PHILIPS

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# 13.56MHz Proximity RFID Antenna Principle

Customer Application Support, 2004

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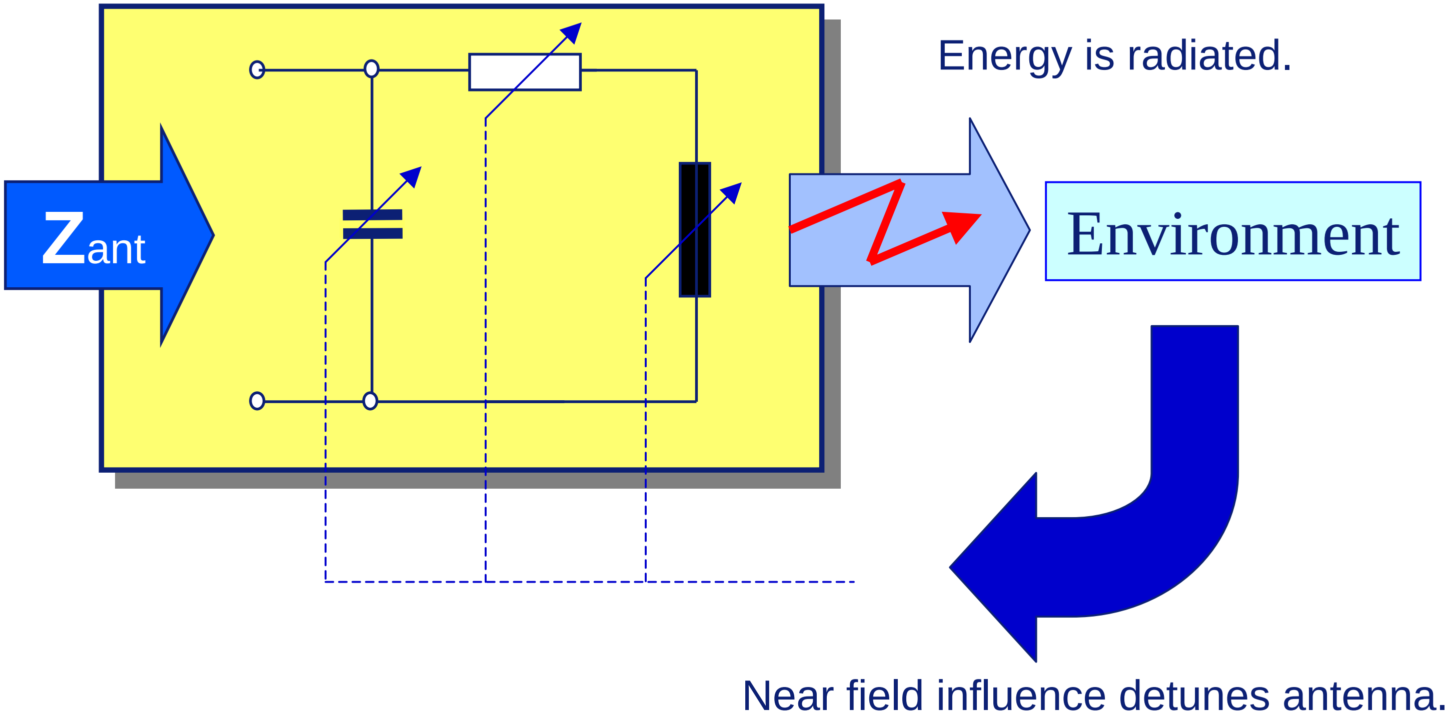
- Equivalent Antenna Circuit
- Electric & Magnetic Antenna
- Common Mode Currents
- Antenna as Transformer
- Estimation of Maximum Operating Distance
  - Electromagnetic Induction
  - Law of Biot & Savart
  - Coupling Coefficient
- Optimum Antenna Radius

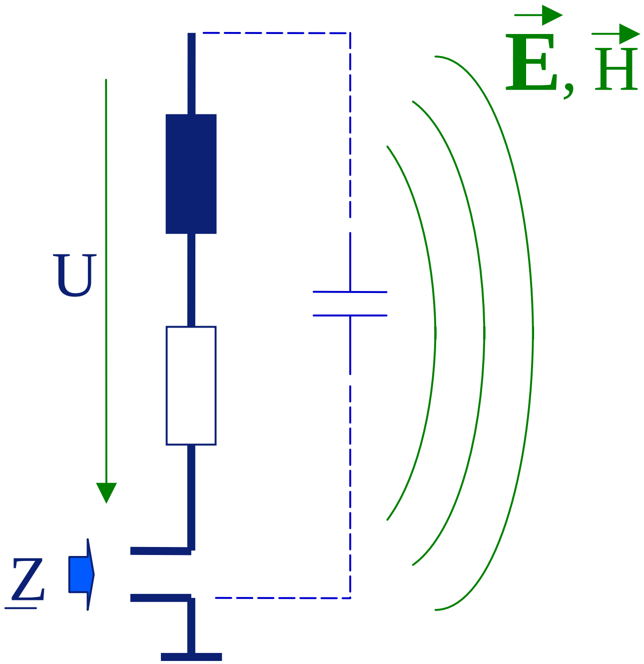
# Equivalent Antenna Circuitry



# Unsymmetrical Antenna

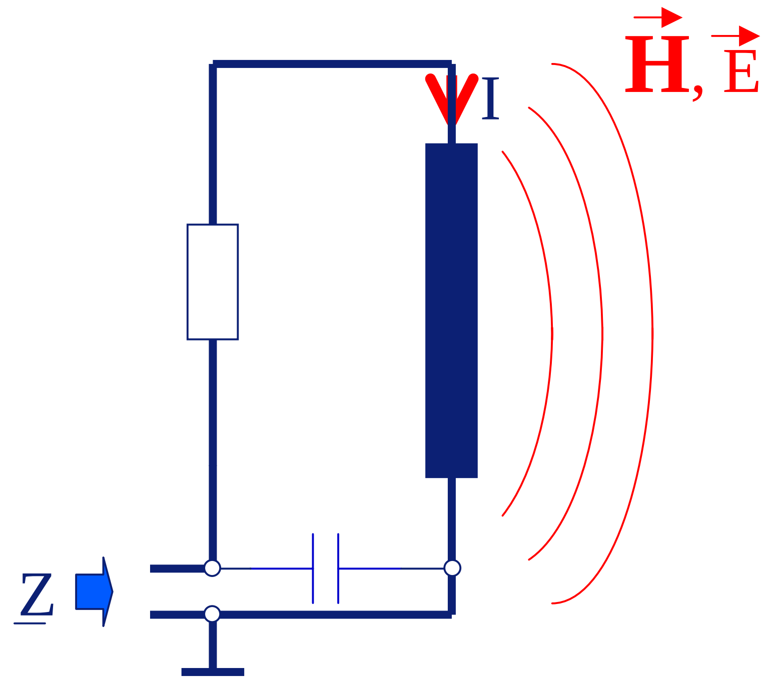
## Electric Antenna:

**("monopole":** e.g. mobile phone, FM-radio)




## Magnetic Antenna:

**("loop":** e.g. mifare®, I·CODE )



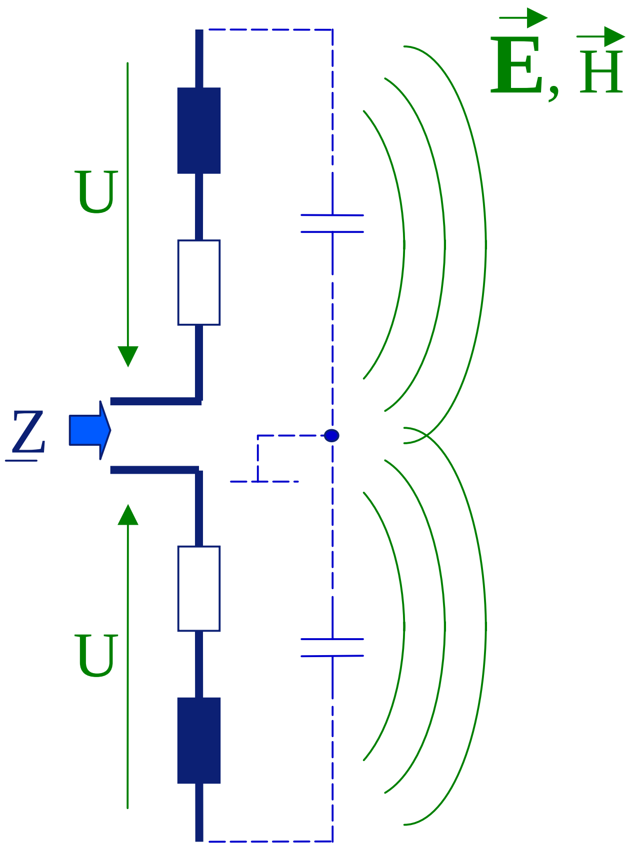

**$\underline{Z}$ :** **complex antenna impedance**

**$\underline{Z} = R(f)+j\omega X(f)$**

# Symmetrical Antenna

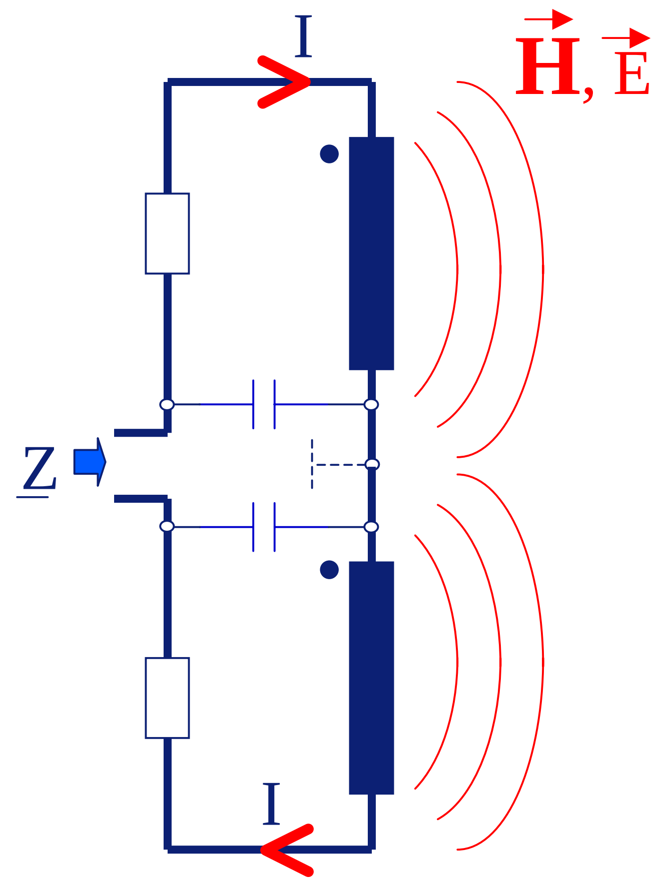
## Electrical Antenna:

(**“dipole”:** e.g. TV, fm-radio)

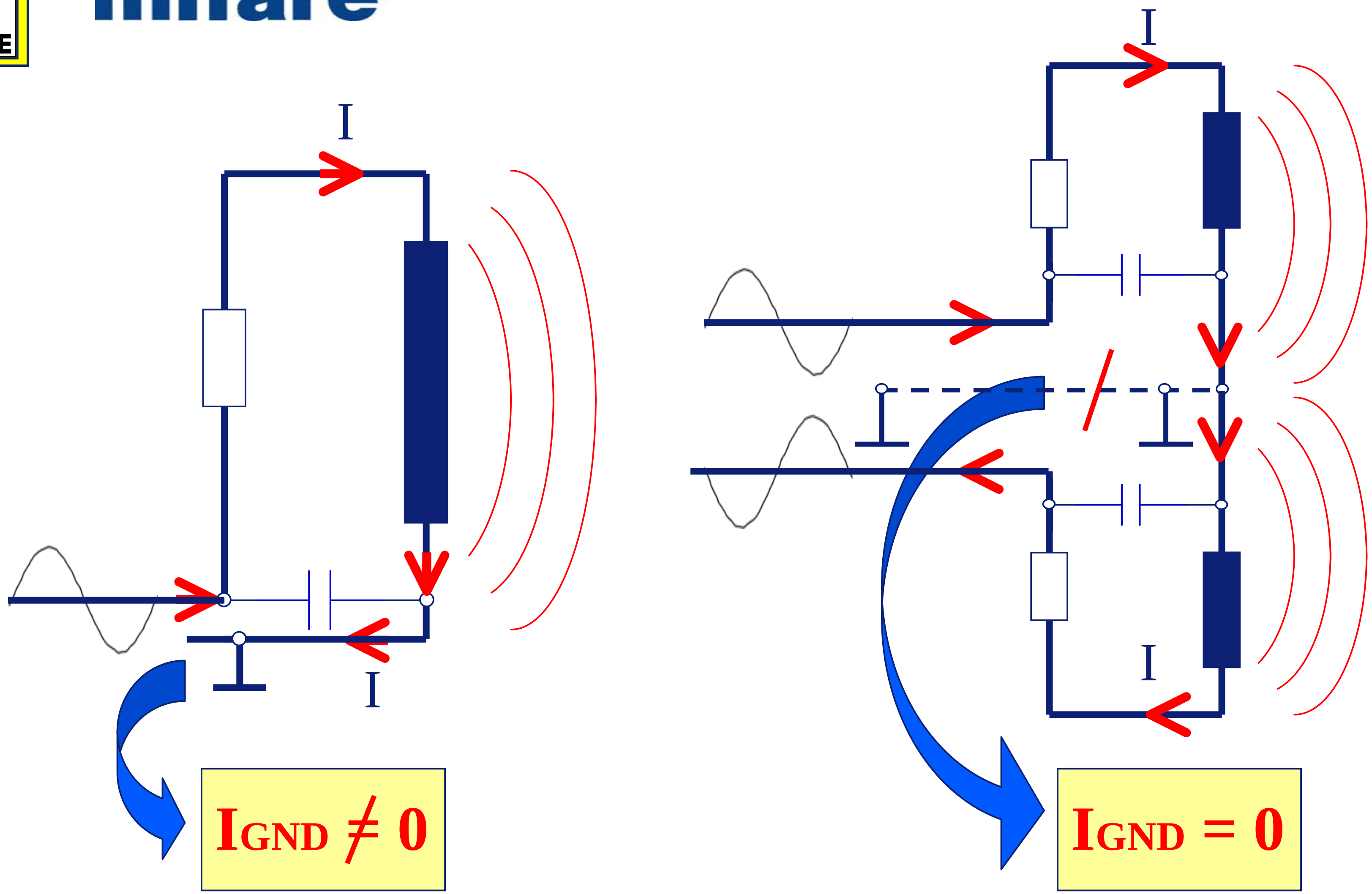



## Magnetical Antenna:

(e.g. mifare®, I·CODE )



# Common Mode Currents



# Antenna as Transformer 1

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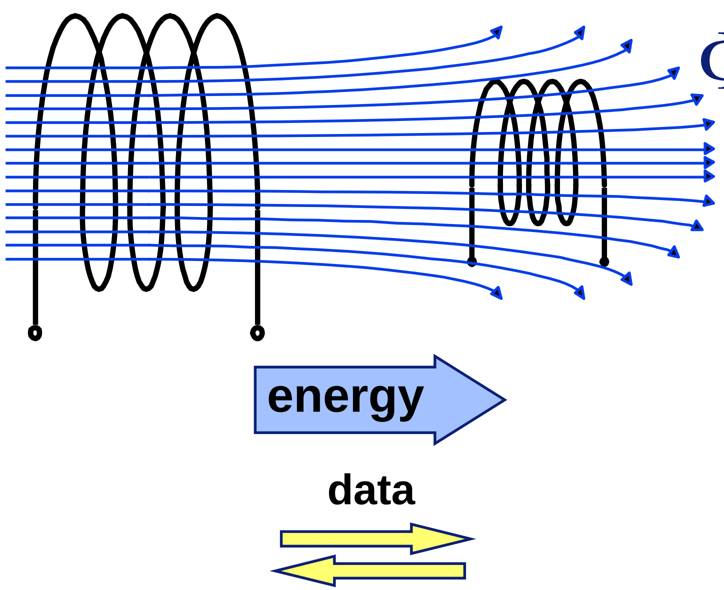


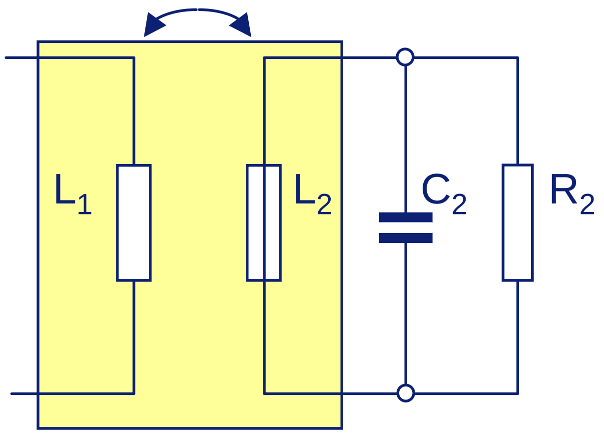


**k : coupling coefficient**

$$k = \frac{\phi_2}{\phi_1}$$

PCD: Proximity Coupling Device („Reader“)
PICC: Proximity Chip Card („Card“)

Index 1: PCD antenna = design parameters
Index 2: PICC antenna = fixed parameters

# Antenna as Transformer 2

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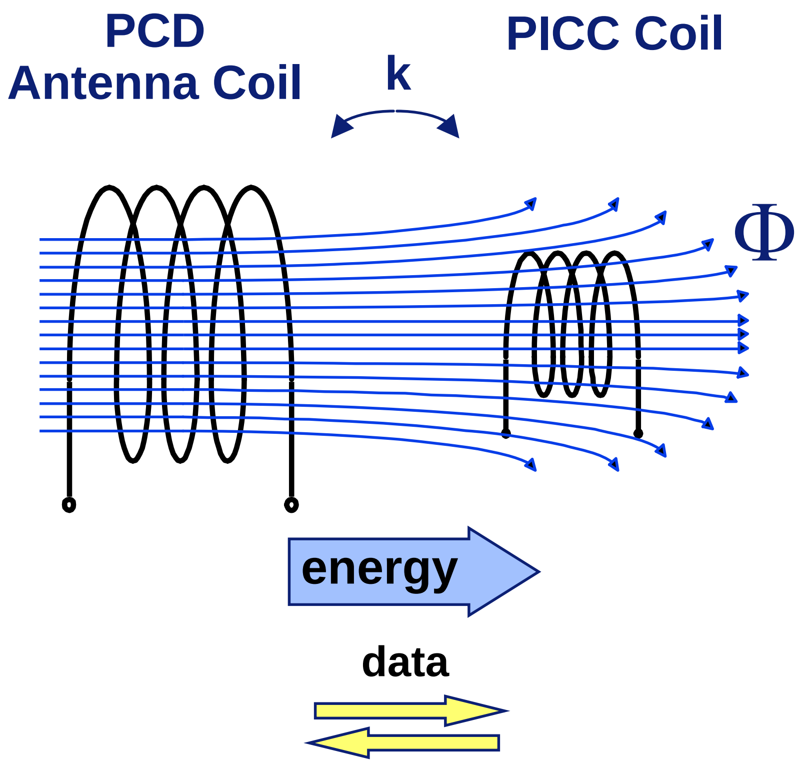


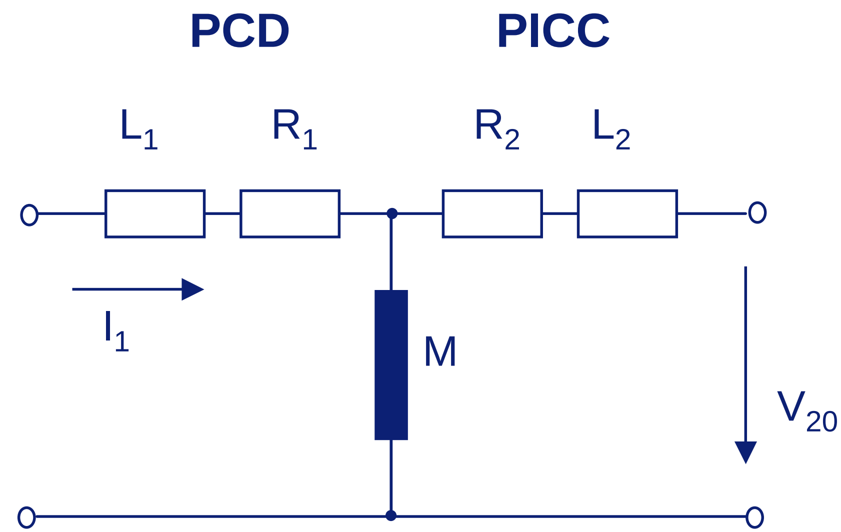


$V_{20}$ = open loop voltage

$$V_{20} = \omega \cdot M \cdot I_1$$

M = mutual inductance

$$M = k \cdot \sqrt{L_1 \cdot L_2}$$

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| | | | |
|---|---|---|---|
| Transformer Model: | $\Phi_1, \Phi_2$ | ⟺ | k |
| Transformer Model: | $I_1$ ,k | ⟺ | $V_{20}$ |
| Electromagnetic Induction: | $N_2, \Phi_2$ | ⟺ | $V_{20}$ |
| Electromagnetic Induction: | $B_2, A_2$ | ⟺ | $\Phi_2$ (B ⟺ H) |
| Law of Biot & Savart: | $I_1$, r, x | ⟺ | $B_2$ |
| Single turn inductance: | L | ⟺ | N |

**Optimum Antenna Radius**

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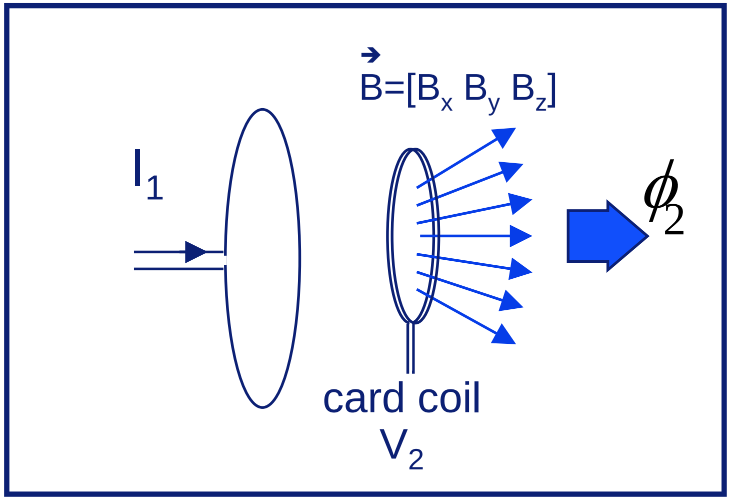
## Electromagnetic Induction:

$$V_{ind} = -N_2 \cdot \frac{d\phi}{dt} = -N_2 \cdot \frac{d}{dt} \int_A B_x \cdot dA$$




## Induced open loop voltage:

$$v_{20}(t) = N_2 \frac{d\,\hat{\phi}_2 \cdot \sin \omega t}{dt}$$

$$= N_2 \cdot \omega \cdot \hat{\phi}_2 \cdot \cos \omega t$$

$$V_{20} = N_2 \cdot \omega \cdot \hat{\phi}_2$$

$$= N_2 \cdot \omega \cdot \hat{B} \cdot A_2$$

card coil parameters:
$A_2$ : area
$N_2$ : number of turns

# Law of Biot & Savat 1

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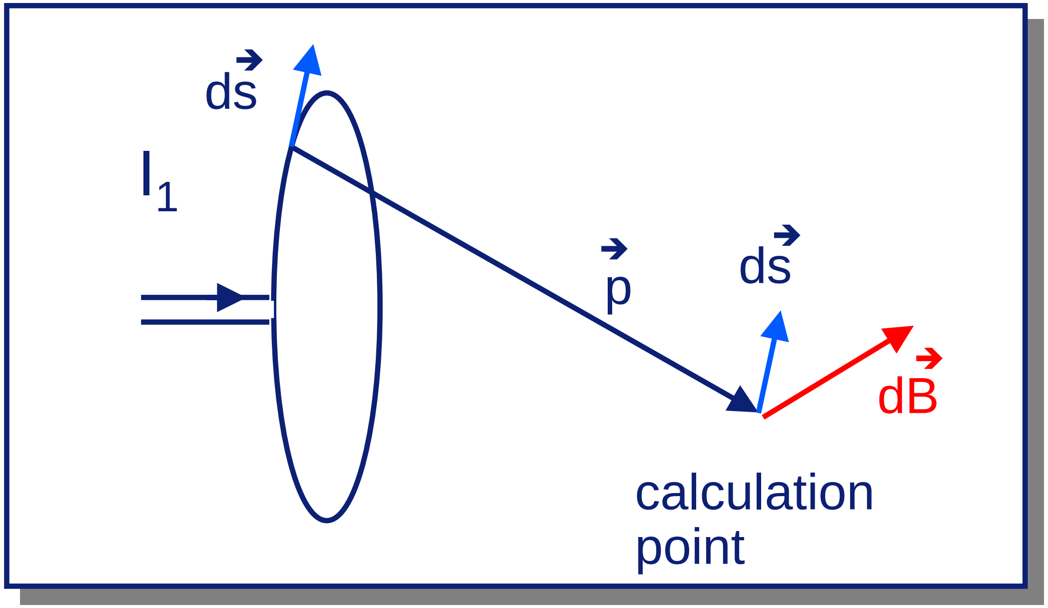


$$\vec{B} = \frac{\mu_o \cdot I_1}{4\pi} \cdot \oint_S \frac{\left[ d\vec{s} \times \vec{p} \right]}{p^3}$$

**Law of Biot and Savart (1820)**

# Law of Biot & Savat 2

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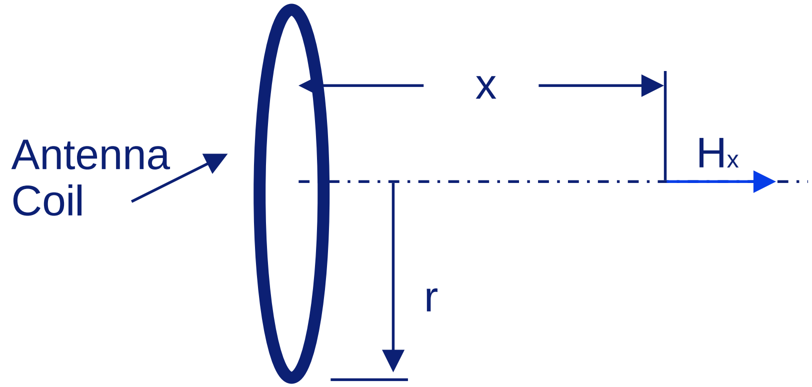
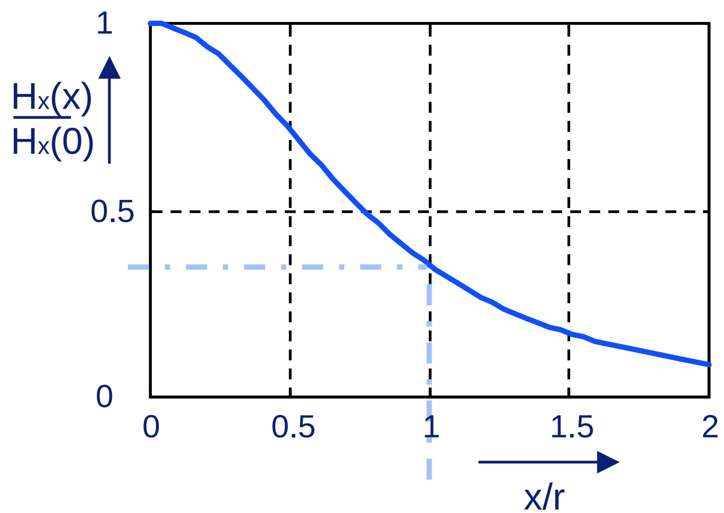



$$H_x = I_1 \cdot \frac{N_1 \cdot r^2}{2 \cdot (r^2 + x^2)^{3/2}}$$




**x = 0**

$$H_x(0) = \frac{I_1}{2} \cdot \frac{N_1}{r}$$

$$\approx \frac{1}{r}$$

**x >> r**

$$H_x(x) = \frac{I_1}{2} \cdot \frac{N_1 \cdot r^2}{x^3}$$

$$\approx \frac{1}{x^3}$$

# Operating Magnetical Fieldstrength

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1. The minimum operating field strength is specified:

| | | |
|---|---|---|
| **ISO14443:** | **$H_{min}$ = 1.5 A/m** | (Mifare) |
| **ISO15693:** | **$H_{min}$ = 0.15 A/m** | (I*Code) |

2. With the **law of Biot and Savart** the flux density in the card coil area can be calculated.

3. Integration of the flux density and calculation of the mean flux density gives the **mean magnetic field strength** as a function of the reader coil radius and the operating distance: H = f (r,x)

> mean field strength $\overset{!}{=}$ specified minimum field strength

# Coupling coefficient

$$V_{20} = \omega \cdot M \cdot I_1$$

$$M = k \cdot \sqrt{L_1 \cdot L_2}$$

$$M = \frac{V_{20}}{\omega \cdot I_1}$$

$$M = \frac{N_2 \cdot \hat{B} \cdot A_2}{I_1}$$

$$V_{20} = N_2 \cdot \omega \cdot \hat{B} \cdot A_2$$

$$\hat{B} = \mu_o \cdot I_1 \cdot \frac{N_1 \cdot r^2}{2 \cdot (r^2 + x^2)^{3/2}}$$

$$k = \mu_0 \cdot \frac{r^2}{2(r^2 + x^2)^{3/2}} \cdot \sqrt{\frac{N_1^2 \cdot N_2^2}{L_1 \cdot L_2}} \cdot A_2$$

# Maximum Coupling Coefficient

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$$k = \mu_0 \cdot \frac{r^2}{2(r^2 + x^2)^{3/2}} \cdot \sqrt{\frac{N_1^2 \cdot N_2^2}{L_1 \cdot L_2}} \cdot A_2$$

**Maximum operating distance ⇔ maximum coupling coefficient**

depends on:

1. Antenna Coil Diameter
2. Number of Turns
3. Inductance

# Simplified Coupling Coefficient

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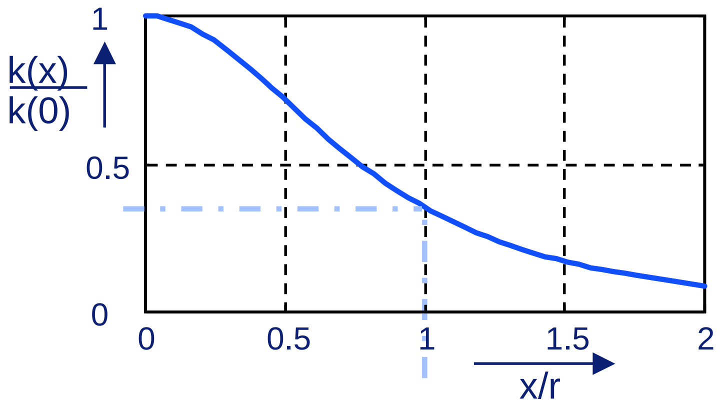
$$k = \mu_0 \cdot \frac{r^2}{2(r^2 + x^2)^{3/2}} \cdot \sqrt{\frac{N_1^2 \cdot N_2^2}{L_1 \cdot L_2}} \cdot A_2$$

$$L_1 = L_{01} \cdot N_1^2 \qquad L_2 = L_{02} \cdot N_2^2$$

$$L_{01} \approx \frac{2 \cdot 10^{-7}}{[\mathrm{m}]} \cdot 2\pi \cdot r \cdot \ln\left(\frac{2\pi \cdot r}{d}\right)$$



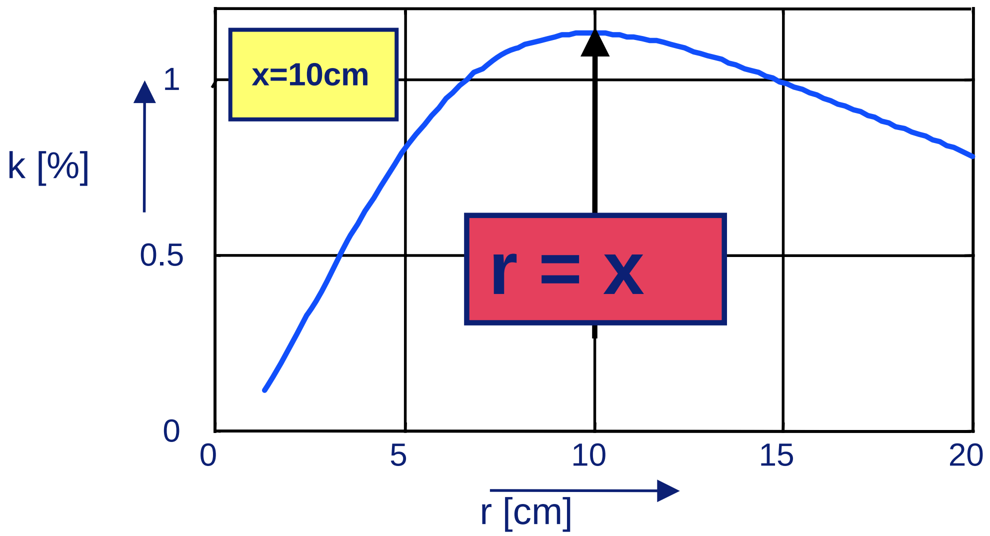

$$k = \mu_0 \cdot \frac{r^2}{2(r^2 + x^2)^{3/2}} \cdot \frac{A_2}{\sqrt{L_{01} \cdot L_{02}}}$$

# Maximum Operating Distance

**Coupling coefficient k = f(r,x):**

$$k = \mu_0 \cdot \frac{r^2}{2(r^2 + x^2)^{3/2}} \cdot \frac{A_2}{\sqrt{L_{01} \cdot L_{02}}}$$

## Optimum Antenna Radius:



# Summary

Every Antenna is a **Resonance Circuitry**.

Mifare & I-Code use **Magnetical Antennas**.

Be aware of Common Mode Currents: use **Symmetrical Antenna.**

Mifare & I-Code use the antenna like a **Transformer**.

The Optimum Radius of an Antenna is given by: **r = x**

r: Antenna Radius
x: (Maximum) Operating Distance