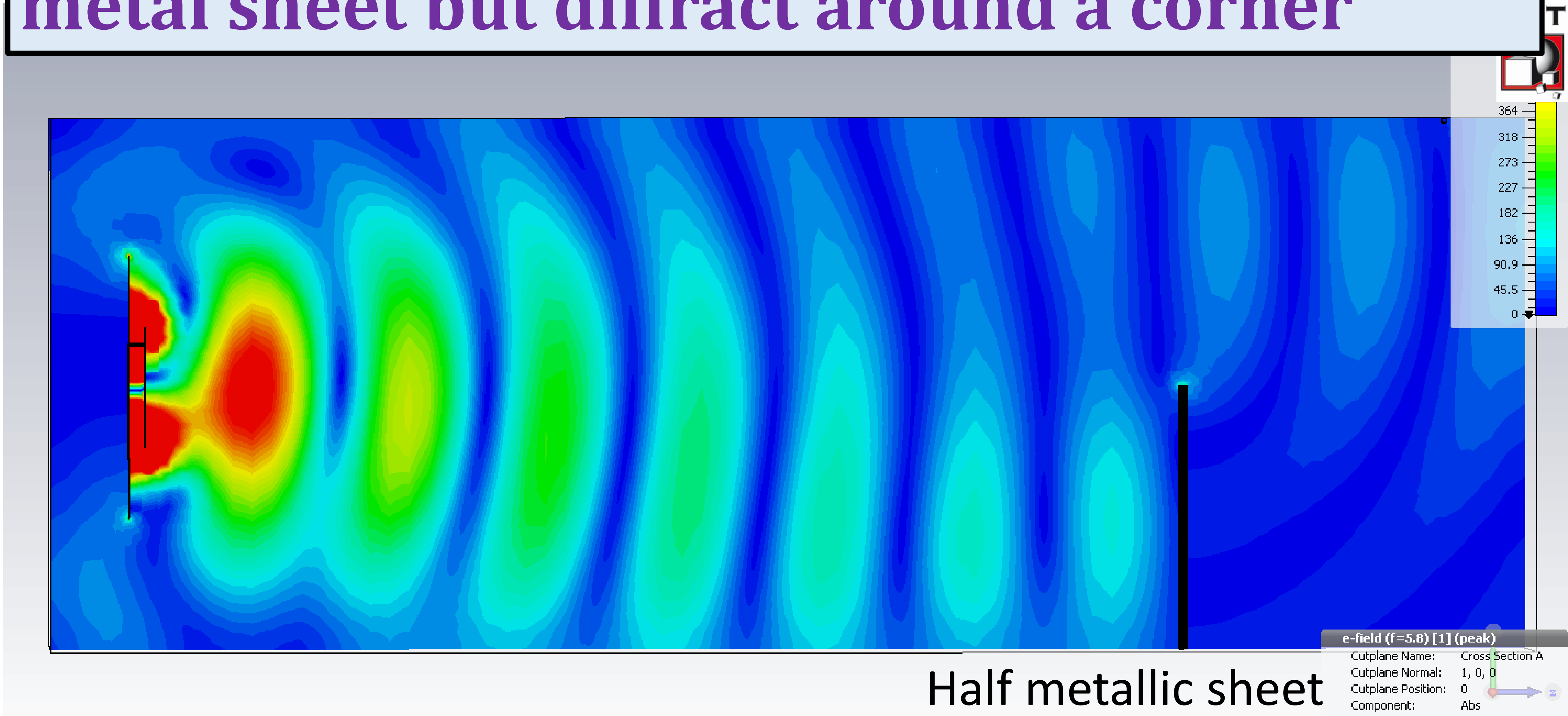


Aperture field will also induce radio waves



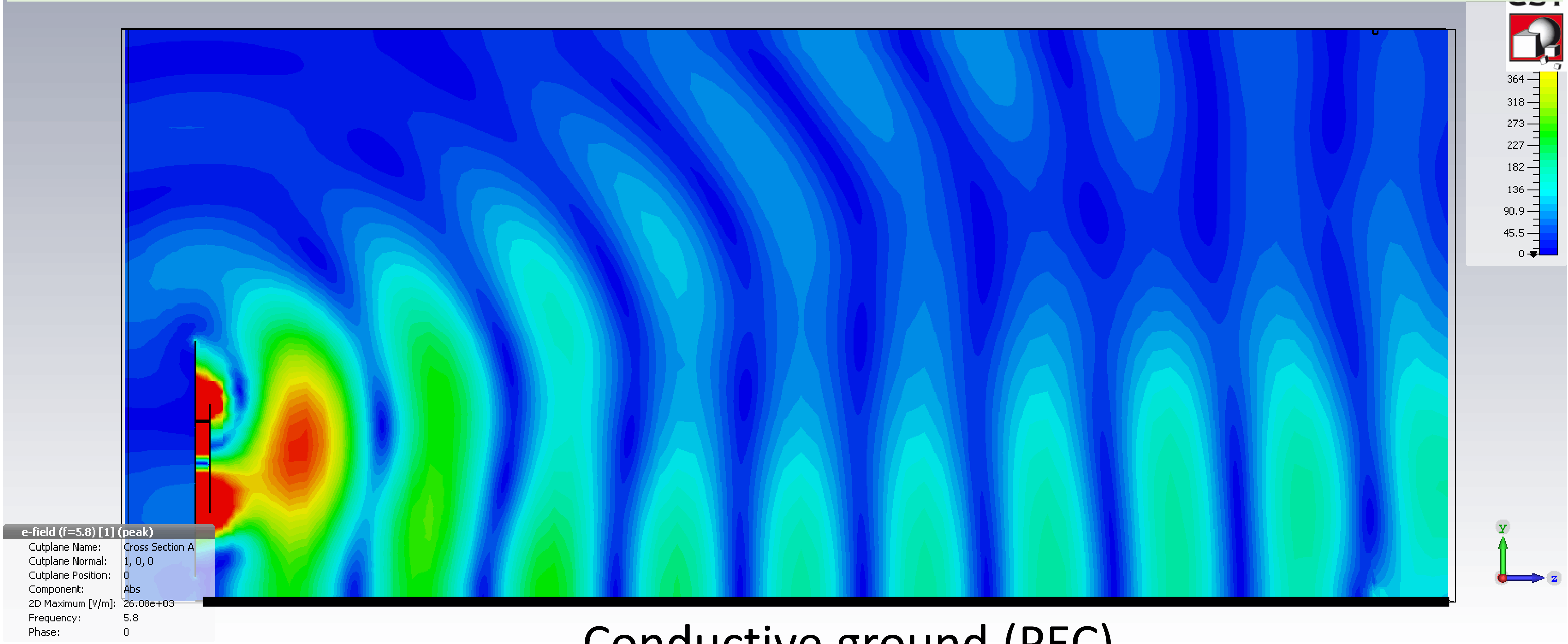


Radio waves do not penetrate through a metal sheet but diffract around a corner



Half metallic sheet

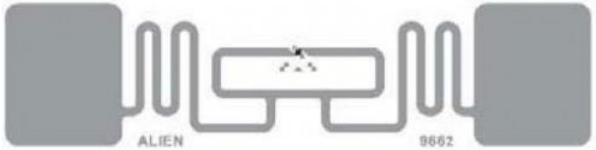
Radio waves can propagate as the ground wave along the interface between free space and conductive surface

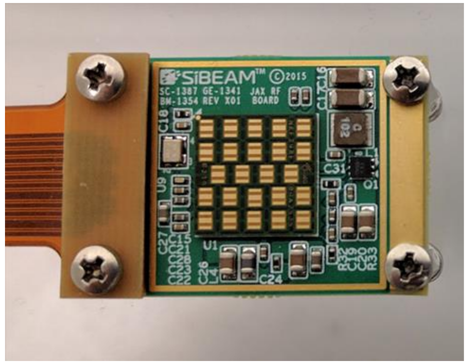


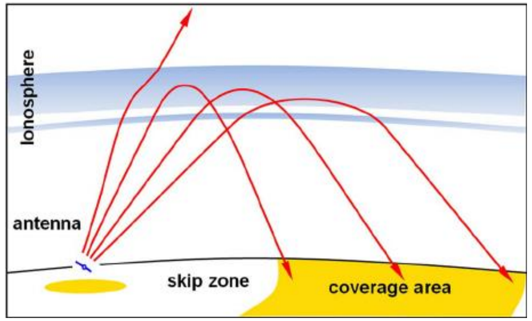
Conductive ground (PEC)

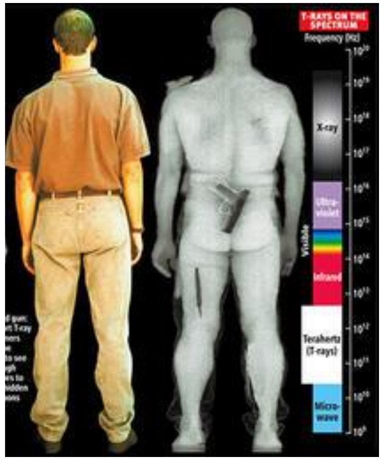
Application of radio waves

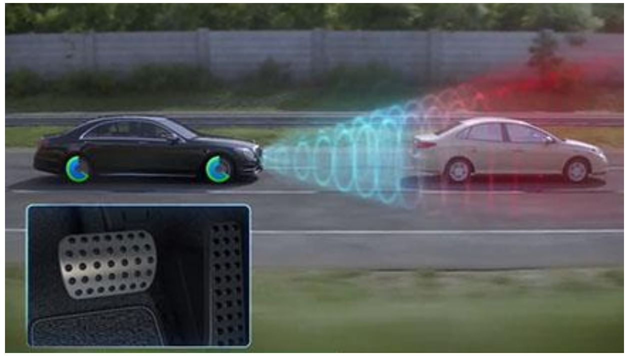
Very hot research topic today: Phased array for 5G communication











During the break, think about any wishes or thoughts regarding the course content.

Write them into the chat of Zoom.

In the beginning of the course

- You need a book for studying!
  - The lectures do not cover all the content that is needed in the exercise problems
  - We use **Pozar – Microwave engineering** as the main studying material
  - Alternatively, you may also consider to use Räisänen/Lehto: Radio engineering (…)

- The preknowledge of the course includes
  - engineering mathematics, electromagnetic field theory, circuit theory, Matlab/Mathematica
  - For instance, bachelor’s level knowledge in electrical engineering or the studies of the first autumn of the ELE Master’s programme should be enough

- Apply for the student licence of the Cadence AWRDE (circuit simulator we use) and install the software on your computer. Instructions in MyCourses.

Intended learning outcomes

- 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. (*Topic 1*)
- The student can **design** impedance matching circuits and **explain** the design principles. (*Topic 2*)
- The student is able to **model** basic microwave circuits and resonators with suitable circuit parameters and **analyse** their operation based on calculations and simulations. (*Topic 3*)
- The student can **explain** the operational principles of basic microwave systems and **calculate** relevant system parameters. (*Topic 4*)
- The student can **explain** the radio wave propagation. He/she is able to **calculate** basic characteristics of radio links based on propagation models. (*Topic 5*)

Topics and related material

Pozar book chapters (edition 4)   Räisänen/Lehto book chapters

- Today: introduction of the topic and the course (Chapters 1 and 14, Chapters 1 and 13)
- Topic 1: transmission line theory and waveguides (Chapters 2 and 3, Chapters 3 and 4)
  - Related interactive lectures on Thu 14 and 21 January
- Topic 2: Smith chart and impedance matching (Chapters 2 and 5, Chapter 4)
  - Thu 28 January and 4 February
- Topic 3: analysis of microwave circuits (Chapters 4 and 6, Chapters 5 and 7)
  - Thu 11 and 18 February
- Topic 4: radio systems (Chapters 10 and 14, Chapter 11)
  - Thu 25 February and 4 March
- Topic 5: radiowave propagation (Chapter 14, Chapter 10)
  - Thu 11 March (only one lecture), Thu 18 March reserved for exercise returning

Chapters 6-13 of Pozar book will be handled in the course Microwave engineering II which starts after this course on Monday, March 22, 2021.

Learning activities

- Preliminary tasks (related to each interactive lecture)
  - Returned in MyCourses before the Thursday interactive lecture
  - Idea is to familiarise you with the topic of the lecture

- Interactive lectures every Thursday at 9 in Zoom
  - "Interactive" means that there are activating tasks integrated to the session
  - They will last 1-2 hours (with a possible break)
  - The lectures do not cover all the learning outcomes, the purpose is to introduce the topic

- Exercise problems
  - They cover all the learning outcomes of the course
  - Current plan is that the answers are returned individually in 1) a pre-allocated or pre-booked session or 2) during the remote sessions when a teacher is available (further details to be communicated)
  - Flexible return date (some DL's still apply, also communicated later)
  - Monday session at 10-12 is reserved for exercise return

Grading

- Continuous evaluation, **no** final exam
- The grading of the course is **individual**, any misconduct of academic integrity is forbidden
- All points earned have **equal** weight on the final grade
- Grading plan: 50% of the maximum points → 1, 60% → 2, 70% → 3, 80% → 4, 90% → 5

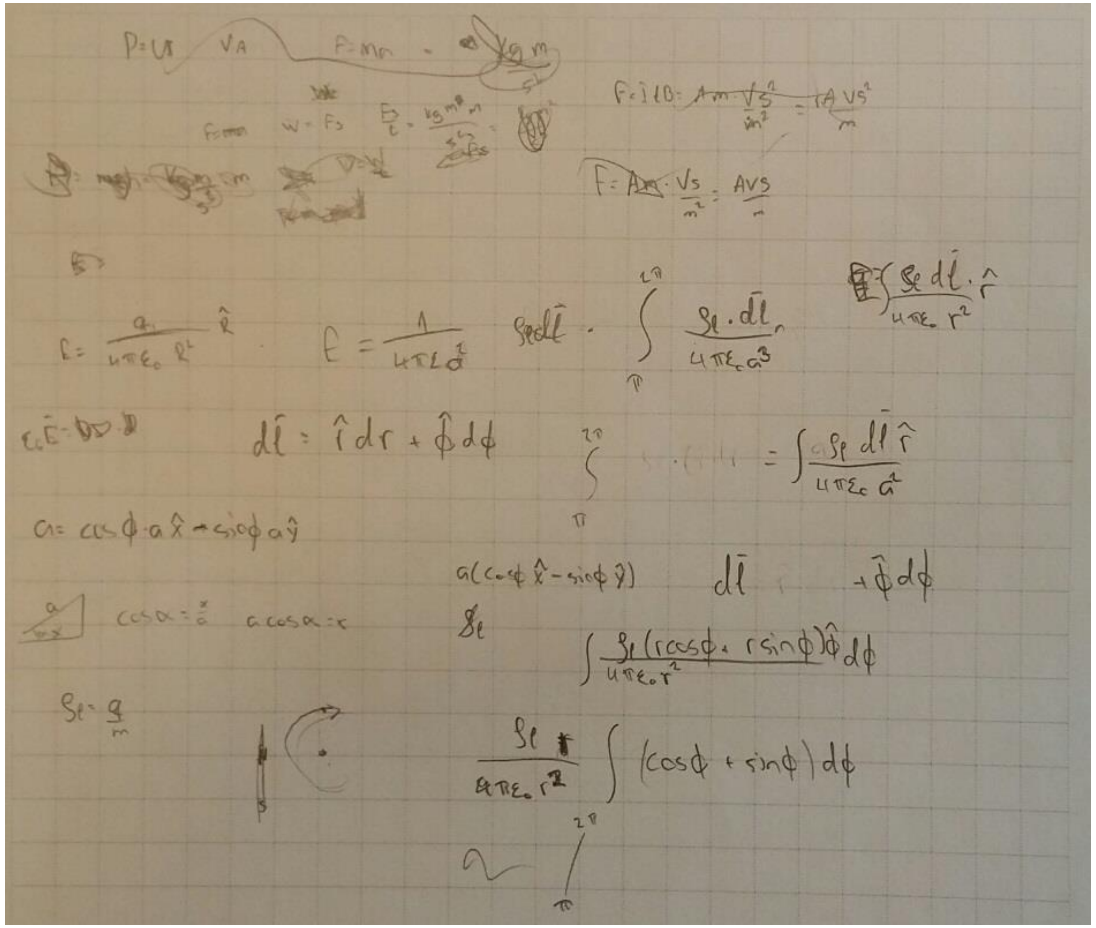
- Interactive lectures every Thursday at 9 in Zoom
  - each graded 0-1 points, maximum 9 x 1 points = **9 points**
  - 1 point = ”active participation” in the lecture – i.e., actively and successfully participate in the activating tasks, possible discussions etc.

- Preliminary tasks (related to each interactive lecture)
  - each graded 0-2 points, maximum 9 x 2 points = **18 points**

- Exercise problems
  - each problem graded 0-3 points
  - 3 – 6 problems per topic, maximum 20…24 x 3 points = **60…72 points**
  - we will fix on the number of exercise problems later

Clear, justified, and consistent answers are assumed

NOT LIKE THIS!!!!!



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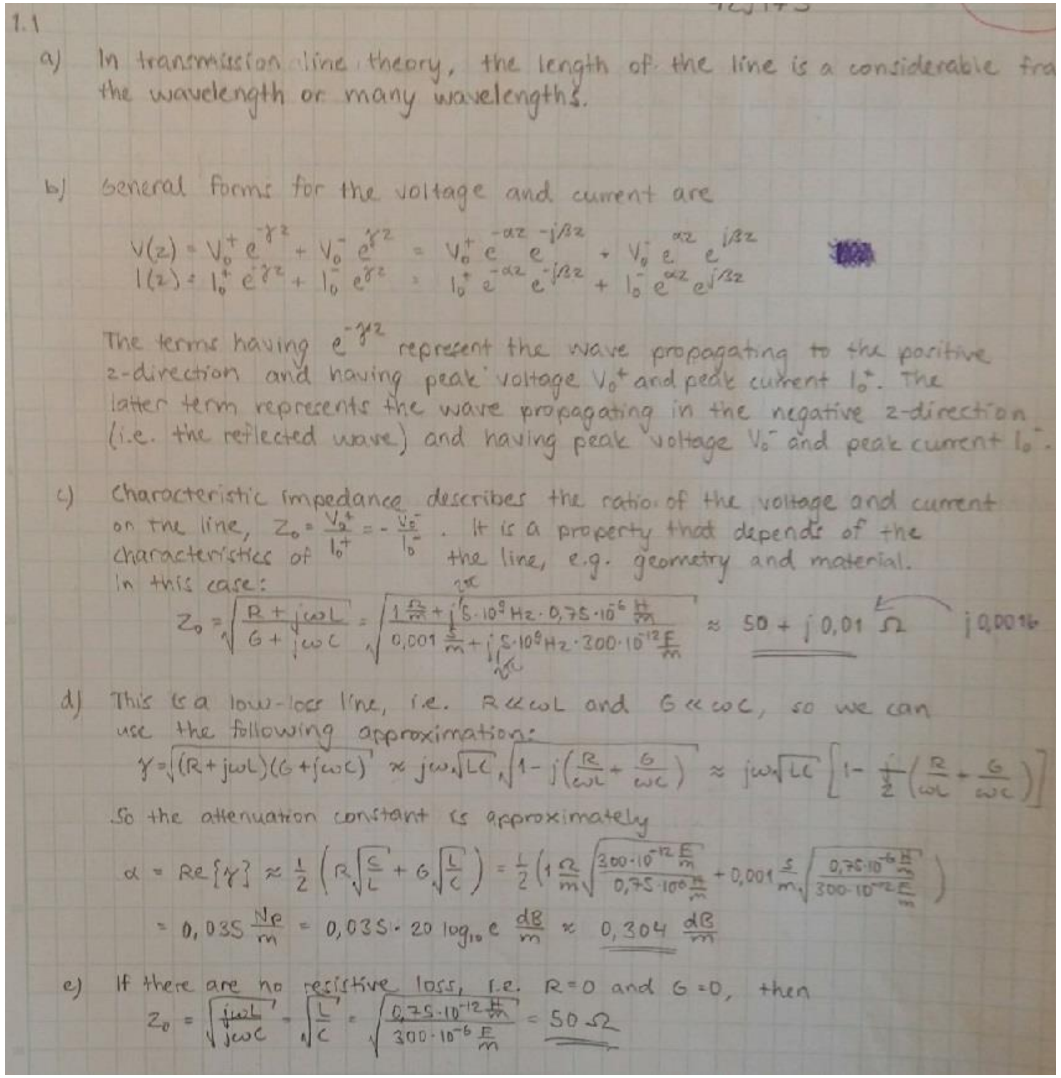

1.1

a) In transmission line theory, the length of the line is a considerable fra
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:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = \sqrt{\frac{1\,\frac{\Omega}{m} + j\,2\pi\,5\cdot10^9\,Hz\cdot 0{,}75\cdot10^{-6}\,\frac{H}{m}}{0{,}001\,\frac{S}{m} + j\,2\pi\,5\cdot10^9\,Hz\cdot 300\cdot10^{-12}\,\frac{F}{m}}} \approx \underline{50 + j\,0{,}01\ \Omega} \quad j\,0{,}0016$$

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

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

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

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

What to do before the Thursday session

- Get a book to enable studying
- Read through the MyCourses pages for further information of the course content, learning outcomes and the arrangements
- Answer the preliminary tasks in MyCourses before the Thursday interactive lecture
- Join the interactive lecture on Thursday, the session starts sharp at 9.00 am.
  - ➢ Sign-in Zoom using the Aalto domain