Meta-Materialien mit negativem Brechungsindex

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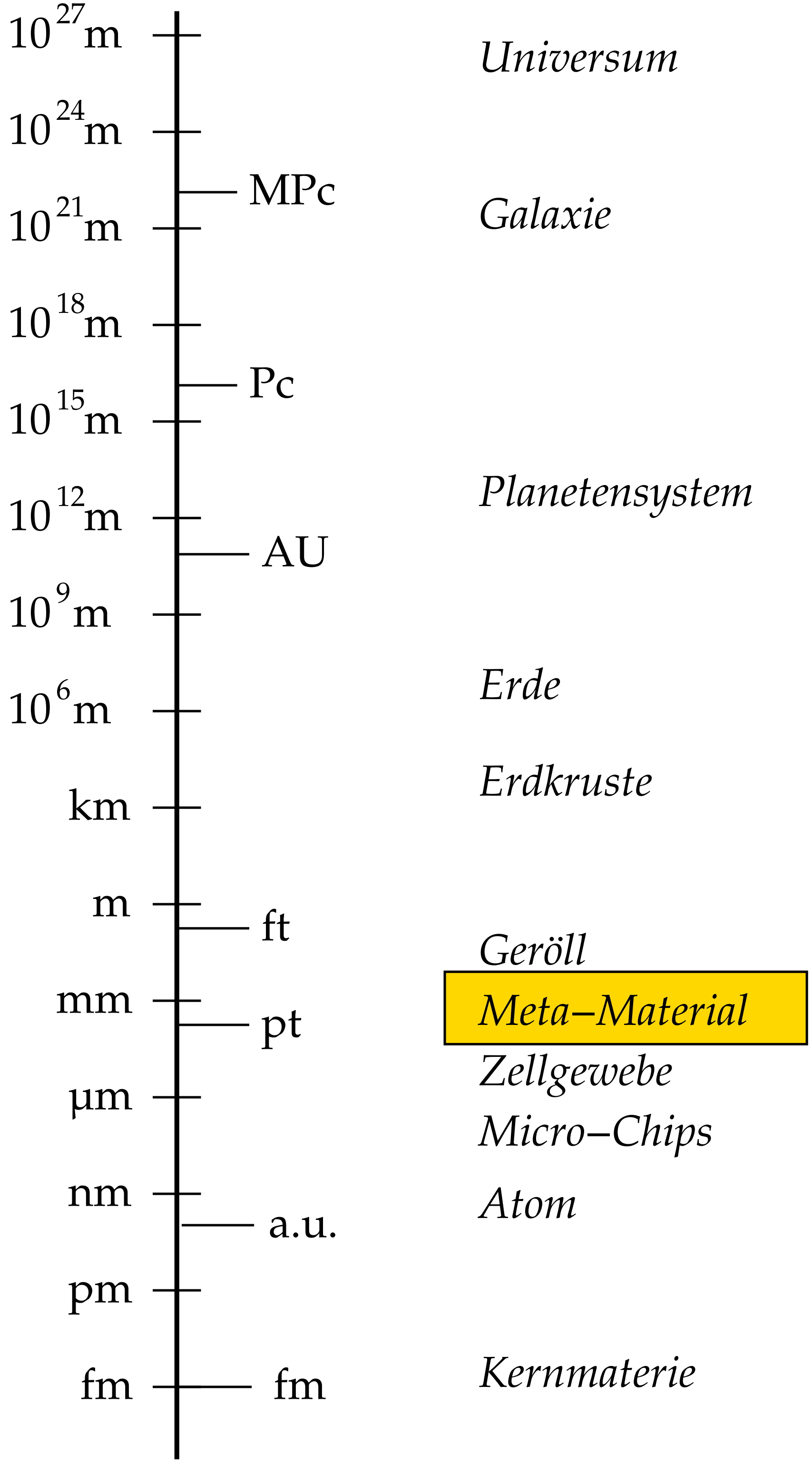
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Galaxie
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Erde
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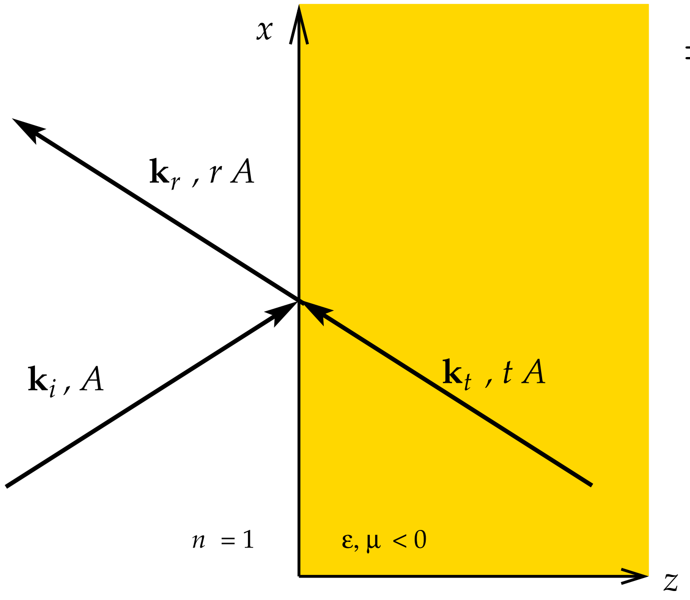
Meta–Material
Zellgewebe
Micro–Chips
Atom
Kernmaterie

Reflexion / Transmission



Stetigkeit von $E_{x,y}$ und $H_{x,y}$

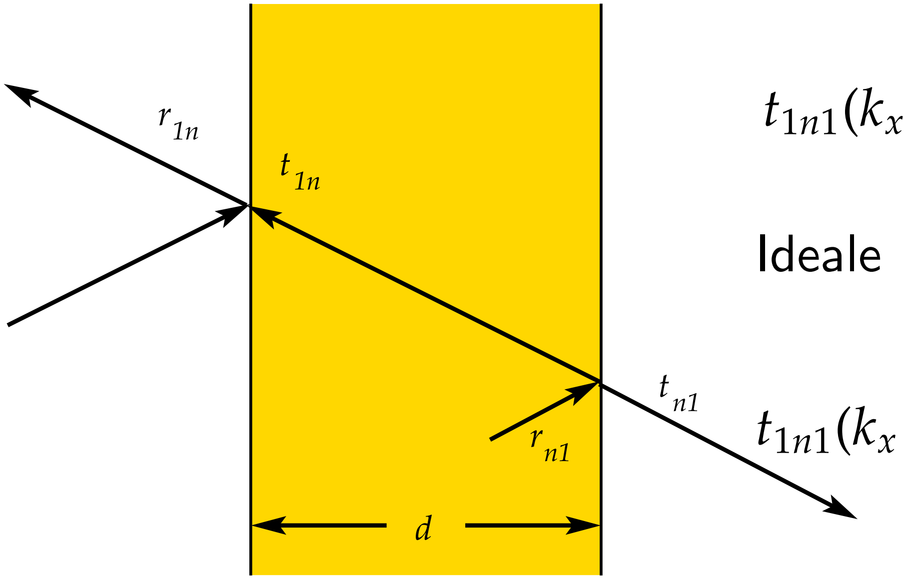
$\Rightarrow$ Reflexionskoeffizient (in s-Polarisation)

$$\begin{aligned} r &= \frac{k_{zn}/\mu - k_{z1}}{k_{zn}/\mu + k_{z1}} \\ k_{z1} &= \sqrt{\omega^2/c^2 - k_x^2} \\ k_{zn}^2 &= \varepsilon\mu\omega^2/c^2 - k_x^2 \end{aligned}$$

$R = |r|^2 \leq 1,$ falls $k_{zn}/\mu > 0 \iff k_{zn} < 0, \quad n = \sqrt{\varepsilon\mu} < 0$

→ Animation

Transmission durch Schicht



Zwei Grenzflächen ⇒ Transmission

$$t_{1n1}(k_x, d) = \frac{t_{1n} t_{n1}\, \mathrm{e}^{\mathrm{i}k_{zn}d}}{1 - r_{n1}^2\, \mathrm{e}^{2\mathrm{i}k_{zn}d}}, \qquad t_{n1} = 1 + r_{n1}$$

Ideale Bedingungen ($\varepsilon = \mu = -1$)

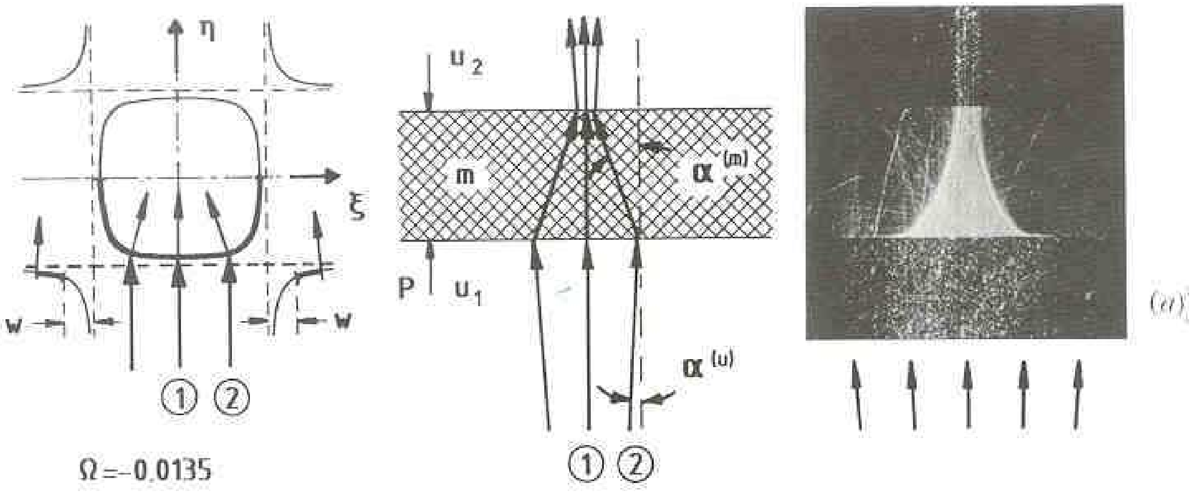
$$t_{1n1}(k_x, d) = \begin{cases} \mathrm{e}^{\mathrm{i}k_{zn}d} = \mathrm{e}^{-\mathrm{i}k_{z1}d}, & |k_x| \le \omega/c \\ \mathrm{e}^{-\mathrm{i}k_{zn}d} = \mathrm{e}^{-\mathrm{i}k_{z1}d}, & |k_x| \ge \omega/c \end{cases}$$

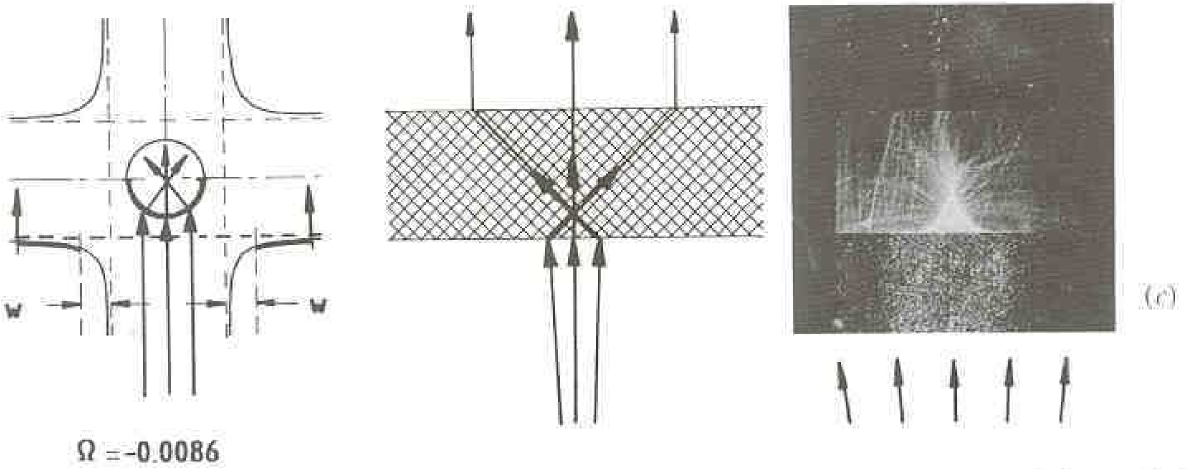
(J. B. Pendry, Phys. Rev. Lett. 2000)

Weglänge d wird exakt kompensiert ⇒ Abstand $2d$ zwischen Bild und Quelle

Experiment: ebener Wellenleiter mit gekreuztem Liniengitter

(Remigius Zengerle, J. mod. Optics 1987)





Experiment: ebener Wellenleiter mit Liniengitter

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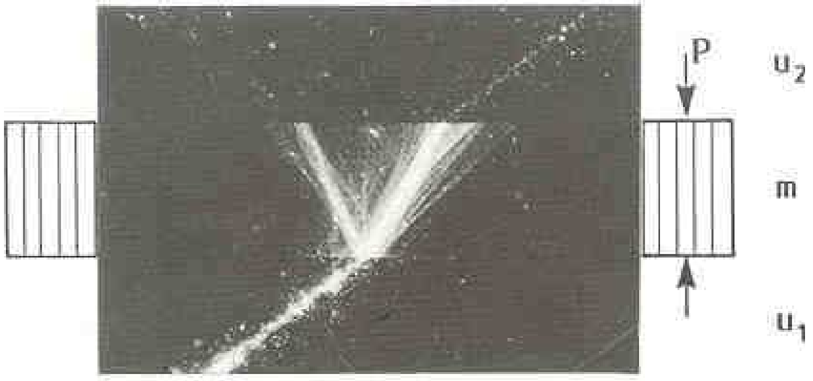
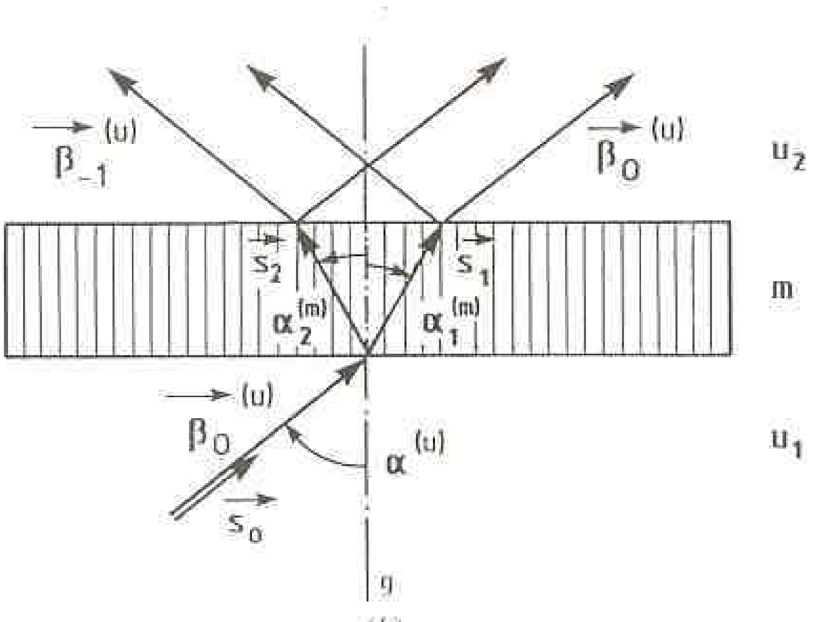


(a)



(b)

Simulation (+ Experiment): Drähte, Kondensatoren, Spulen (Mikrowellen)

(Grbic & Eleftheriades, Appl. Phys. Lett. 2003 + Phys. Rev. Lett. 2004)

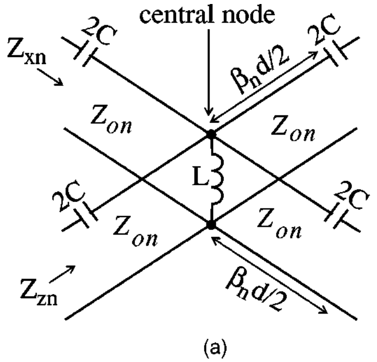


FIG. 1. TL unit cells. (a) Unit cell of dual TL structure (NRI medium) and (b) unit cell of TL mesh (PRI medium).

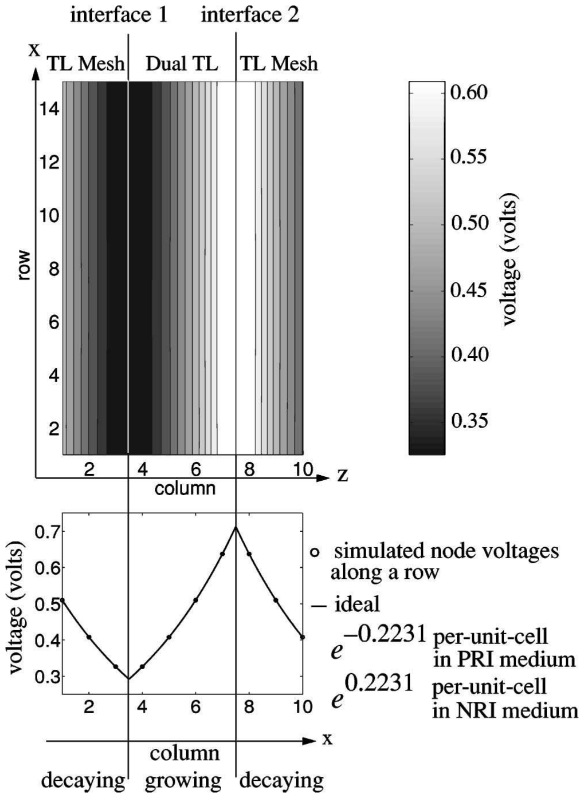


FIG. 3. Simulated voltage magnitudes for infinitely long interfaces (in the x direction).

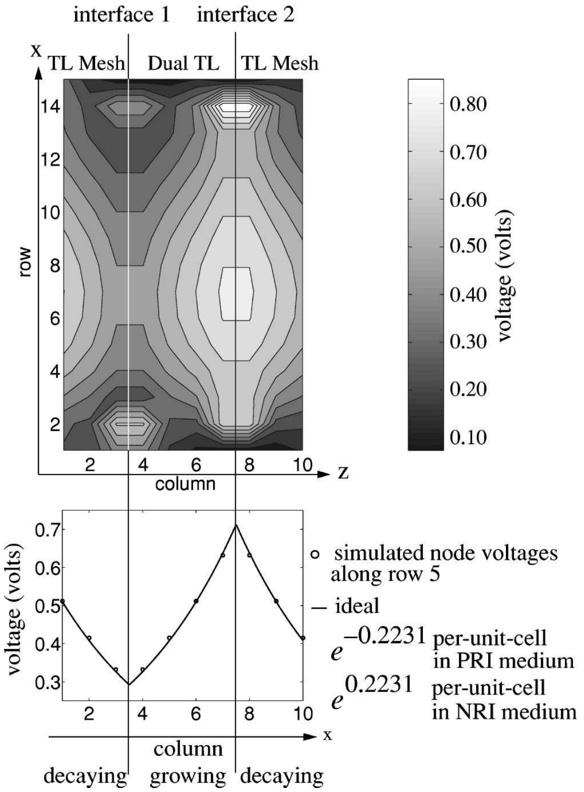
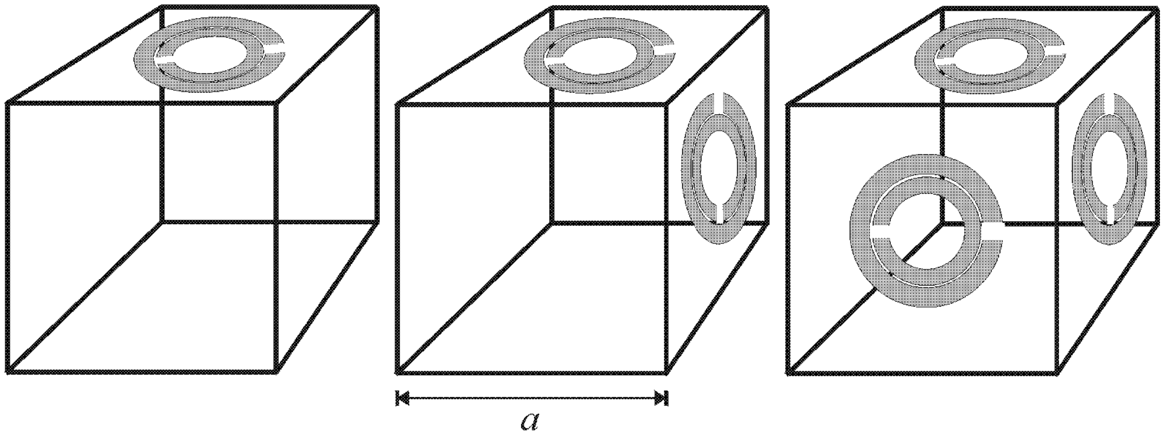


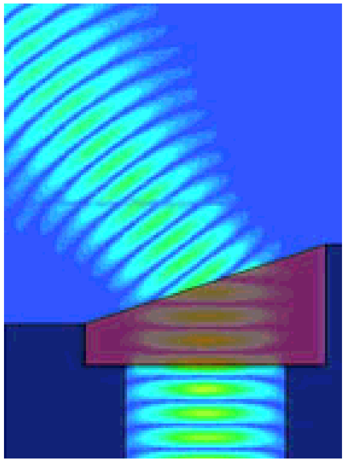
FIG. 4. Simulated voltage magnitudes for finite interfaces (in the x direction).

Gitter aus Drähten und Ringen (Mikrowellen)

Pendry & al. 1999 + Experiment: Shelby, Smith & Schultz, Science 2001)

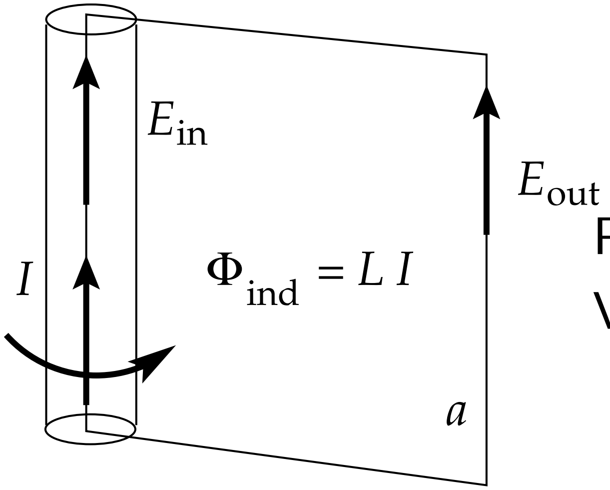


Struktur



Simulation

Draht als Schaltkreis



emK entlang Schlaufe $=-$ magnetische Flussänderung

$$RI - aE_{\text{out}} = -L\frac{\mathrm{d}I}{\mathrm{d}t} = \mathrm{i}\omega LI$$

Widerstand R, Induktivität L (für Länge a)

Polarisationsstrom pro Volumen ($\mathbf{j}_{\text{pol}} = \partial_t \mathbf{P}$)

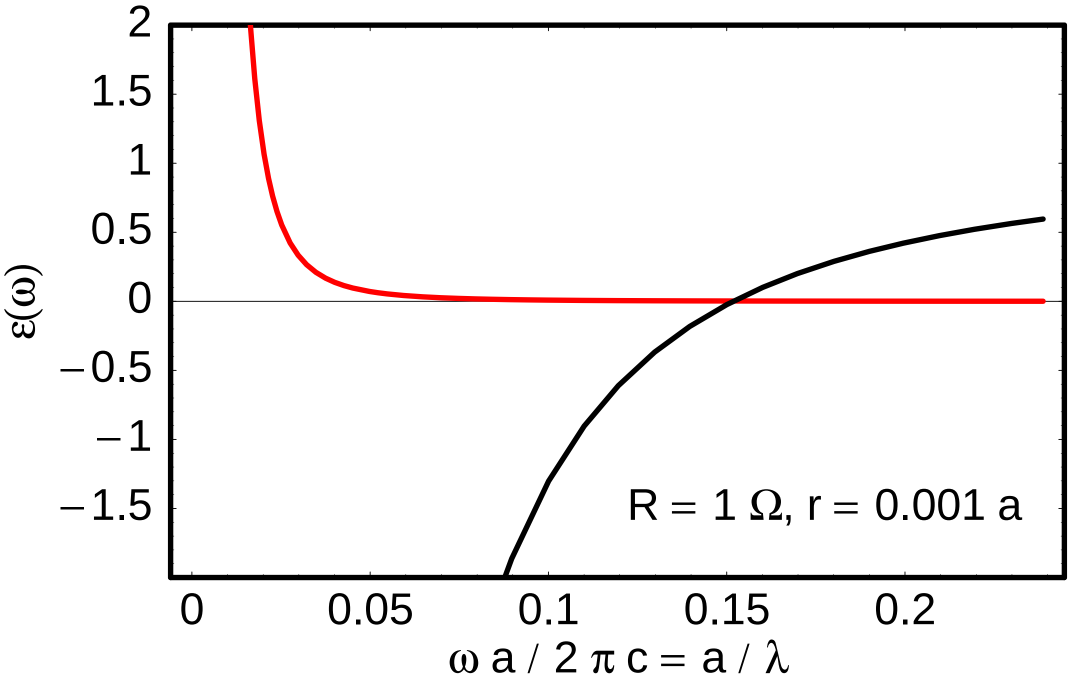
$$aI = -\mathrm{i}\omega \overline{P} a^3$$

Volumen-gemitteltes Feld (dünner Draht)

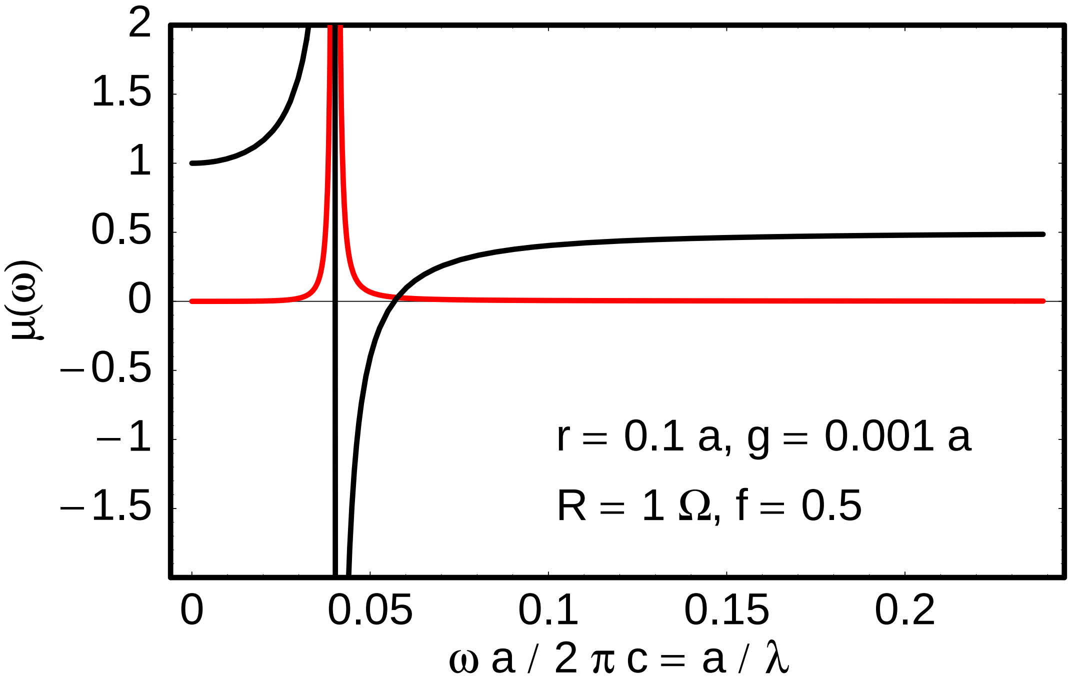
$$\overline{E} \approx E_{\text{out}}$$

$$\Rightarrow \qquad \varepsilon = 1 - \frac{1/\varepsilon_0 a}{\omega^2 L + \mathrm{i}\omega R}, \qquad \mathbf{\Omega}_{\text{eff}}^2 = \frac{c^2}{a^2}\frac{\mu_0 a}{L}$$

Dünne Drähte: dielektrische Funktion



Geschlitzte Ringe: Permeabilität



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