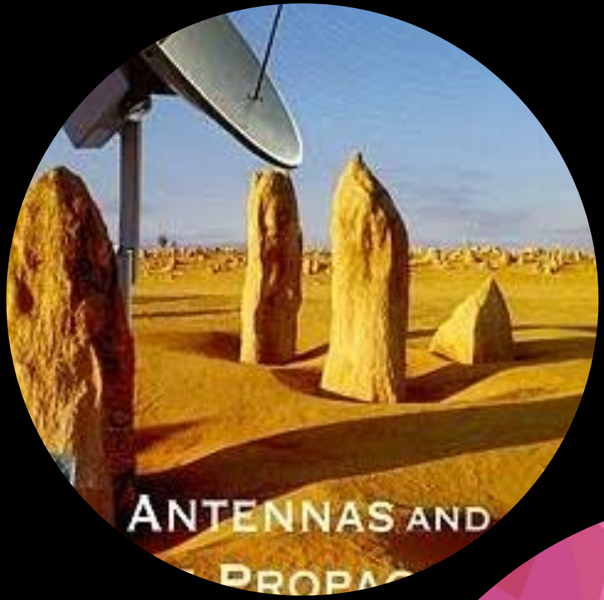
ELEC-E4450 Antennas

(5 ECTS)

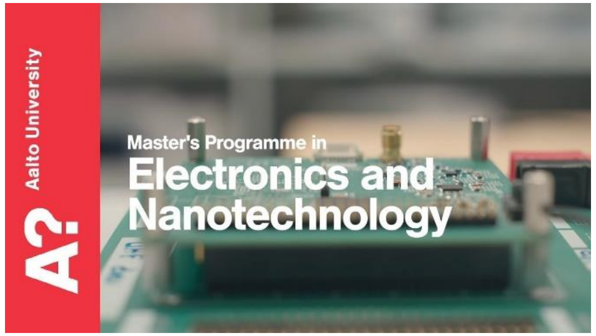


Aalto University
School of Electrical
Engineering

27 February – 4 June 2024

Jari Holopainen, Pyry Kiviharju

What is your current study programme & major?



1. microwave engineering major of the ELE master's programme
2. other major of the ELE master's programme
3. other master's programme of Aalto University
4. EST bachelor's studies of Aalto University
5. doctoral studies in Aalto University (any school)
6. ERASMUS exchange studies
7. Other

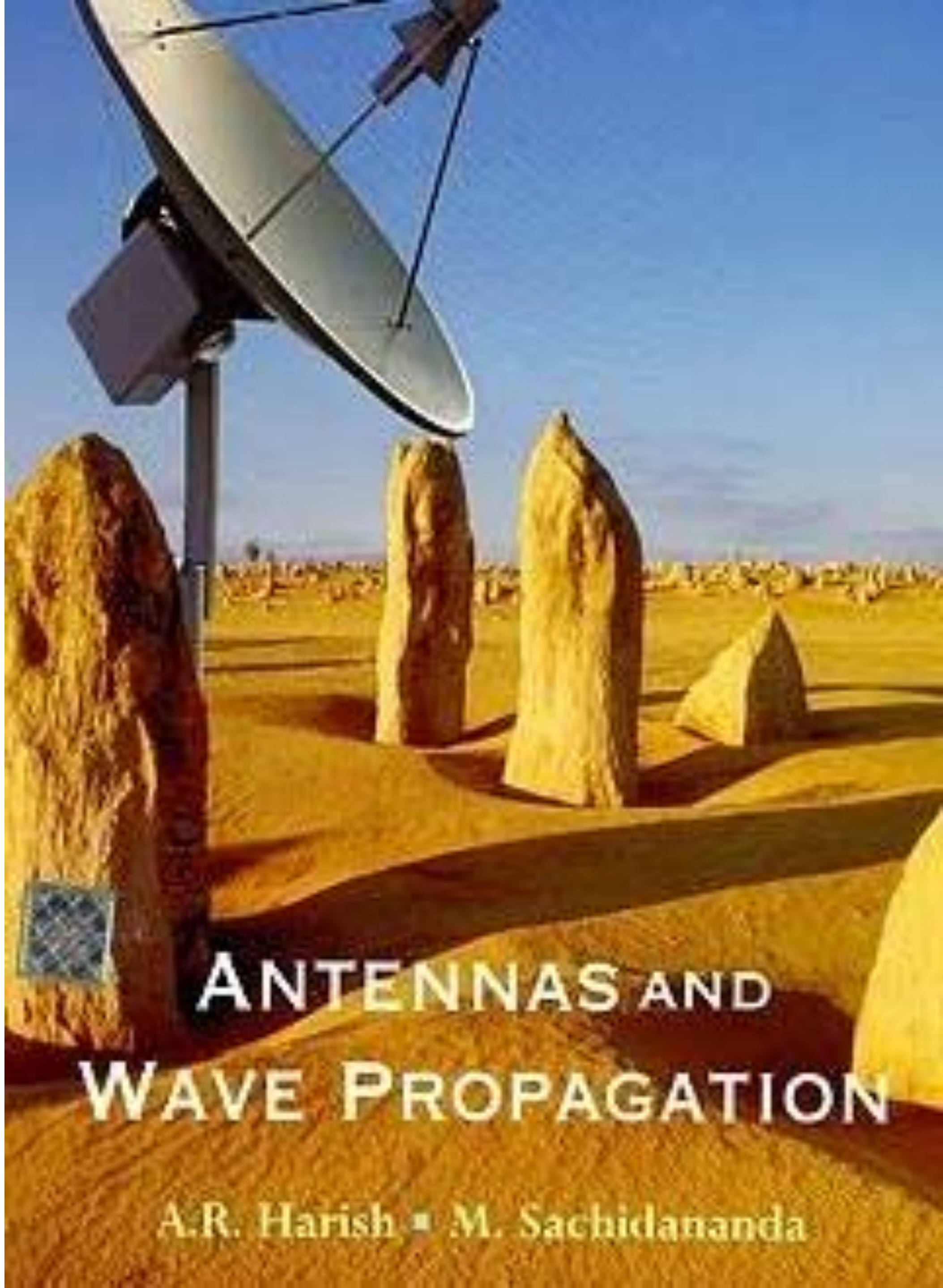
Pre-knowledge of the course

1. **bachelor's level engineering mathematics**
   - e.g., algebra, trigonometry, linear algebra, complex numbers, complex vectors, vector calculus, differential equations etc.
2. **circuit theory**
   - e.g., ELEC-C4110 *Piirianalyysi I* and ELEC-C4120 *Piirianalyysi II* **or** ELEC-E3120 *Analysis and design of electronic circuits*
3. **electromagnetic field theory**
   - e.g., ELEC-C4140 *Kenttäteoria* or ELEC-E4130 *Electromagnetic fields*
4. **microwave engineering**
   - e.g., ELEC-E4420 *Microwave engineering I*
5. **some mathematical software, for instance, Matlab and Wolfram Mathematica**
   - e.g., ELEC-C4140 *Matematiikkaohjelmistot* or ELEC-E9111 *Mathematical computing*
6. **(EM and circuit simulations)**
   - e.g., in Period III in the course ELEC-E4410 *Electromagnetic and circuit simulations*

You need a book for studying!

- **Harish - Sachidananda: Antennas and Wave Propagation**
  - e-book available through lib.aalto.fi

- Other famous/ suitable basic antenna books are
  - Stutzman: Antenna Theory and Design
  - Balanis: Antenna Theory: Analysis and Design
  - Kraus: Antennas for All Applications



Course content and preliminary schedules

- Today: introduction of the course and the pre-knowledge quiz
- Topic 1: **Electromagnetic radiation** (Ch. 1), related sessions 1.-8.3.
- Topic 2: **Antenna characteristics** (Ch. 2), related sessions 12.-22.3.
- Topic 3: **Wire antennas** (Ch. 3), related sessions 26.3.-12.4.
  - Spring break 28.3.-3.4., Evaluation week of Period IV 15.-19.4.2024
- Topic 4: **Antenna arrays** (Ch. 5), related sessions 23.4.-3.5.
- Topic 5: **Aperture antennas** (Ch. 4), related sessions 7.-17.5.
- Topic 6 **Antenna measurements** (Ch. 10), related sessions 21.-28.5.
- **Final quiz,** Fri 31.5.

Intended learning outcomes

After successful completion of the course,

- The student is able to **solve** electromagnetic fields and basic antenna parameters for simple microwave radiators.
- The student is able to **explain** fundamental antenna concepts and **calculate** common parameters used to describe their properties.
- The student can **analyse** the effect of the antenna on the performance of radio communication systems.
- The student can **describe** the operation principles of most common antenna types, such as wire antennas, array antennas, and aperture antennas. They can **compute** the far-field radiation due to known current distributions.
- The student has a readiness to **perform** basic antenna measurements such as the antenna impedance and radiation pattern measurements. The student can **analyse** the measurement results and estimate the error sources.

Taking the course requires active participation and learning

- **Preliminary tasks** related to each topic
  - ➢ Returned in MyCourses before Tuesday interactive lectures (first time Tue March 5)
  - ➢ The main idea is that you are *prepared* for the lecture

- **Interactive lectures** Tuesdays at 12-14
  - ➢ "Interactive" means that there are activating tasks integrated to the session

- **Exercise problems,** we will inform further details later
  - ➢ Friday session is reserved for exercises and their return
  - ➢ There will be 15-20 exercise problems + measurement assignment

- **Final quiz tentatively on Tuesday, 31 May at 12-14**
  - ➢ Pen & paper quiz that is "*do you understand the basics*" type – i.e., there are no long mathematical calculations or design problems in the final exam.

Continuous assessment is in use

- **Preliminary tasks** (6 times, first time on March 5) affect **15%**
  - Returned in MyCourses

- **Exercise problems** (to be decided 15 … 20 problems) affect **50%**
  - Each problem graded 0–4 points

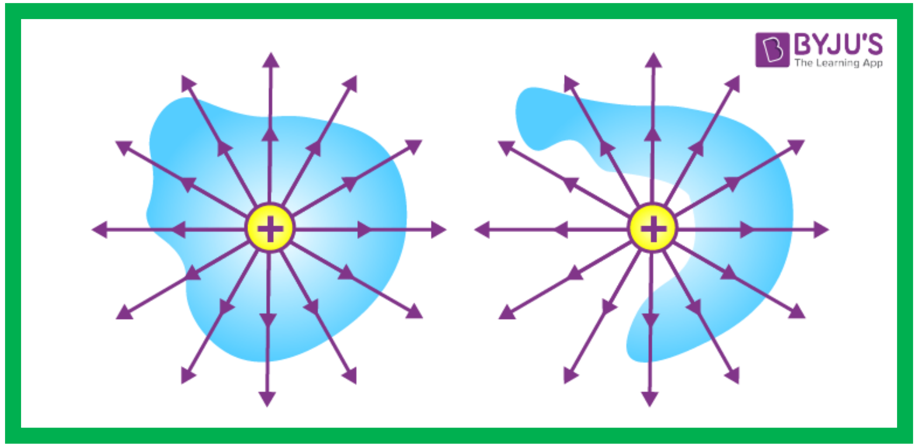
- **Measurement assignment** affects **20%**
  - Reporting and analyzing measurement results

- **Final exam/quiz** (tentatively on Tuesday 31 May at 12-14) affects **15%**

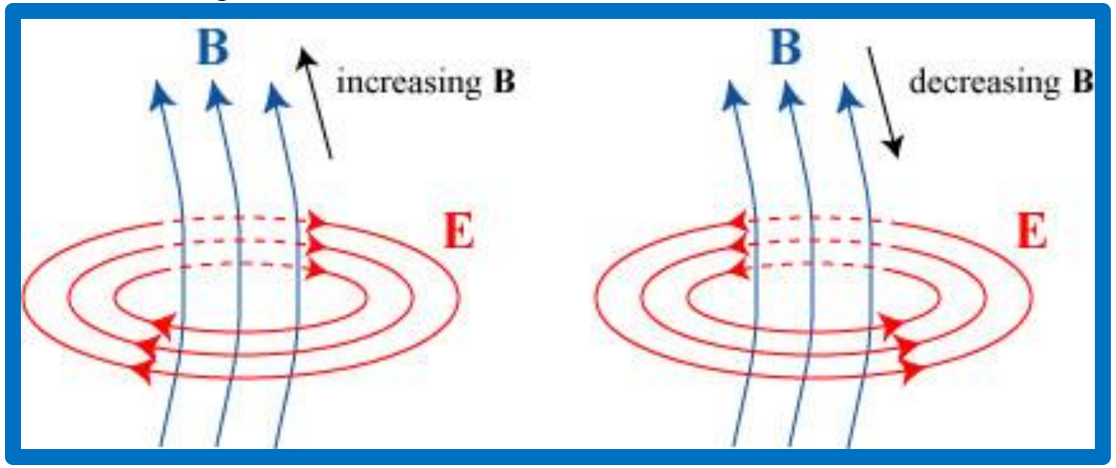
- The grading of the course is **individual**, any misconduct of academic integrity is forbidden and will be handled according to the official procedure.
- Tentative grading plan: 50.0% of the maximum points → passed (1), 60.0% → 2, 70.0% → 3, 80.0% → 4, 90.0% → 5

Maxwell introduced the famous equations in 1865

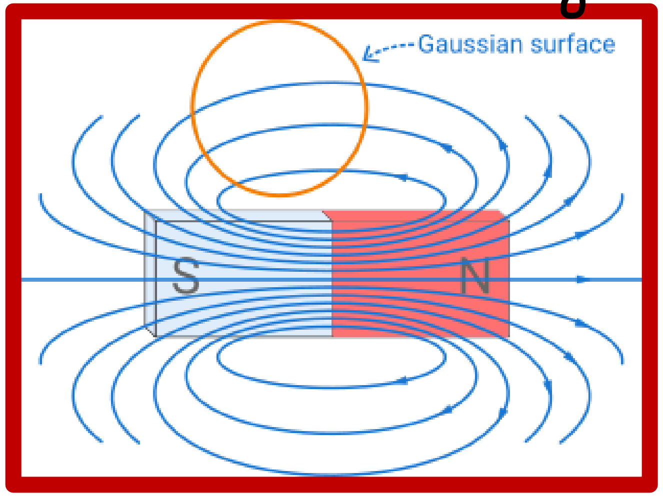
Gauss's law $\nabla \cdot \bar{D} = \rho$



Faraday's law $\nabla \times \bar{E} = -\frac{\partial \bar{B}}{\partial t}$



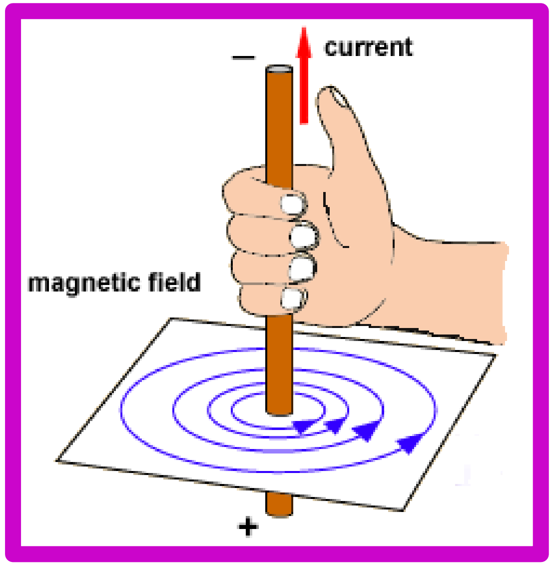
Gauss's law for magnetism



$\nabla \cdot \bar{B} = 0$

Ampere's law

$\nabla \times \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t}$



Maxwell predicted the existence of electromagnetic waves purely based on the equations

Gauss's law	Gauss's law for magn. field	Faraday's law	Ampère's law
$\nabla \cdot \mathbf{D} = \rho$	$\nabla \cdot \mathbf{B} = 0$	$\nabla \times \mathbf{E} = -j\omega \mathbf{B}$	$\nabla \times \mathbf{H} = \mathbf{J} + j\omega \mathbf{D}$

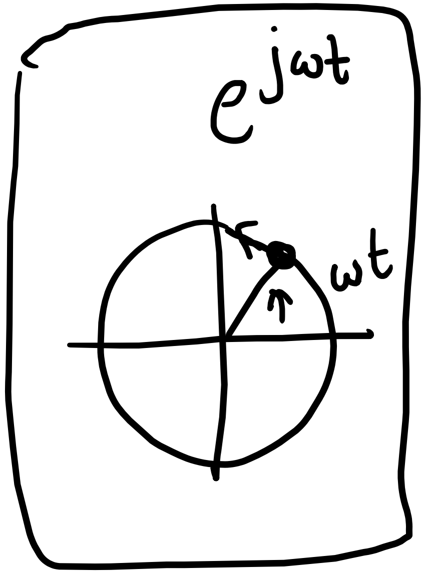
$\nabla^2 \bar{E} + k^2 \bar{E} = 0$ Helmholtz equation

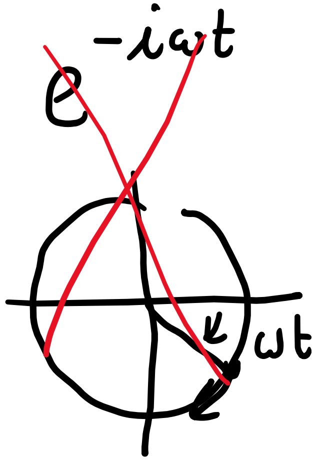
$k = \omega\sqrt{\varepsilon\mu}$ wave number

solution: $\bar{E} = E_0 e^{-jkz} \bar{u}_x$

$E(t) = Re\{\bar{E} \cdot e^{j\omega t}\} = Re\{E_0 e^{-jkz} \bar{u}_x \cdot e^{j\omega t}\}$

$= \bar{u}_x E_0 \cos(\omega t - kz)$





Maxwell noticed on “paper” that these “new” waves propagate at the same speed as the visible light

$$\mathbf{E}(z,t) = \mathbf{u}_x E_0 \cos(\omega t - kz)$$

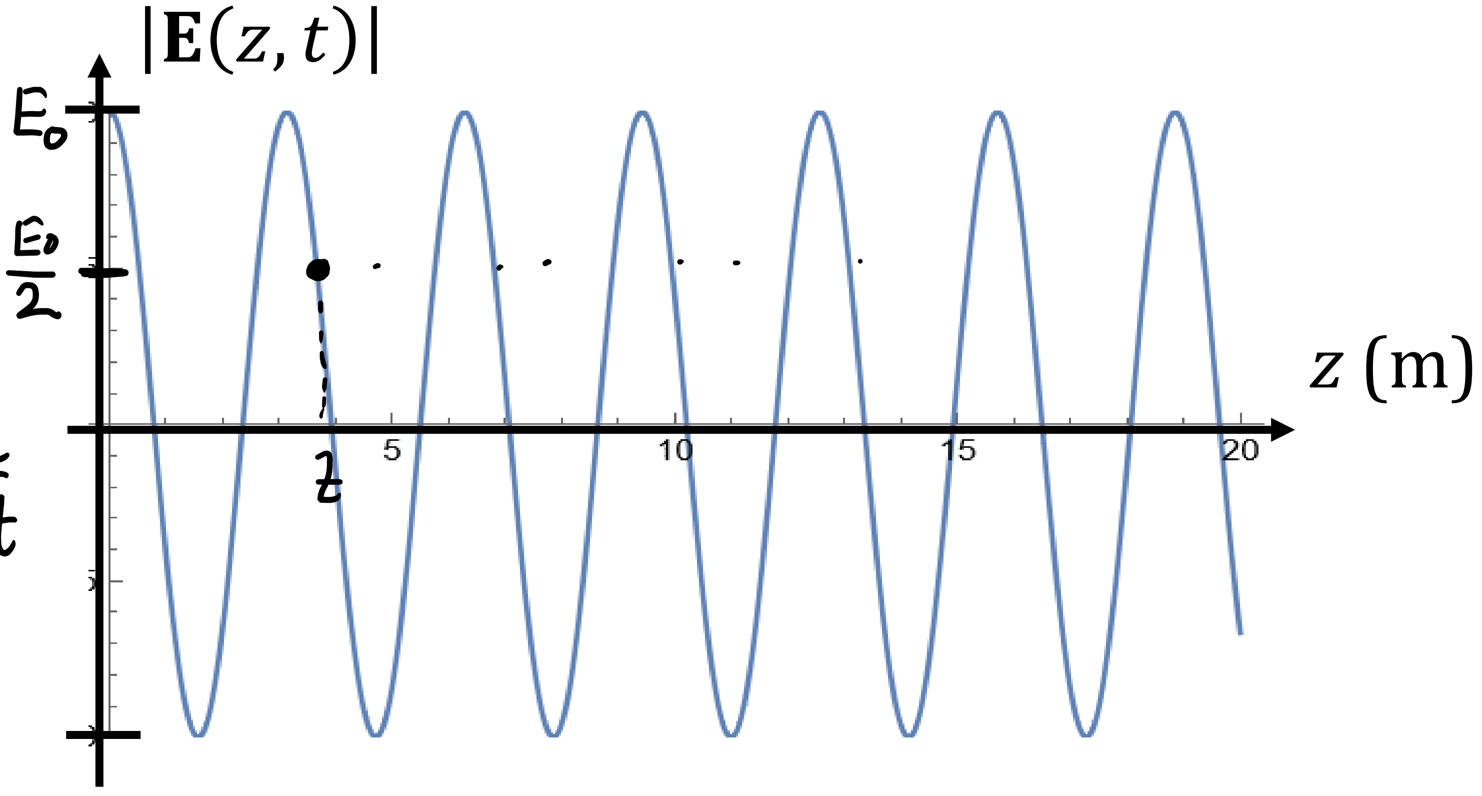
$$\cancel{E_0}\cos(\omega t - kz) = \frac{\cancel{E_0}}{2} = \frac{1}{2}$$

$$\omega t - kz = \frac{\pi}{3} \quad (\pm n \cdot 2\pi) \Big| \frac{d}{dt}$$

$$\frac{d}{dt}(\omega t - kz) = 0$$

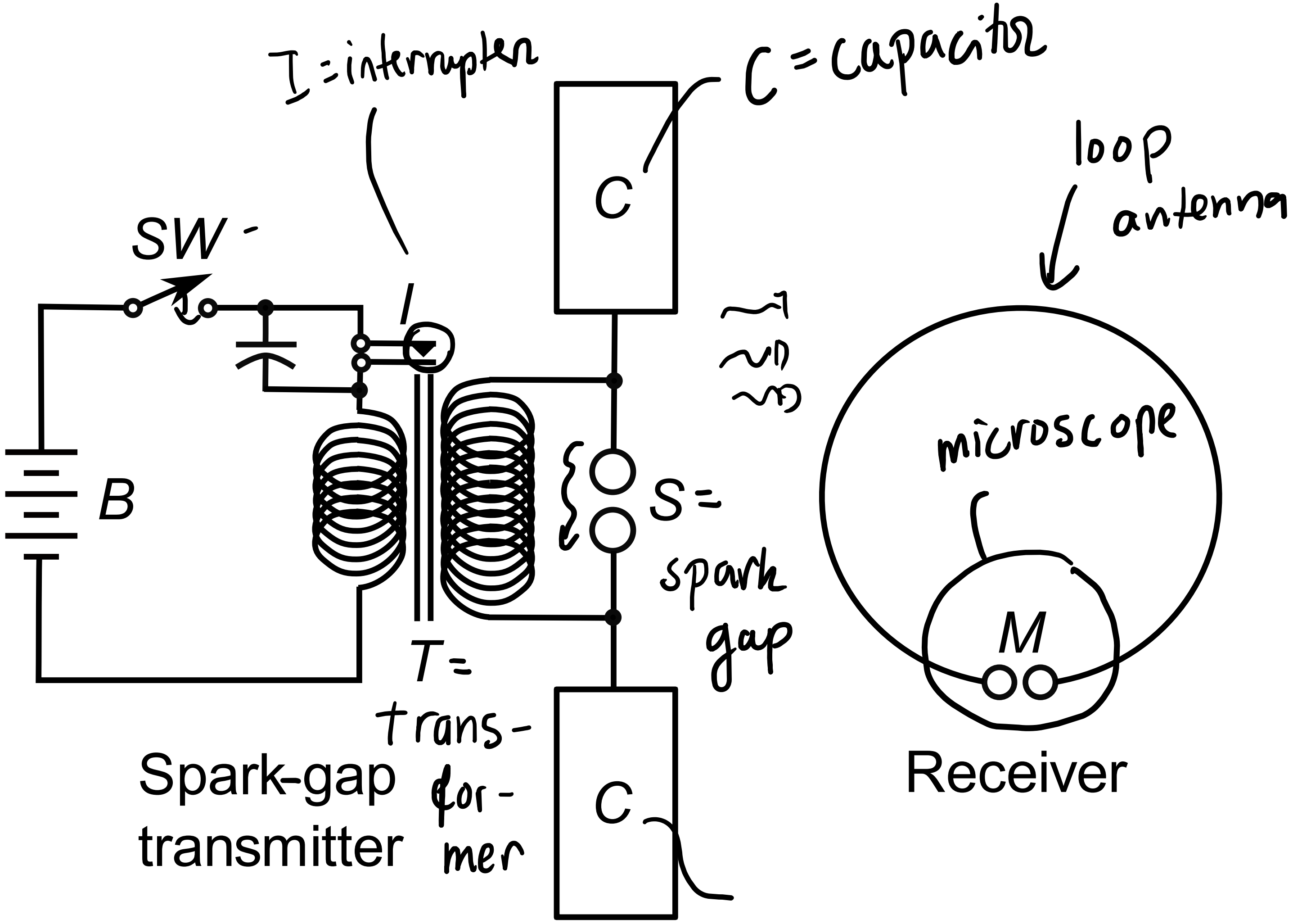
$$\omega - k \cdot \underbrace{\frac{dz}{dt}}_{} = 0$$

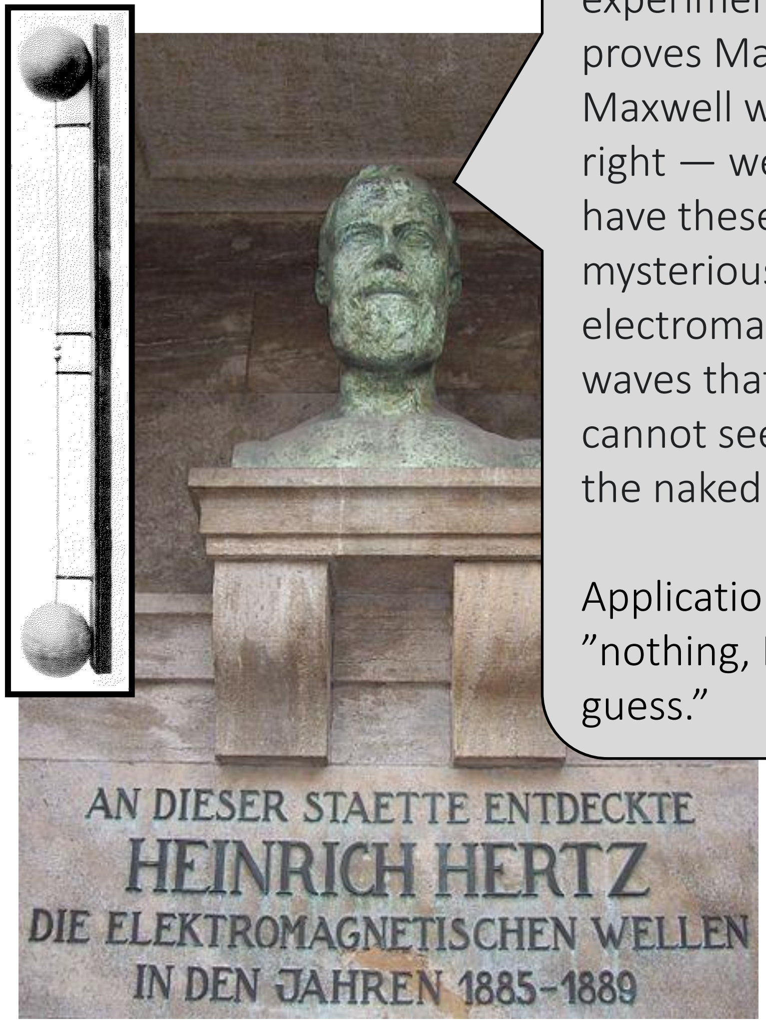
v_p = phase velocity



$$v_p = \frac{\omega}{k} = \frac{\cancel{\omega}}{\cancel{\omega}\sqrt{\varepsilon\mu}} = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = 3 \cdot 10^8 \frac{m}{s}$$

Hertz proved the existence of EM waves in 1887 with a spark-cap transmitter



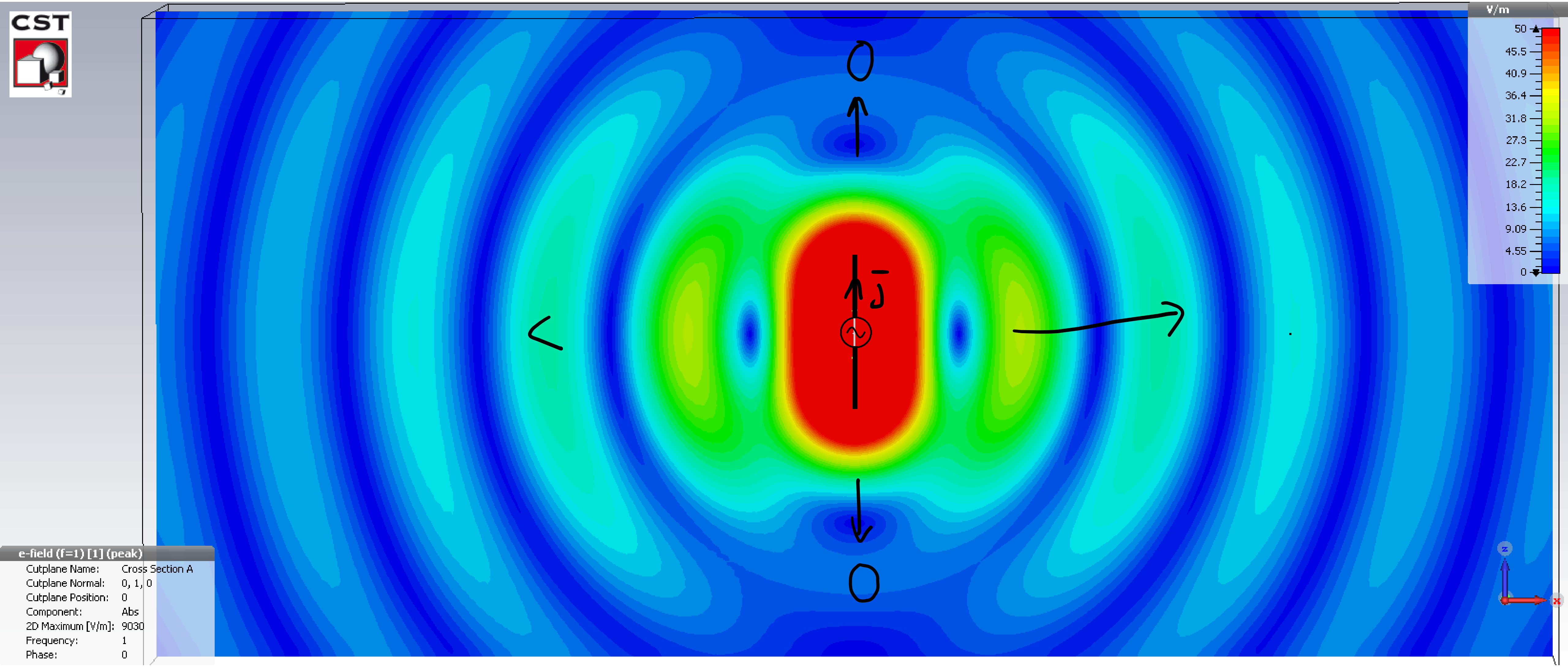


Karlsruhe, Germany

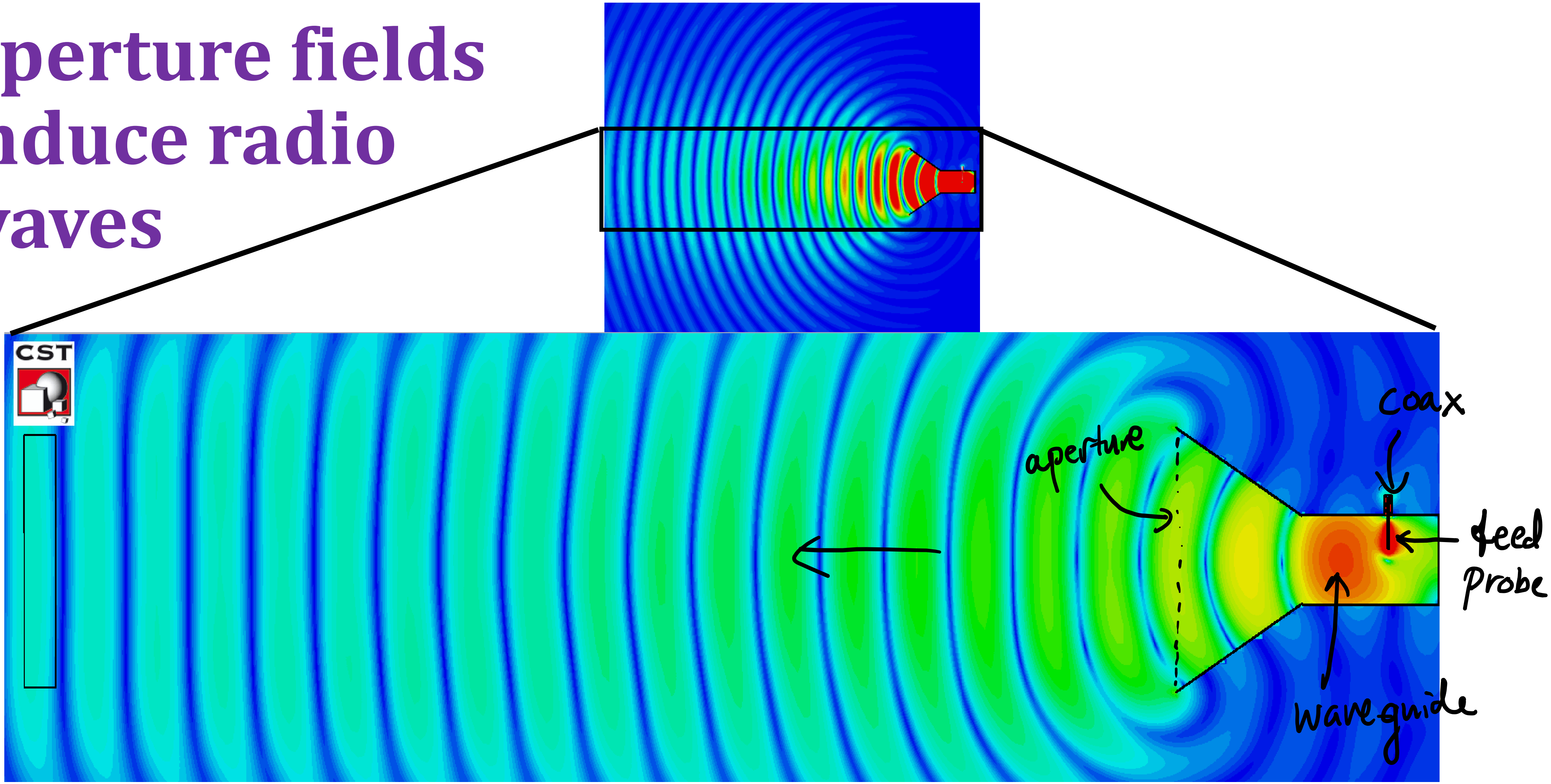
"This is just an experiment that proves Maestro Maxwell was right — we just have these mysterious electromagnetic waves that we cannot see with the naked eye."

Applications? "nothing, I guess."

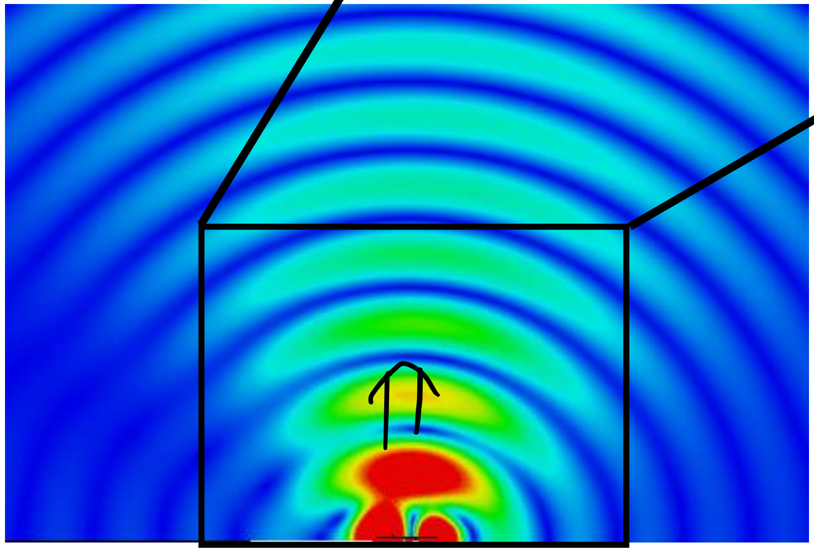
Alternating current in a wire induces radio waves that propagate to the surrounding free space

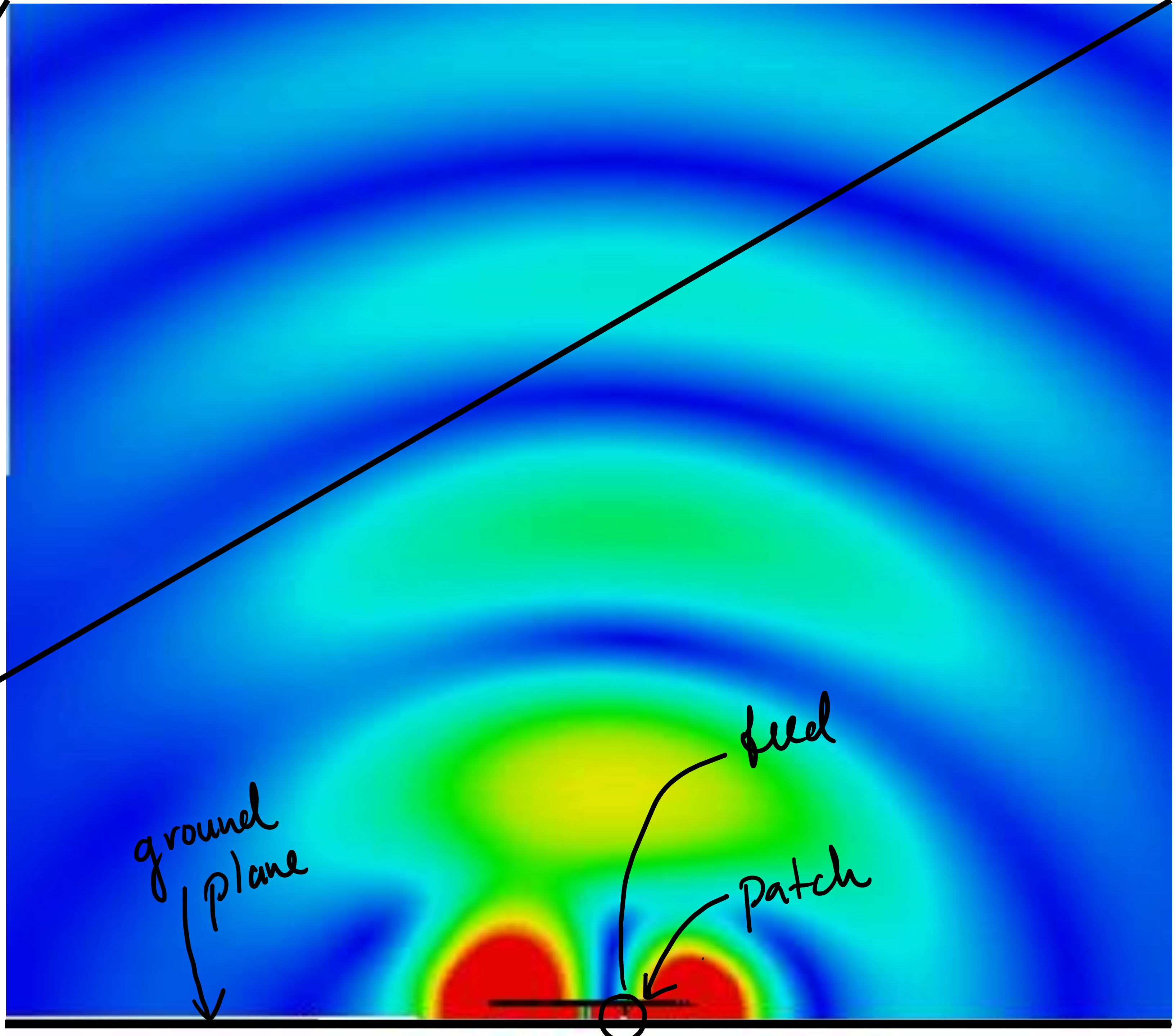


Aperture fields induce radio waves

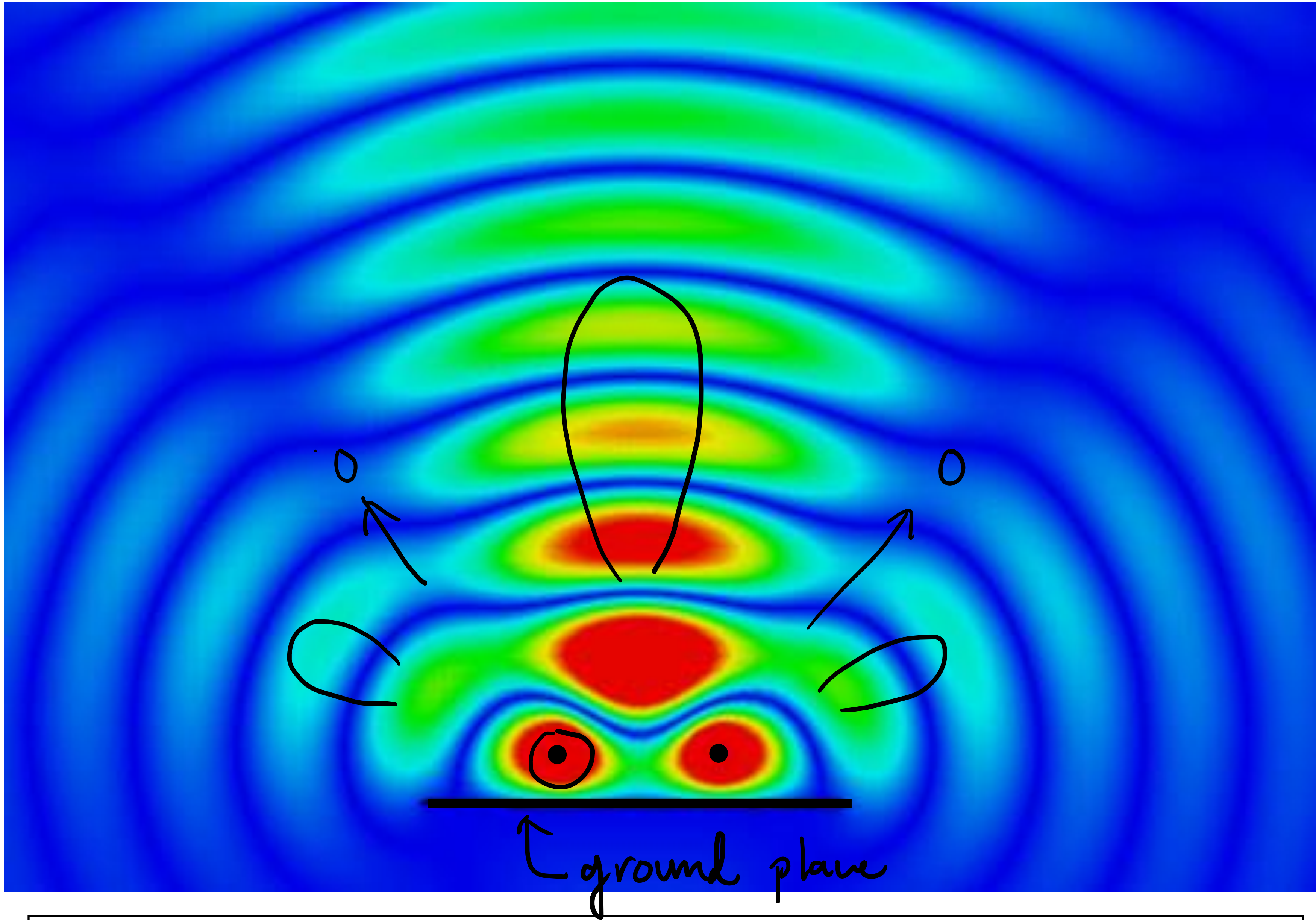


Microstrip patch antennas radiate from open ends



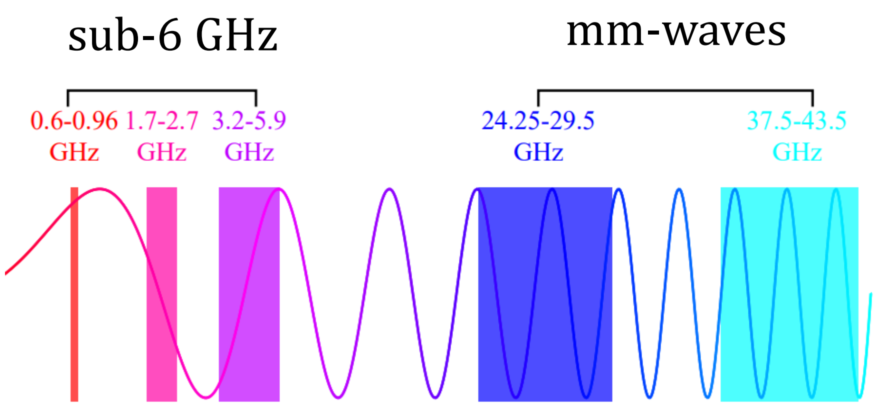


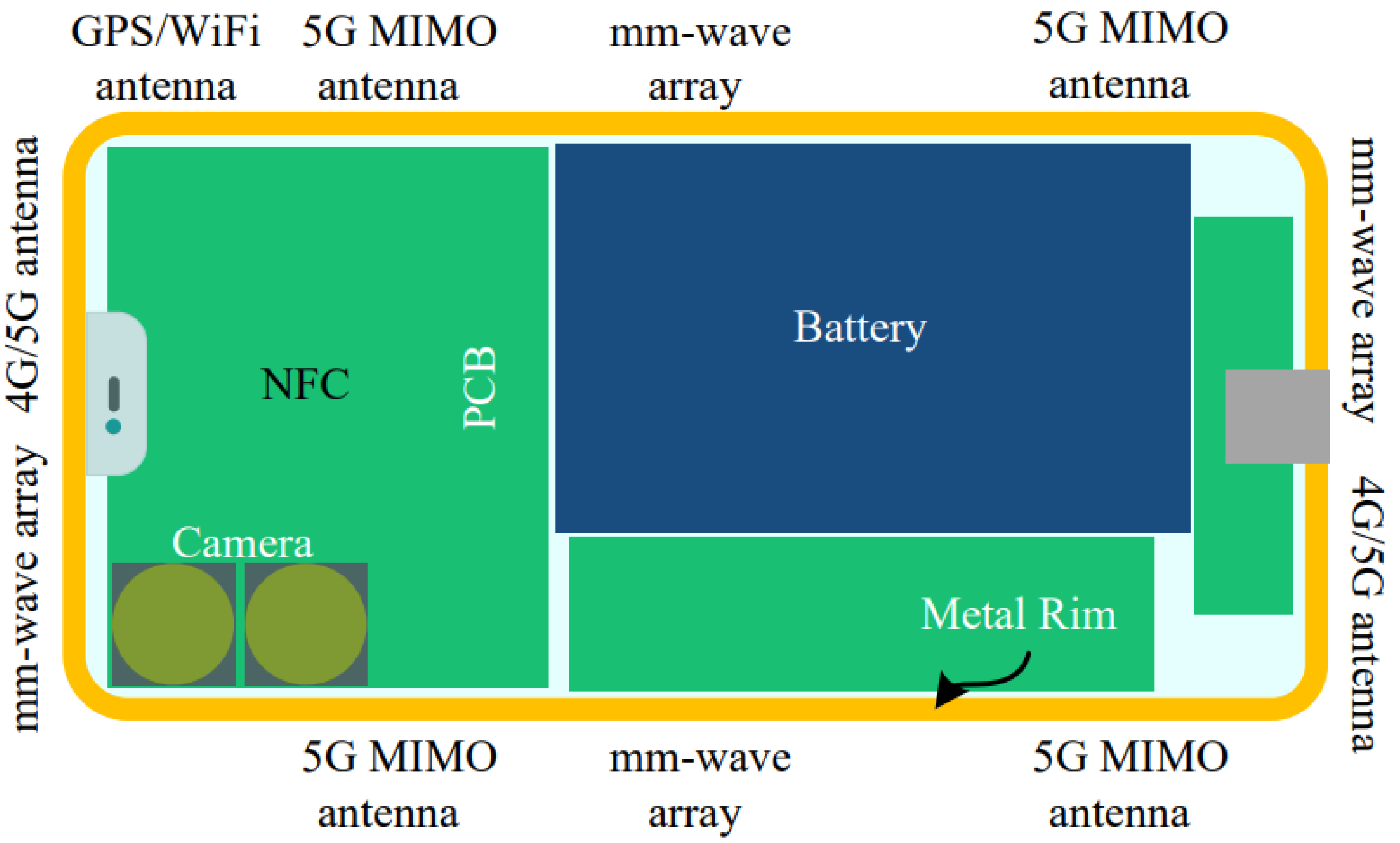
Antenna arrays allow synthetizing narrow-beam radiation



two isotropic in-phase radiators in front of a reflecting sheet

Conceptual view of a modern smartphone





Source: Quangang Zhen's doctoral thesis, "*Multi-band 5G antenna designs for smartphones*", 2024.