Visualization of Magnetic Field

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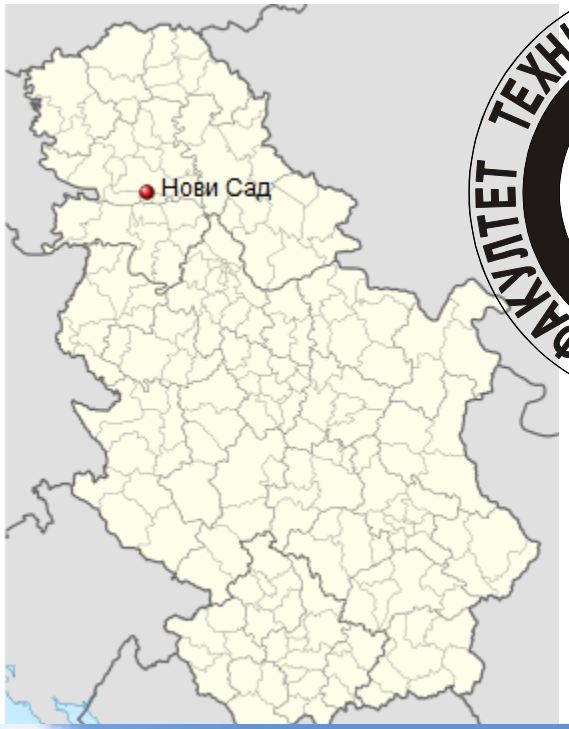
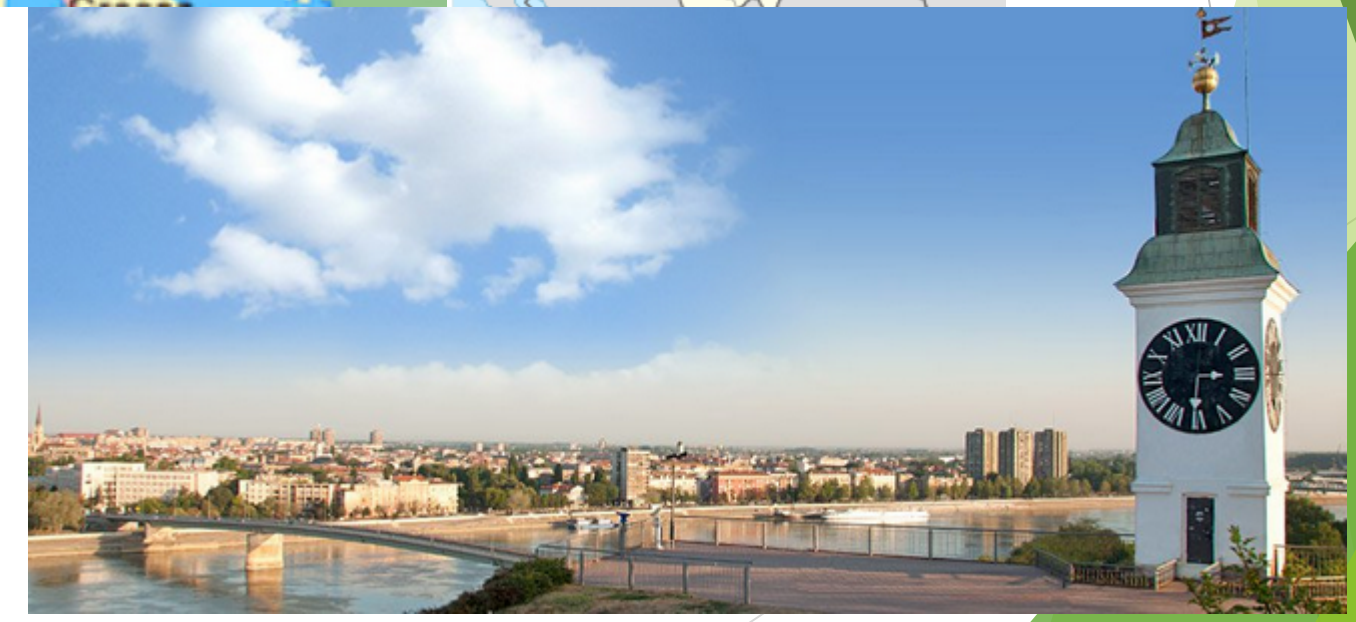


ФАКУЛТЕТ ТЕХНИЧКИХ НАУКА НОВИ САД

Where we are

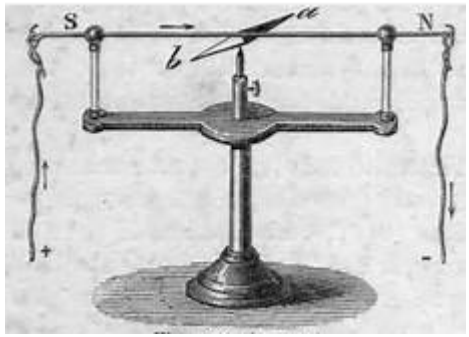


OUTLINE

- Intro
- Magnetic field around handheld hair drier.
- Magnetic field of an electric floor heating system.
- Magnetic field in a building above multiple transformer station.
- Conclusion: visualization of magnetic field may help people decide on their behavior and priorities.

Intro
How everything started

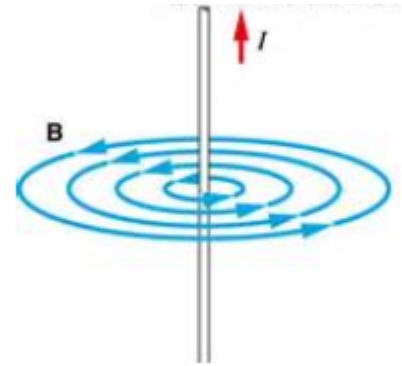
- Danish physicist, Hans Christian Oersted discovered in 1820 that magnetic needle is affected by electric current.



- Magnetic field of the conductor with current affects the magnetic needle.

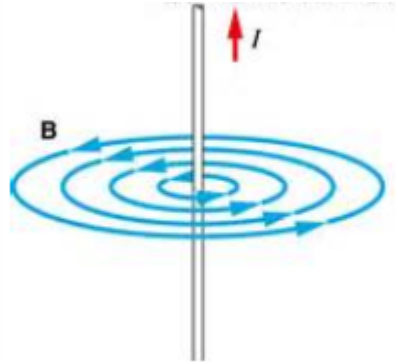
Intro

- Today, only 200 years later, everybody knows that a credit card should not be placed near a magnet or a current carrying conductor, as the magnetic domains in the magnetic strip on the card will be disturbed.



Intro

- But, should we place our head or belly?



- The answer probably depends on many factors: current intensity, exposure time, motion

Intro

- The aim of this presentation will be to help you visualize magnetic field of a few devices and decide what you want to do in magnetic field.
- Because the happiest people do not have the best of everything, they make the best of everything they have.

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MAGNETIC FIELD OF HANDHELD HAIR DRYERS

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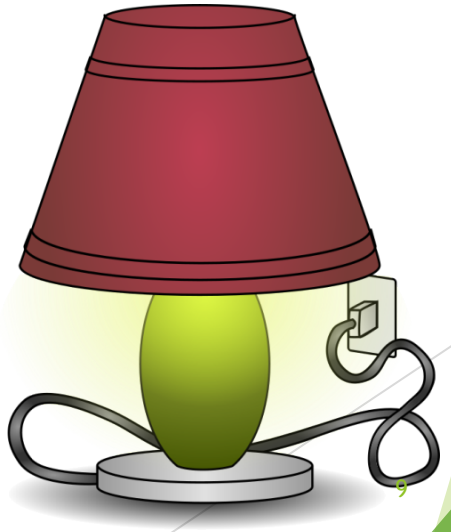
INTRODUCTION

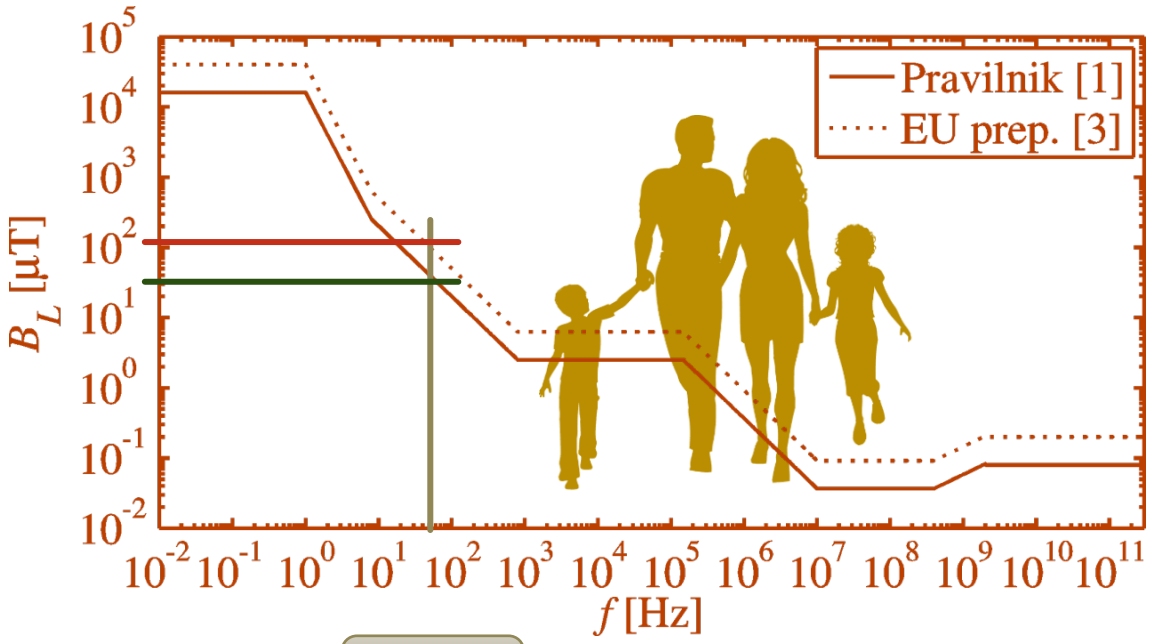
- The operation of electric appliances is always associated with generation of electric and magnetic fields.
- These fields became a source of public concern because of their potential health risks.
- The magnetic fields are directly proportional to electric current and inversely proportional to the distance from the appliances.



INTRODUCTION

- In this presentation, the magnetic field of a handheld hair dryer is considered.
- Since hair dryers use electric current of several amps, they produce considerable level of magnetic fields.

Magnetic field (MF) reference levels



50Hz

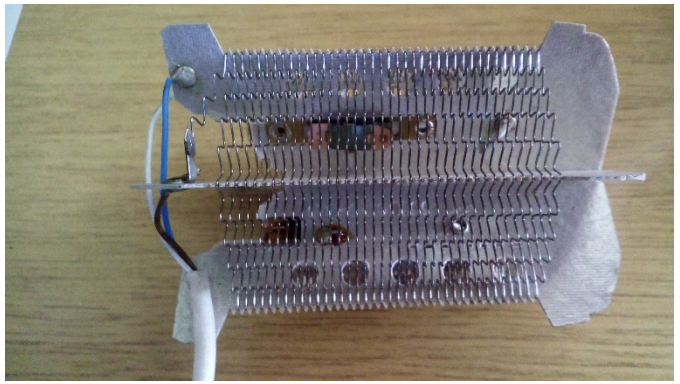
100 μT
EU recommendation

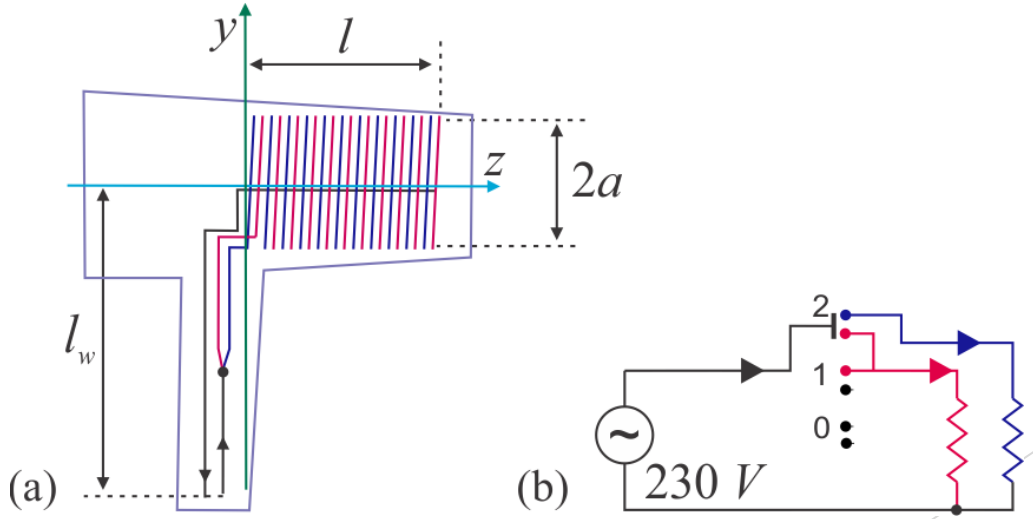
40 μT
Republic of Serbia

Exposure to the MF generated by hair dryer can be determined comparing the MF obtained by measurement or calculation with the reference level.

MATHEMATICAL MODEL

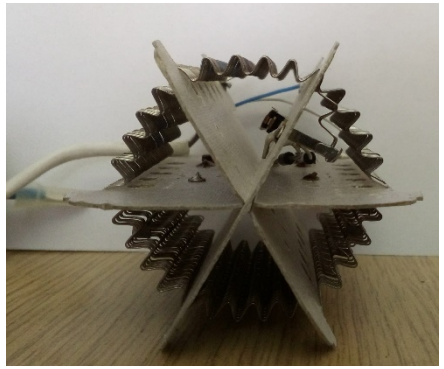
- In order to calculate MF of the hair dryer at an arbitrary point, an appropriate mathematical model needs to be used.
- The model is tested on the handheld hair dryer with two coils as heating elements.

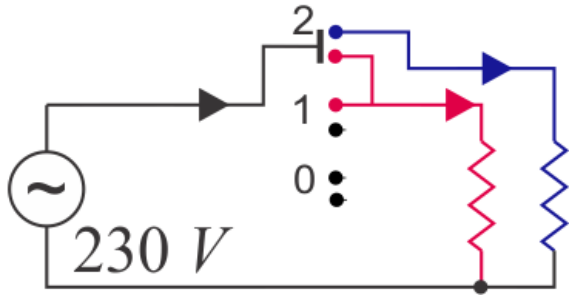




MATHEMATICAL MODEL

- One of the commonly used types of the heating element for a handheld hair dryer is made of the zigzag conductor wound into a spiral around a non-conducting frame.

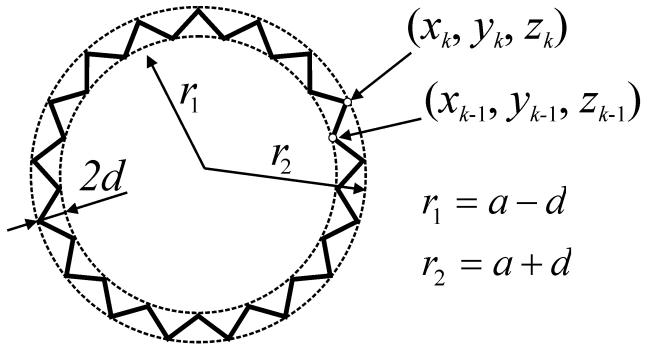




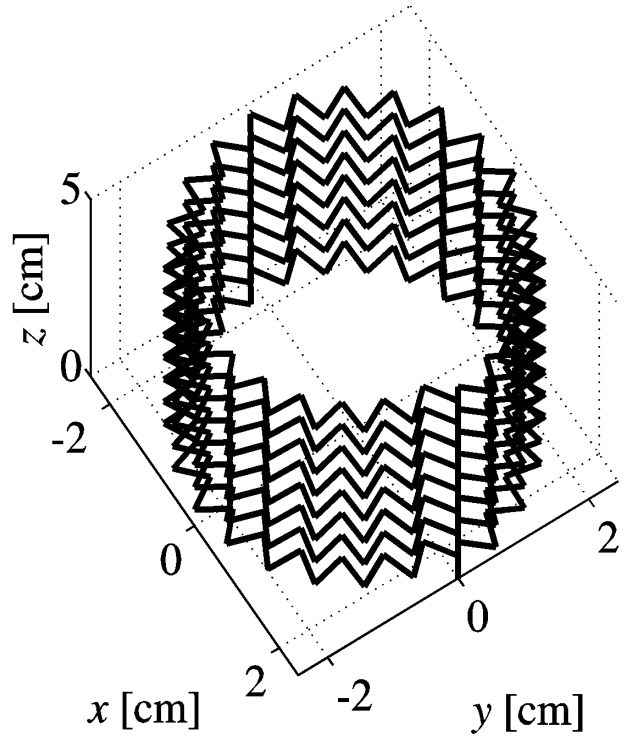
- Typically, a hair dryer has two heating elements (coils) connected in parallel, which are wound in the same direction. Since the currents in the coils are in the same direction, the MF generated by two coils is higher than MF generated by one coil.

Magnetic field of helical zigzag conductors

- The heating elements and connecting wires are modeled by the chain of short straight line segments.



$$v_k = v_0 + k \cdot 2\pi/n,$$
$$x_k = \left[a + (-1)^k d\right] \cos v_k,$$
$$y_k = \left[a + (-1)^k d\right] \sin v_k,$$
$$z_k = b v_k,$$



Magnetic field of helical zigzag conductors

- The heating element is represented by *K* short straight line segments. Starting from Bio-Savart low, the magnetic flux density at point (*x*, *y*, *z*) generated by *k*th segment (*k* = 1,…,*K)* can be approximated by

$$\vec{B}_k(x,y,z) = \frac{\mu_0 i}{4\pi} \cdot \frac{\vec{l}_k \times \vec{R}_k}{R_k^3} \quad (1)$$

where *i* denotes the current in the heating element and

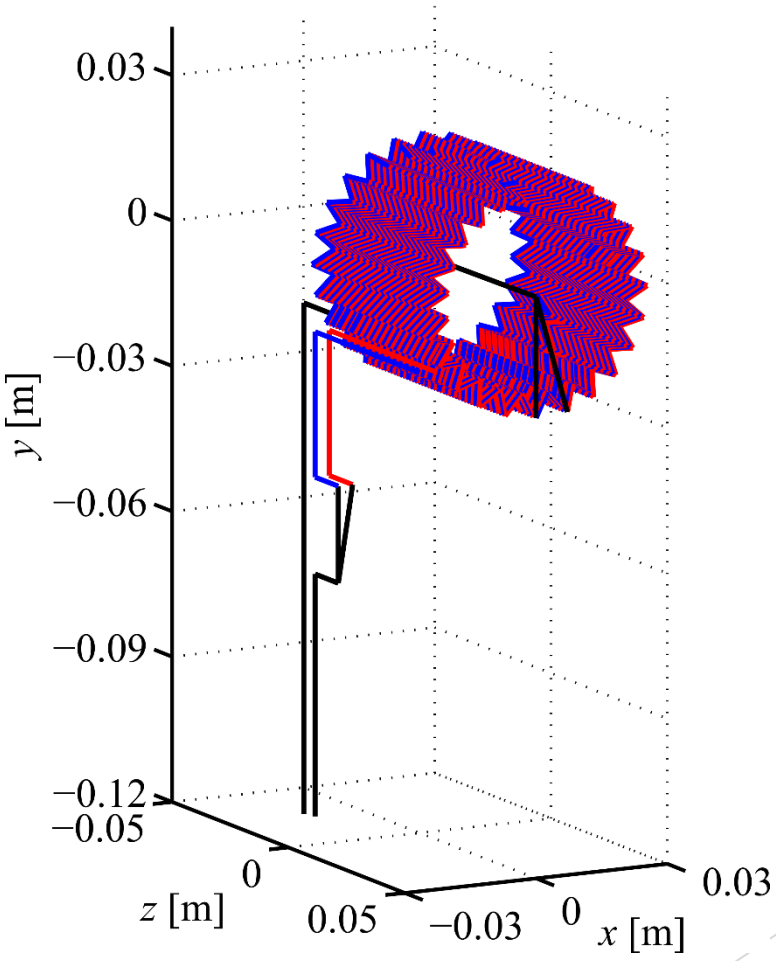
$$\vec{r}_k = x_k \vec{i}_x + y_k \vec{i}_y + z_k \vec{i}_z,$$
$$\vec{l}_k = \vec{r}_k - \vec{r}_{k-1},$$
$$\vec{R}_k = x\vec{i}_x + y\vec{i}_y + z\vec{i}_z - \frac{1}{2}(\vec{r}_k + \vec{r}_{k-1}), \qquad R_k = |\vec{R}_k|.$$

- The magnetic flux density can be calculated as

$$\vec{B}(x,y,z) = \sum_{k=1}^{K} \vec{B}_k(x,y,z) \quad (2)$$

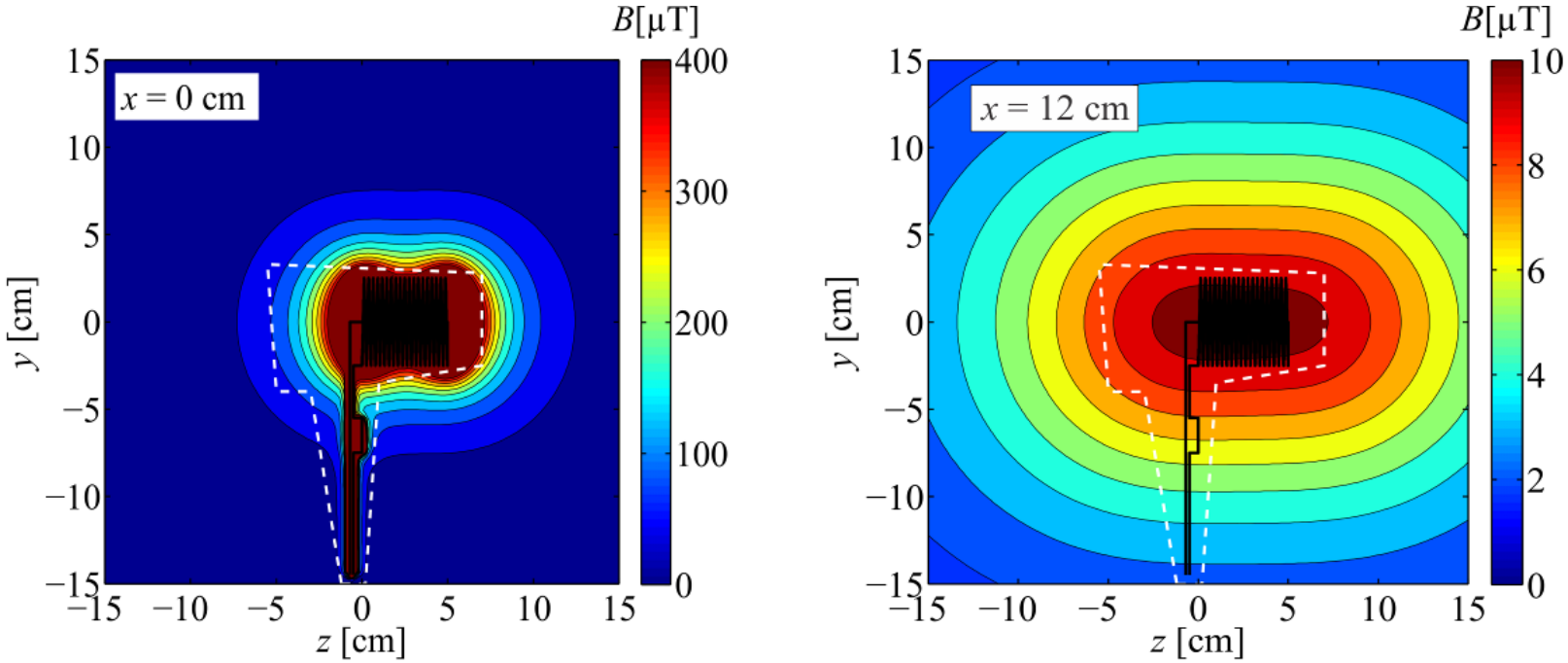
CALCULATIONS

- The sources of the MF are:
  - two helical zigzag conductors,
  - the phase conductors and
  - the neutral conductor.
- The calculations are performed in four planes.
- All values of magnetic flux densities presented in next slides correspond to the current of 3A per coil.



CALCULATIONS for I=3A at

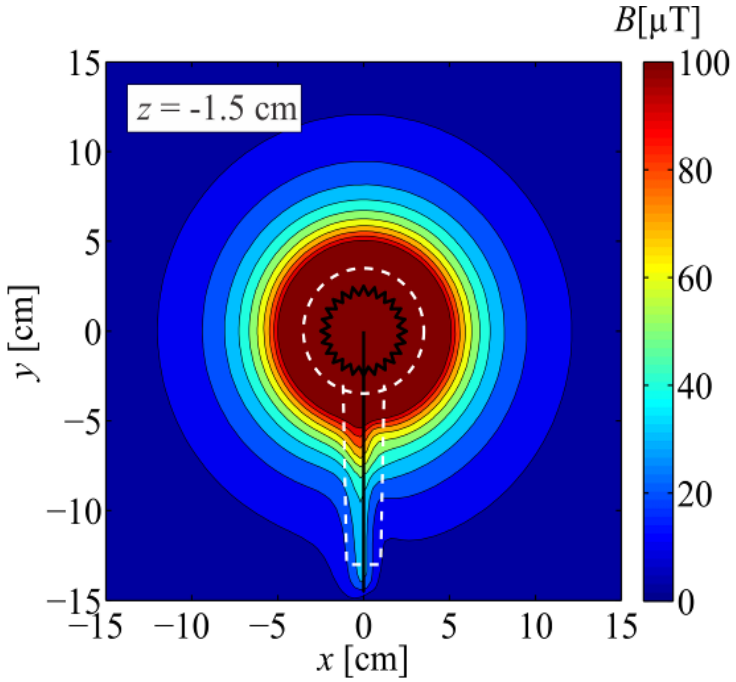
1. Plane of symmetry $x = 0$
2. Plane left or right from the coils at $x = 12$ cm

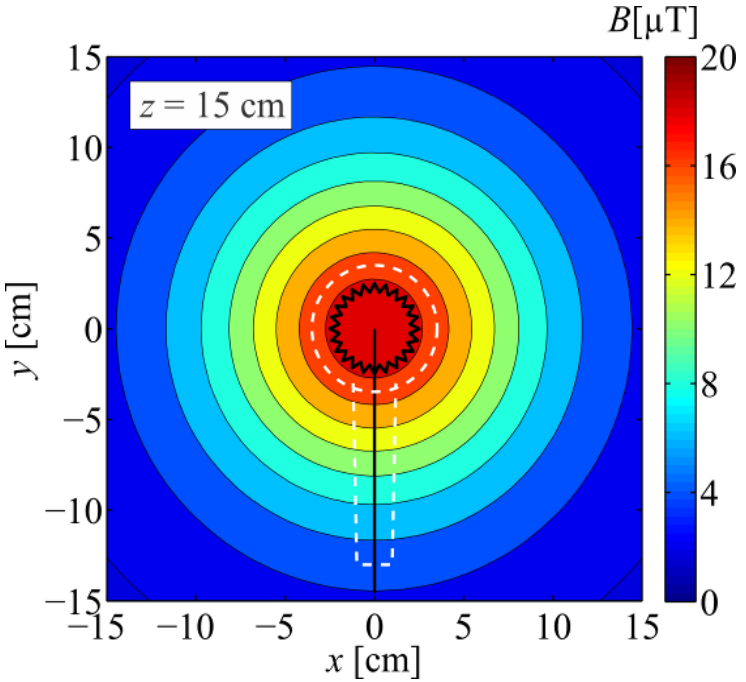


Magnetic flux density at plane $x = 0$ exceeds 400 μT inside the heating elements, but it drops to 50 μT at distances of 5 cm from the dryer.

CALCULATIONS for I=3A at

1. Plane z = -1.5 cm behind the coils,
2. Plane z = 15 cm in front of the coils.

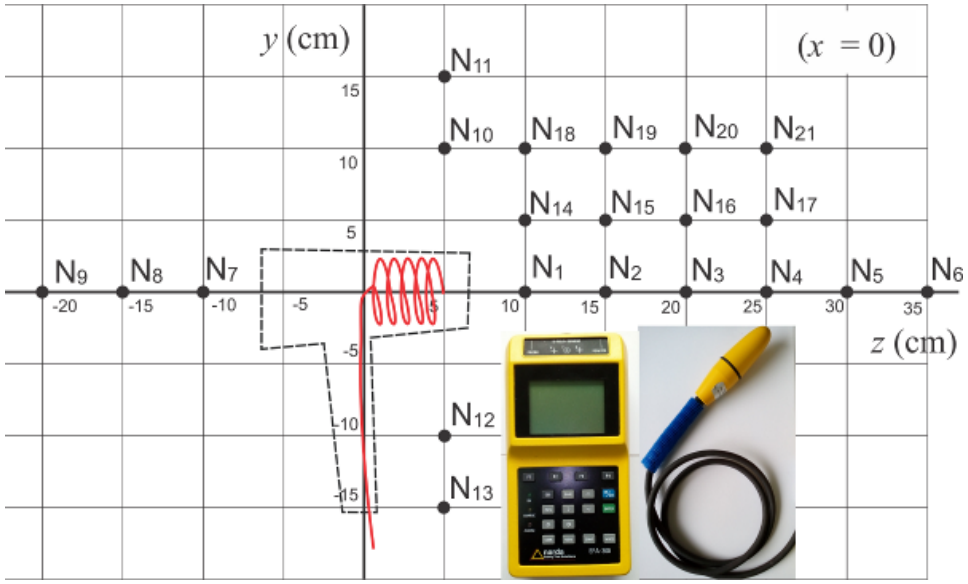




In the plane z = -1.5 cm, in vicinity of the handle, the magnetic flux density ranges from 50 μT to 100 μT.

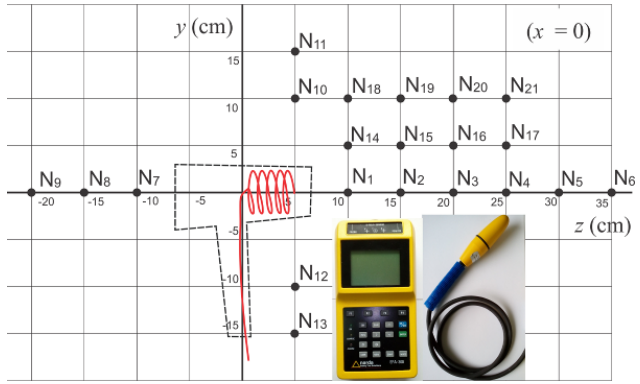
MEASUREMENTS

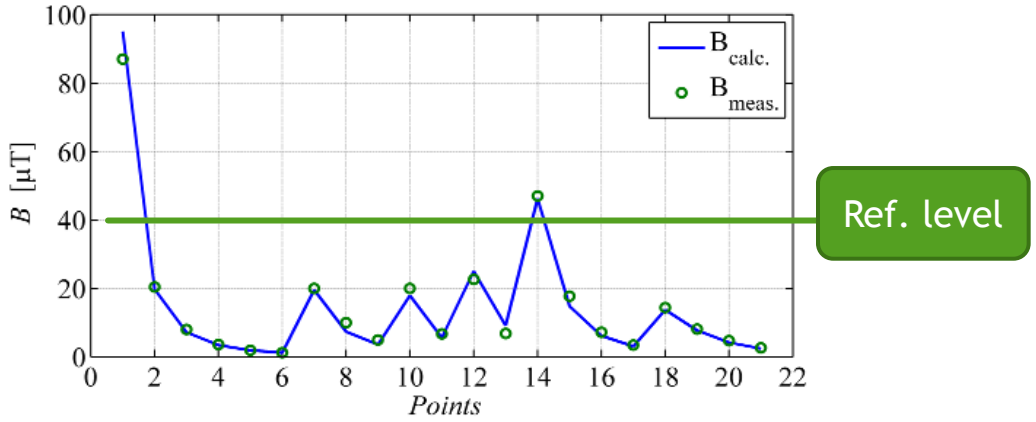
- The developed mathematical model is tested on Philips Salon Dry Compact hair dryer HP4961 with nominal power of 1700 W.
- The current of the hair dryer is measured with multimeter MS8226T. At 230 V it carries a total current of 6 A (3 A per coil).
- The magnetic flux density is measured at 21 points in the plane $x = 0$, using EFA-300 field analyzer with 3 cm isotropic magnetic field probe.



MEASUREMENTS

- Measurements verify the developed mathematical model.





CONCLUSIONS about HANDHELD HAIR DRYERS

- Typically, hair dryers have two coils with currents in the same direction which increases the net magnetic flux density.
- At some points, in close vicinity to the hair dryer, magnetic flux density exceeds the reference levels proposed by the standards.
- Electric paint remover is similar to a hair dryer, so it may also generate substantial levels of the magnetic field.
- The procedure for the magnetic field caculation described here can be utilized for a better design. If designed carefully, opposite currents in the coils can release the same amount of heat at considerably lower the level of magnetic field.

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MAGNETIC FIELD OF ELECTRICAL RADIANT HEATING SYSTEM

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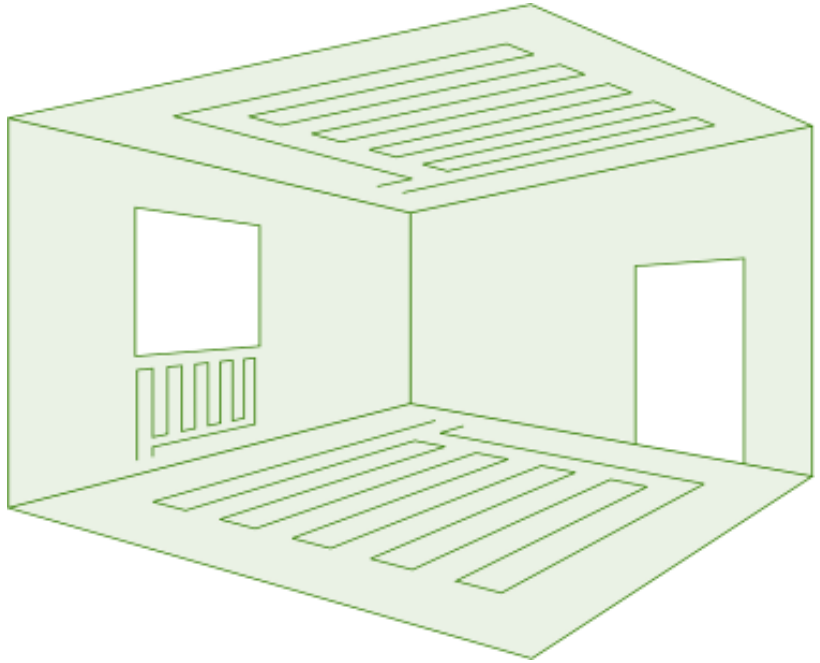
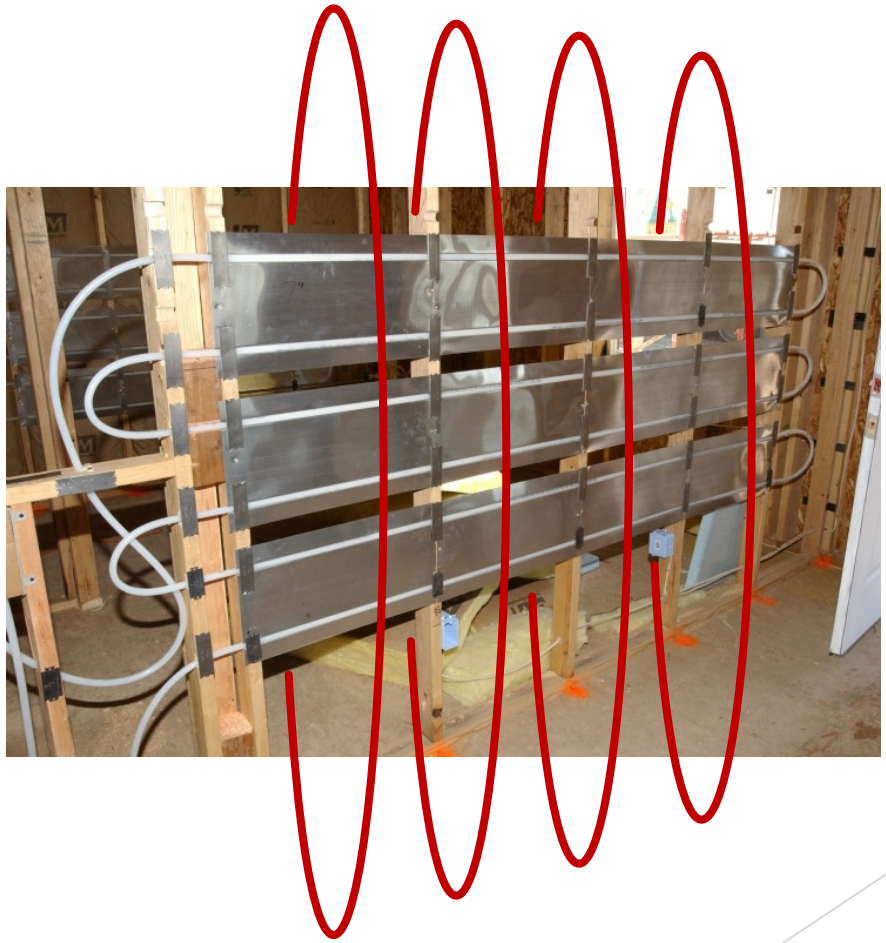
INTRODUCTION

- Electrical radiant heating system (ERHS) is one of the heating systems used in homes and offices.
- ERHS typically consists of electric conductors built into the floor.
  - Other ERHS may also include wall or ceiling mounted radiant panels.



INTRODUCTION

- Advantages:
  - It is very efficient naturally turning electric loss to heat.
  - Quiet and clean.
  - Doesn’t produce allergens.
  - Gives uniform heat distribution.
- Disadvantages:
  - Risk of Fire in Electric Systems.
  - Risk of Electric shock.
  - Difficult to Access for Repairs.
  - Increases ambient level of magnetic field.



INTRODUCTION

- Magnetic flux density reference level at 50 Hz is
  - 100 μT (European recommendation)
  - 40 μT (Serbian national rule book, 2.5 times lower.)
- There is ongoing discussion whether the magnetic flux density below the reference level causes any health effects.
  - Findings reported in some studies are related to increased rates of childhood leukemia.
  - Increased risk starts as low as 0.4 μT or even lower.

EHRS REALIZED WITH WIRES

- An ERHS can be realized as a single wire or a twin wire system.
- The magnetic field produced by a twin wire is considerably lower. However, the single wire ERHS is popular due to its lower price. In what follows a **single wire** ERHS is considered.
- The magnetic field of an ERHS depends on the current in the system, which may be as high as 45 A.

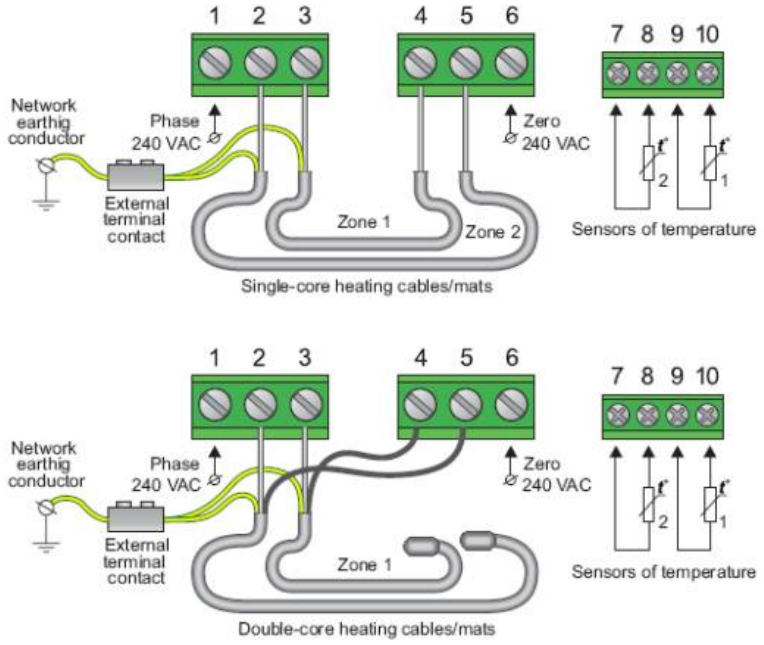
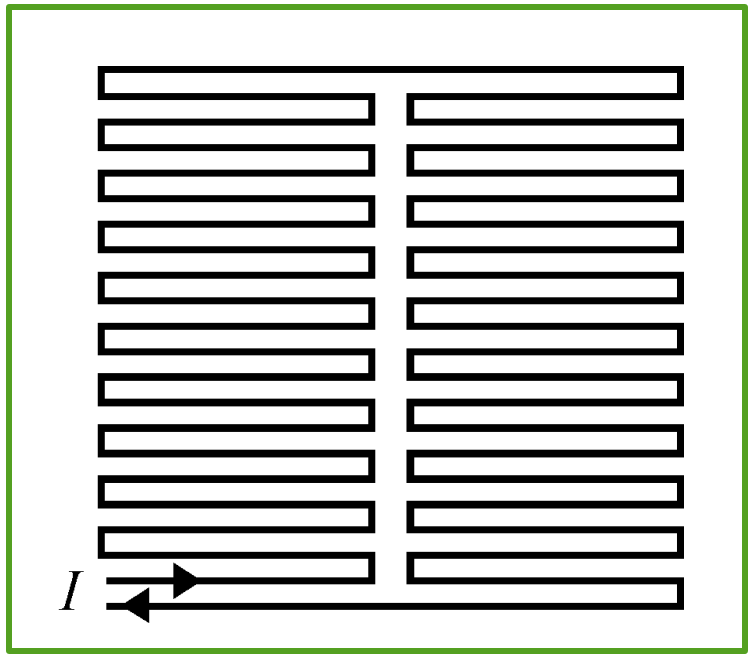


Fig. 7 *Scheme of connection to the triple-wire electric network*

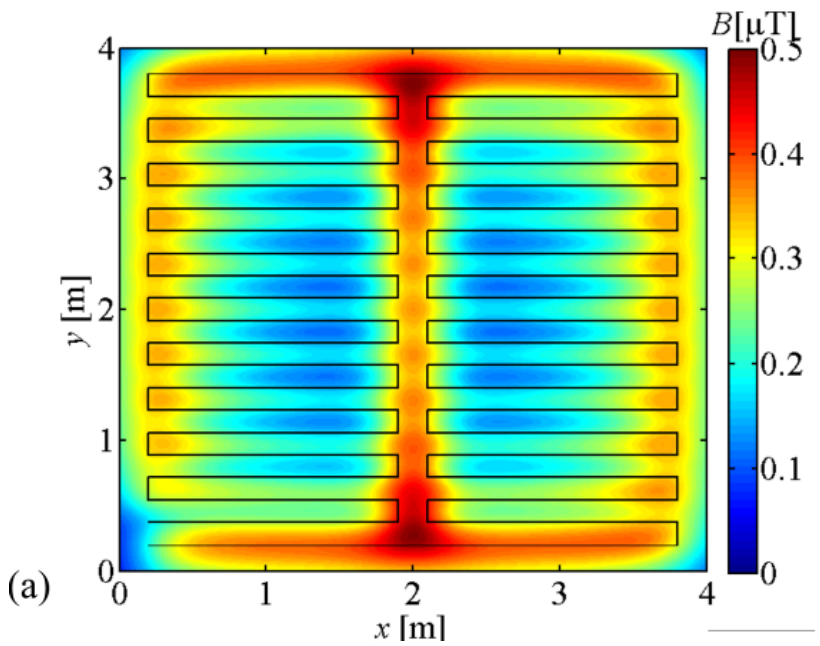
CALCULATIONS

- In our study, magnetic field calculations are performed analytically and numerically.
  - Analytical calculations were based on **Bio-Savart law**, where the conductors were modelled as current filaments in air.
  - Numerical calculations are based on **finite element method** (FEM) using Comsol 3.5 software package.
- These two methods are compared on a heating element built into the floor, in a room of size 4 x 4 m.

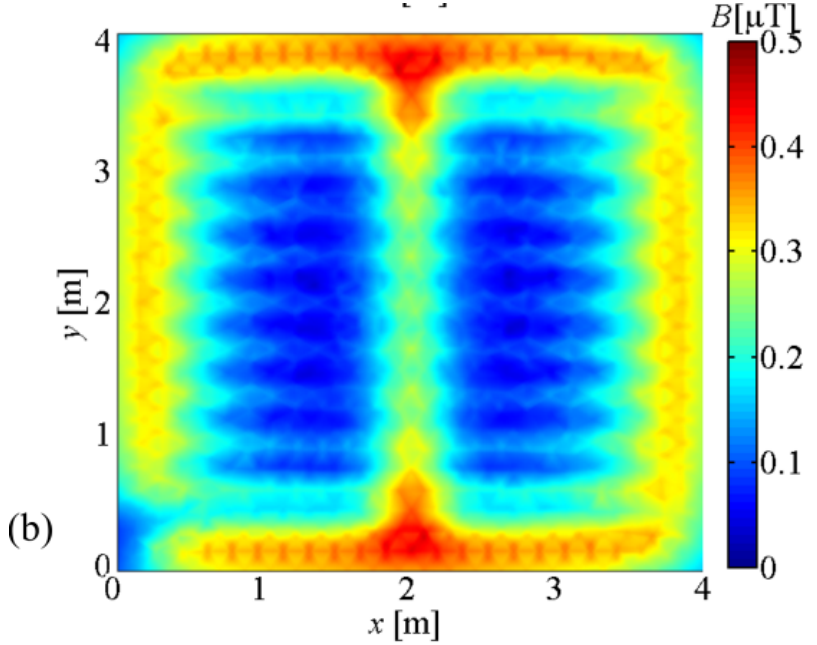


4 m x 4 m

Magnetic flux density 30 cm above the conductors, I=1 A



Analytical calculations in Matlab



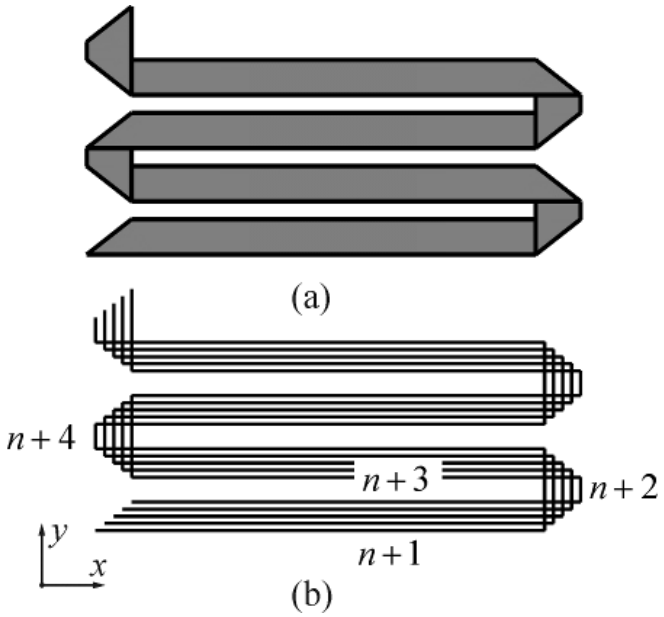
Numerical calculations in Comsol

EHRS REALIZED WITH ALUMINUM STRIPS

- In such type of the heating system, the aluminum strip is placed on the floor area and in a big loop returns to the connection point.
- In order to cover the floor, aluminium strips should be bended and folded usually according to some regular pattern.

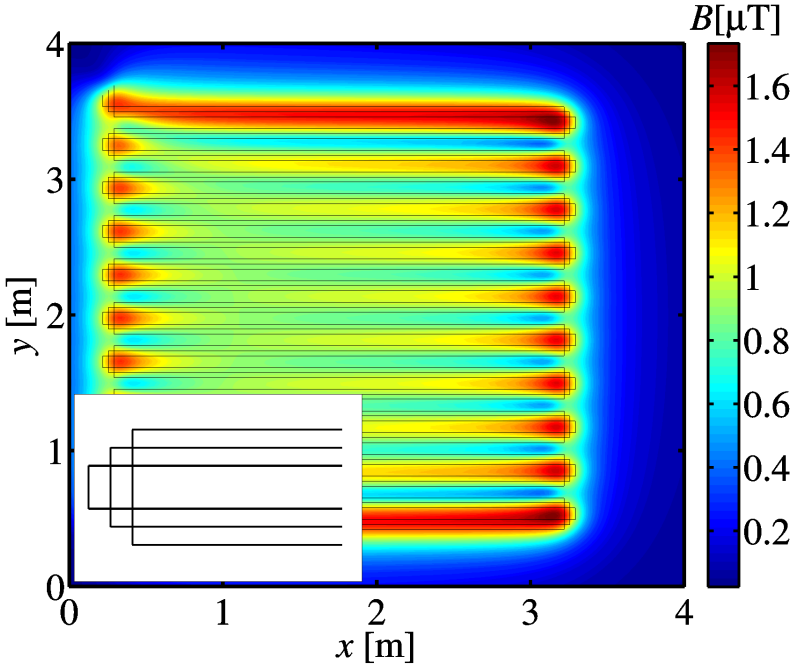
CALCULATIONS

- The magnetic field calculations are performed analytically, based on **Bio-Savart law.**
- The strips (a) are modeled with line conductors (b)-current filaments in the air.

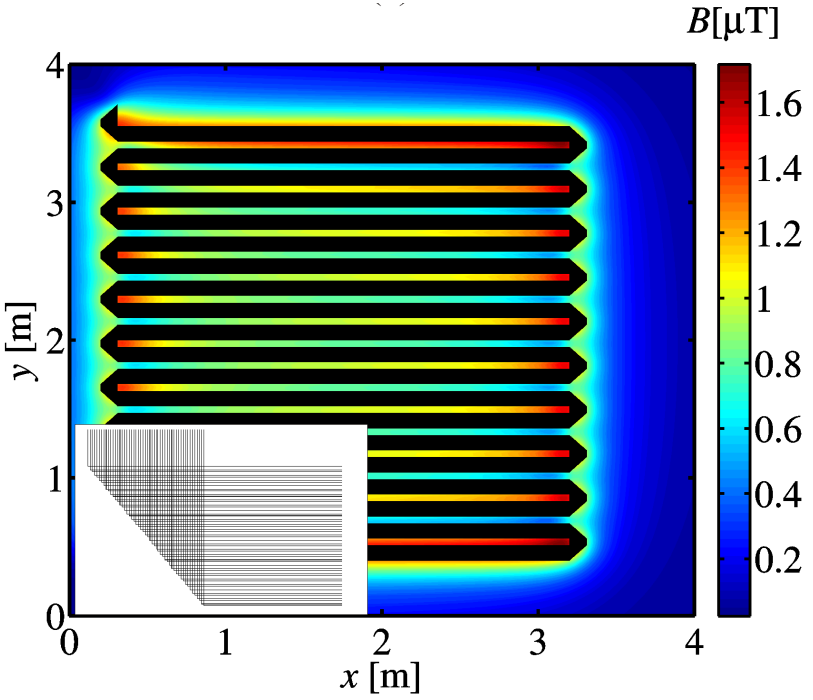


$$\vec{B}(x,y,z) = \sum_{k=1}^{K_{\max}} \sum_{m=1}^{4N_{\max}} \vec{B}_{m,k}(x,y,z),$$

Magnetic flux density 10 cm above the strip, I=1 A



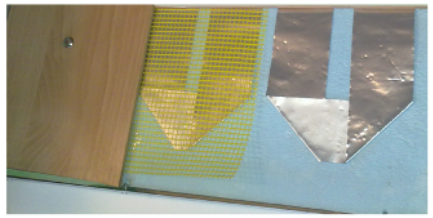
Strips modeled by 3 line conductors



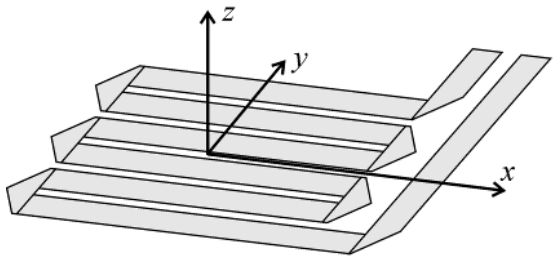
Strips modeled by 52 line conductors

MEASUREMENTS

- ERHS sample is shown in Fig. (a)
- The magnetic flux density is measured along z – axis at three different heights (20 cm, 40 cm, and 60 cm) above the middle part of the sample, as illustrated in Fig. (b).
- For the measurements, EFA-300 field analyser by Narda is used.
- During the measurements, the rms value of the current was 42 A.



(a)



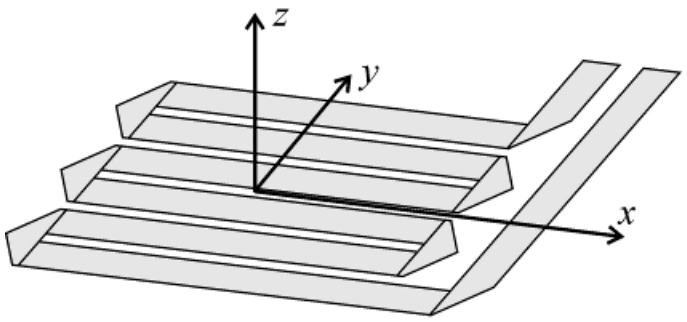
(b)

(c)

MEASUREMENTS

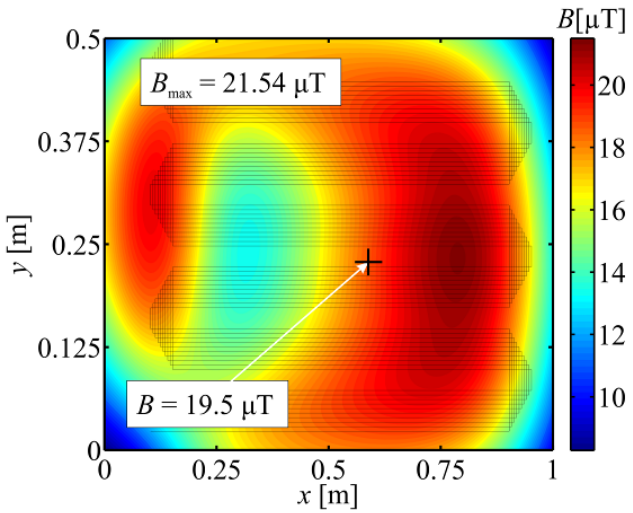
- The results of the measurements (B_{meas}) and calculations (B_{calc}) are compared in Table.
- The relative difference between measured and calculated values are obtained from the following formulae

$$\varepsilon[\%] = \left|1 - \frac{B_{calc}}{B_{meas}}\right| \cdot 100.$$

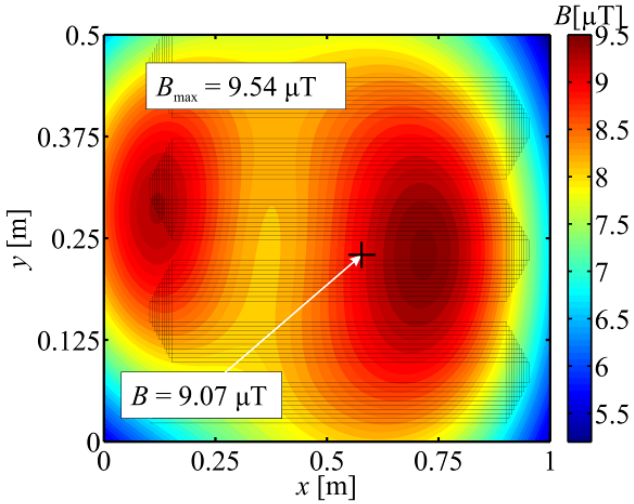


Point No.	z [cm]	B_{meas} [μT]	B_{calc} [μT]	ε [%]
1	20	20.9	19.5	6.69
2	40	9.97	9.07	9.03
3	60	5.08	4.41	13.18

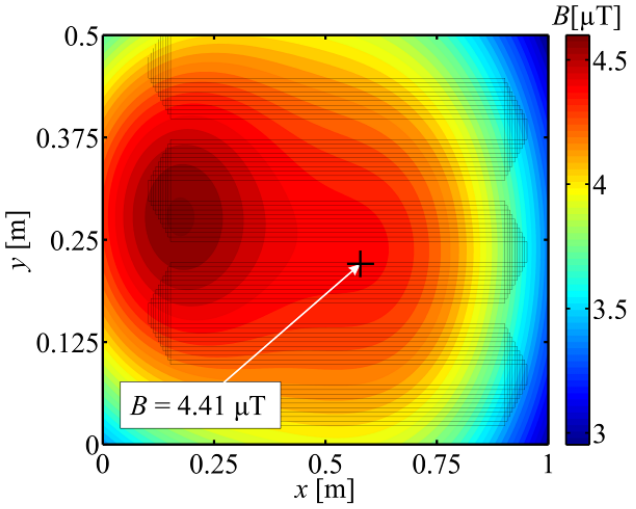
Magnetic flux density distributions above the EHRS sample



20 cm



40 cm



60 cm above the EHRS sample.

CONCLUSIONS ABOUT ELECTRICAL RADIANT HEATING SYSTEM

- In this work, we consider the magnetic flux density above ERHS heating elements realized with **single** aluminium strip.
- The current in the heating element as low as 1 A generates up to 1.7 μT, 0.35 μT and 0.2 μT at heights of 10, 30 and 50 cm above the conductors, respectively.
- Since the current in the heating element can be significantly higher than 1 A, it follows that magnetic flux density above the single wire ERHS heating element can significantly increase the ambient level of magnetic field.
- Manufacturers already offer zero field heaters. It makes a lot of sense buying them.

Thank you for your time