

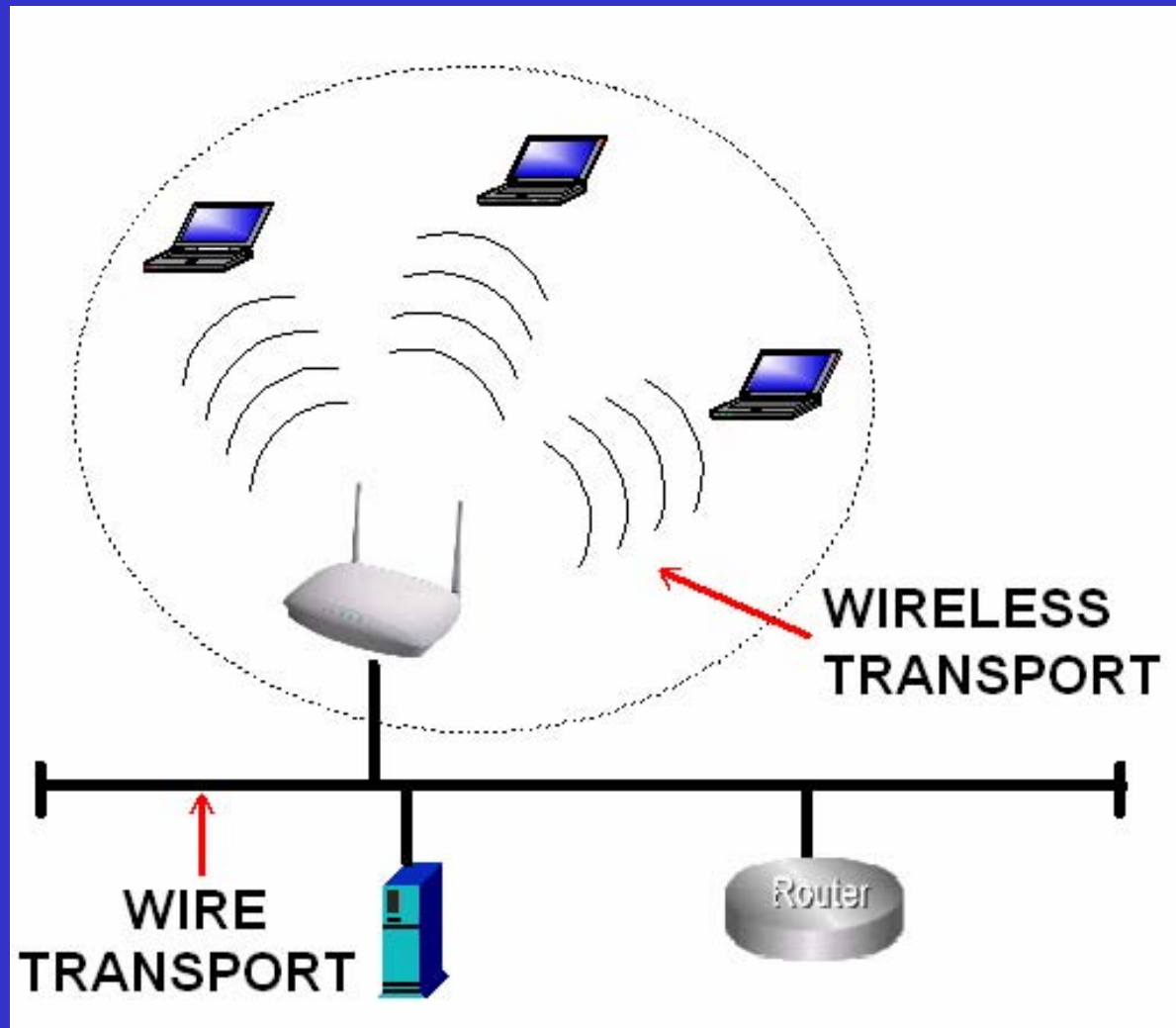
Wireless
Non-Radiative
Energy Transfer

Motivation

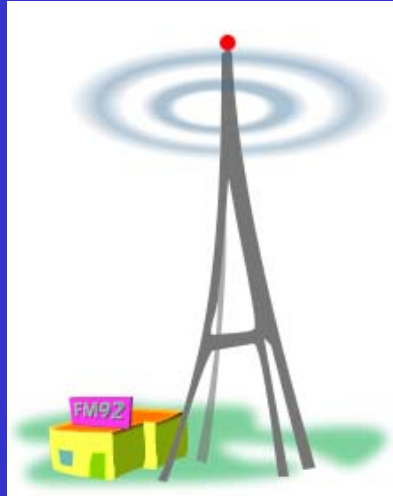


**Tesla tower:
cca. 1904**

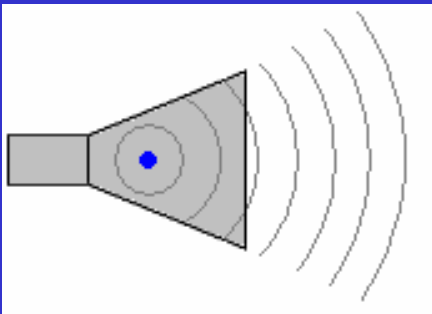
WLAN (wireless local area network) concept: radiation



Radiative energy transfer



Omni-directional radiation



Directed radiation



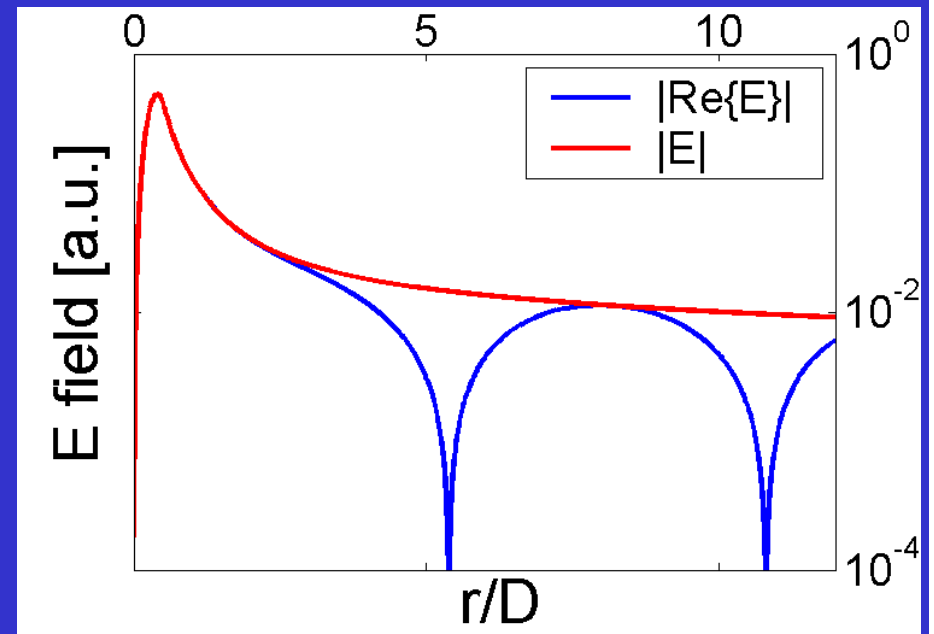
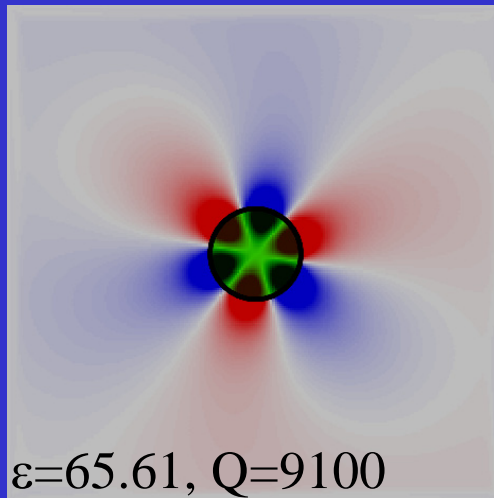
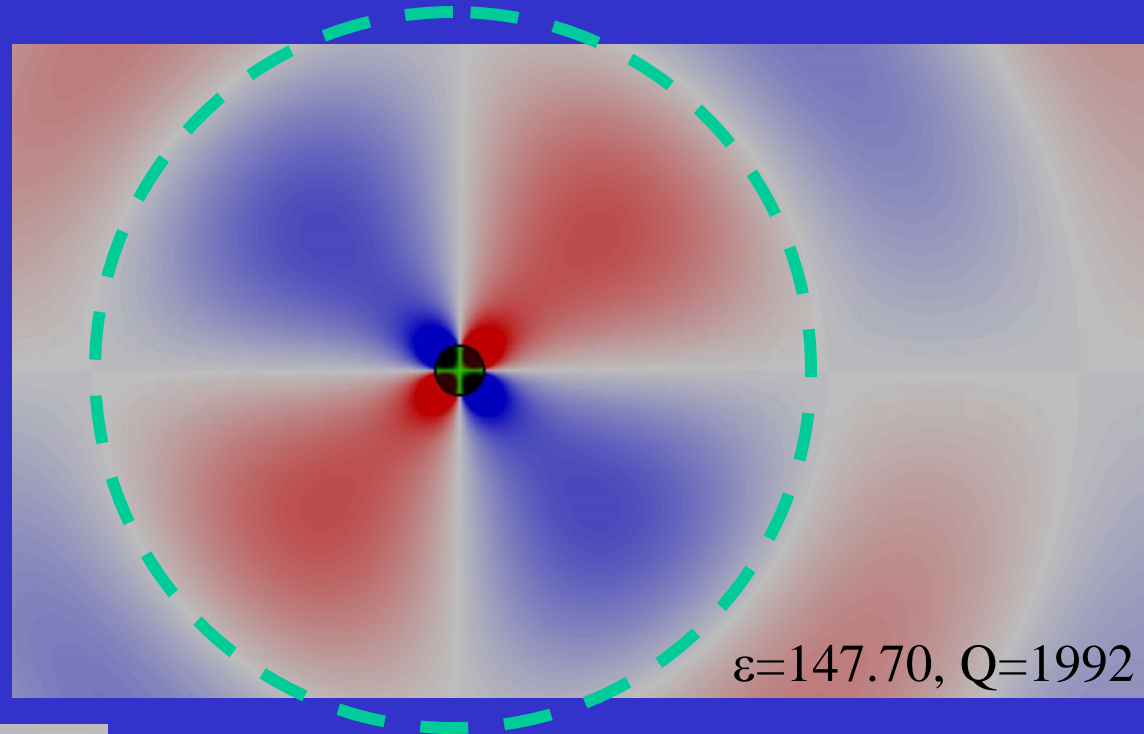
Resonance phenomena

$$-\frac{\hbar^2}{2m}\nabla^2\psi = E\psi$$

Schrödinger equation

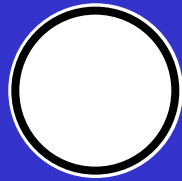
$$-c^2\nabla^2\mathbf{E} = \omega^2\mathbf{E}$$

Maxwell equation

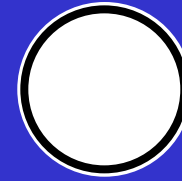


Titania ($\epsilon \approx 96$, $\text{Im}\{\epsilon\}/\epsilon \sim 10^{-3}$)
Barium tetratitanate ($\epsilon \approx 37$, $\text{Im}\{\epsilon\}/\epsilon \sim 10^{-4}$)
Lithium tantalite ($\epsilon \approx 40$, $\text{Im}\{\epsilon\}/\epsilon \sim 10^{-4}$)

Resonant coupling



resonant object (Source)



resonant object (Device)

$$\frac{da_S}{dt} = -i(\omega_S + i\Gamma_S)a_S + i\kappa_{SD}a_D$$

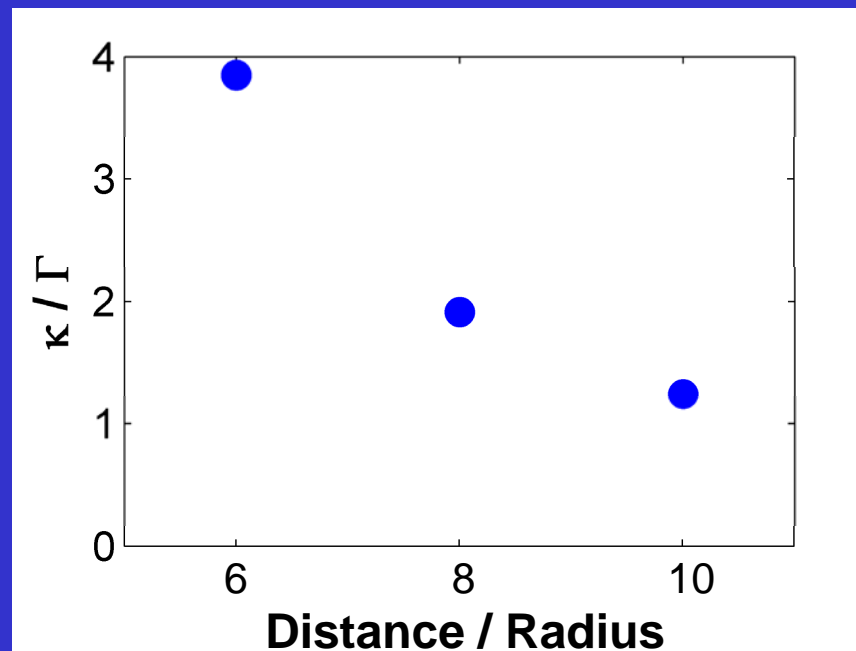
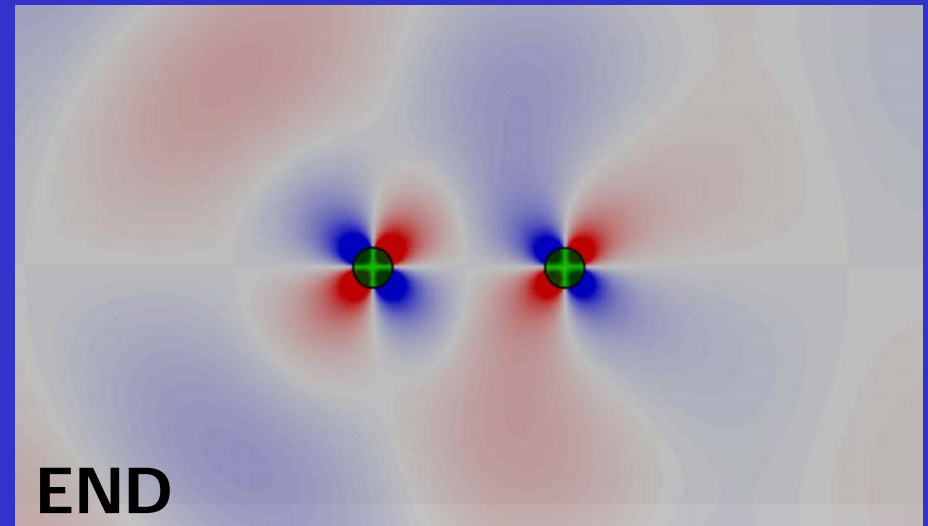
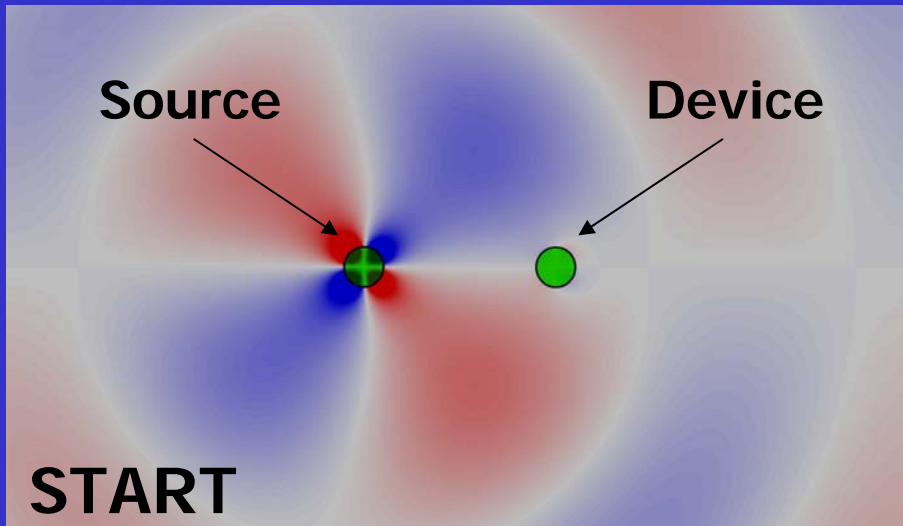
$$\frac{da_D}{dt} = -i(\omega_D + i\Gamma_D)a_D + i\kappa_{DS}a_S$$

$$\kappa_{SD} \equiv \frac{\omega_S \int d^3\mathbf{r} \mathbf{E}_S^*(\mathbf{r}) \mathbf{E}_D(\mathbf{r}) [\varepsilon_S(\mathbf{r}) - \varepsilon_0]}{2 \int d^3\mathbf{r} |\mathbf{E}_S(\mathbf{r})|^2 \varepsilon(\mathbf{r})}$$

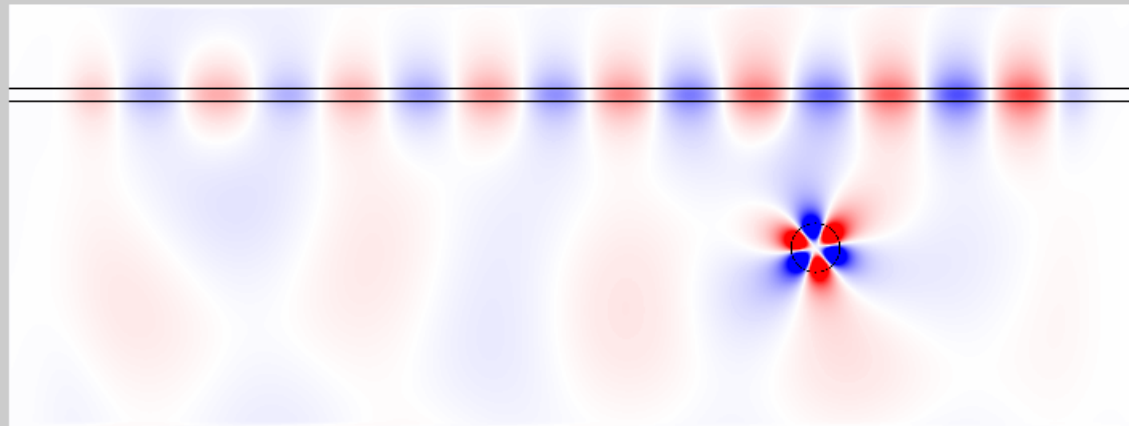
$$\kappa_{DS} \equiv \frac{\omega_D \int d^3\mathbf{r} \mathbf{E}_D^*(\mathbf{r}) \mathbf{E}_S(\mathbf{r}) [\varepsilon_D(\mathbf{r}) - \varepsilon_0]}{2 \int d^3\mathbf{r} |\mathbf{E}_D(\mathbf{r})|^2 \varepsilon(\mathbf{r})}$$

$$\kappa \equiv \sqrt{|\kappa_{SD} \kappa_{DS}|}$$

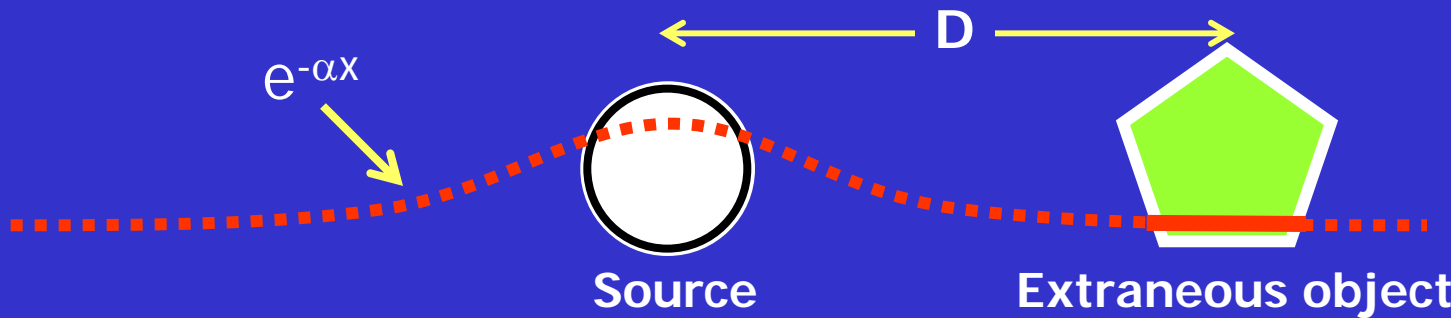
Example of resonant coupling



One more example of resonant coupling

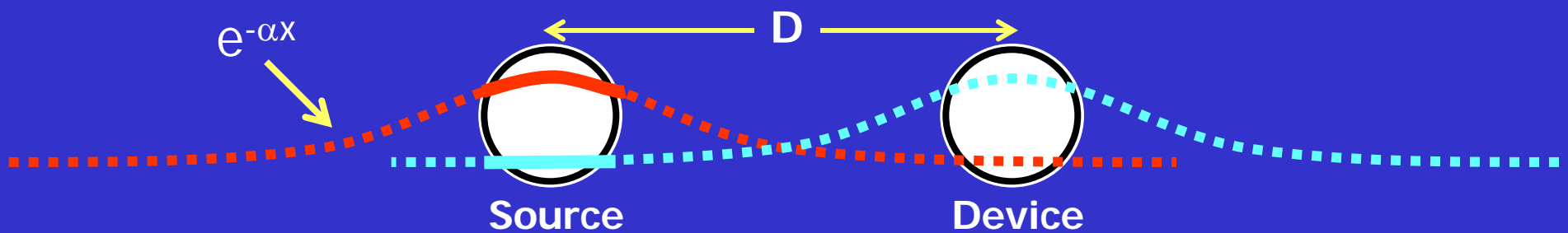


Coupling with extraneous objects



$$\frac{da_S}{dt} = -i(\omega_S + i\Gamma_S)a_S + i\kappa_{SE}a_S$$

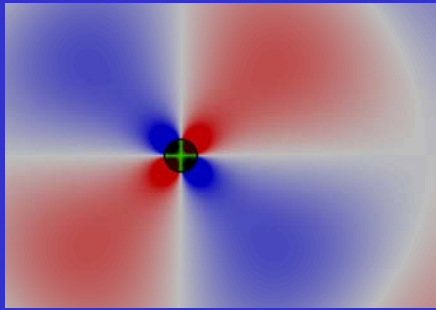
$$\kappa_{SE} \equiv \frac{\omega_1}{2} \frac{\int d^3\mathbf{r} |\mathbf{E}_S(\mathbf{r})|^2 [\varepsilon_E(\mathbf{r}) - \varepsilon_0]}{\int d^3\mathbf{r} |\mathbf{E}_S(\mathbf{r})|^2 \varepsilon(\mathbf{r})} \propto e^{-2\alpha D}$$



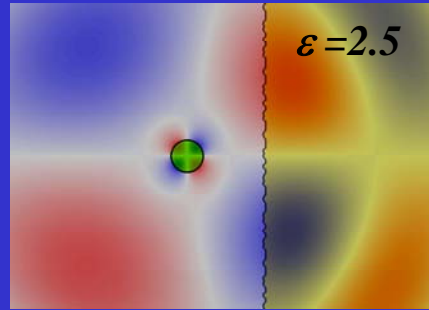
$$\frac{da_S}{dt} = -i(\omega_S + i\Gamma_S)a_S + i\kappa_{SD}a_D$$

$$\kappa_{SD} \equiv \frac{\omega_S}{2} \frac{\int d^3\mathbf{r} \mathbf{E}_S^*(\mathbf{r}) \mathbf{E}_D(\mathbf{r}) [\varepsilon_S(\mathbf{r}) - \varepsilon_0]}{\int d^3\mathbf{r} |\mathbf{E}_S(\mathbf{r})|^2 \varepsilon(\mathbf{r})} \propto e^{-\alpha D}$$

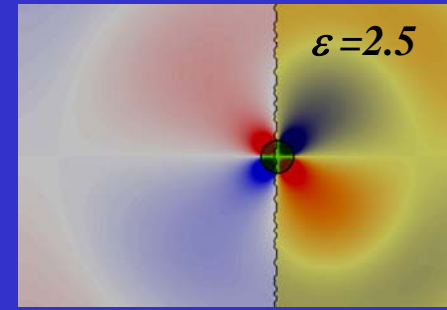
Examples of extraneous coupling



$Q = 1992$



$Q = 1832$

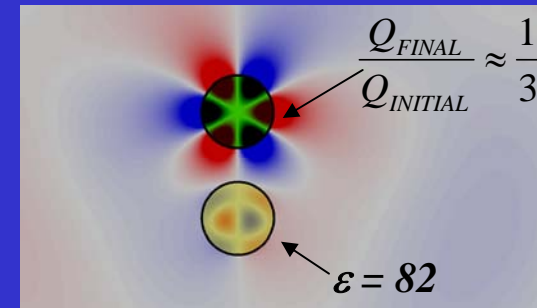


$Q = 873$

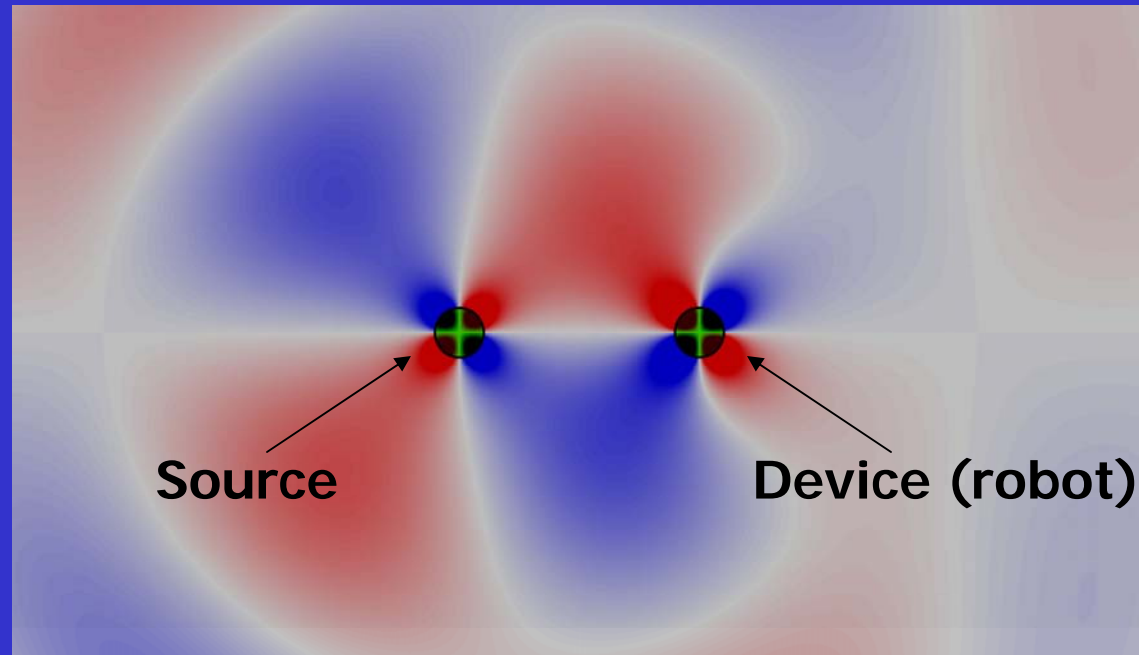
Concrete ($\epsilon \approx 4.5$, $Im\{\epsilon\}/\epsilon \sim 10^{-2}$)

Wood ($\epsilon \approx 1.2-5$, $Im\{\epsilon\}/\epsilon \sim 10^{-3}$)

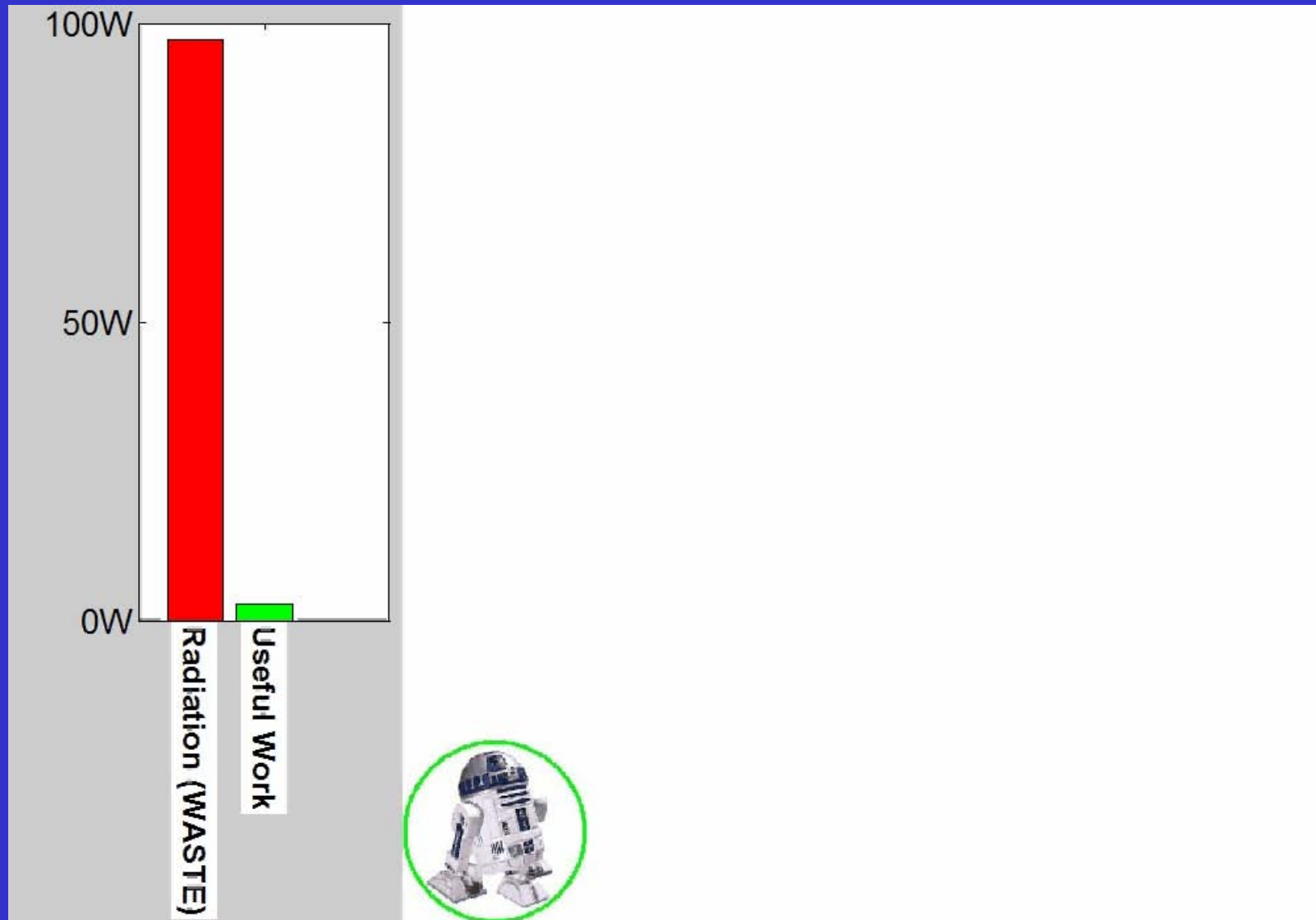
Fused quartz ($\epsilon \approx 4.0$, $Im\{\epsilon\}/\epsilon \sim 10^{-4}$)



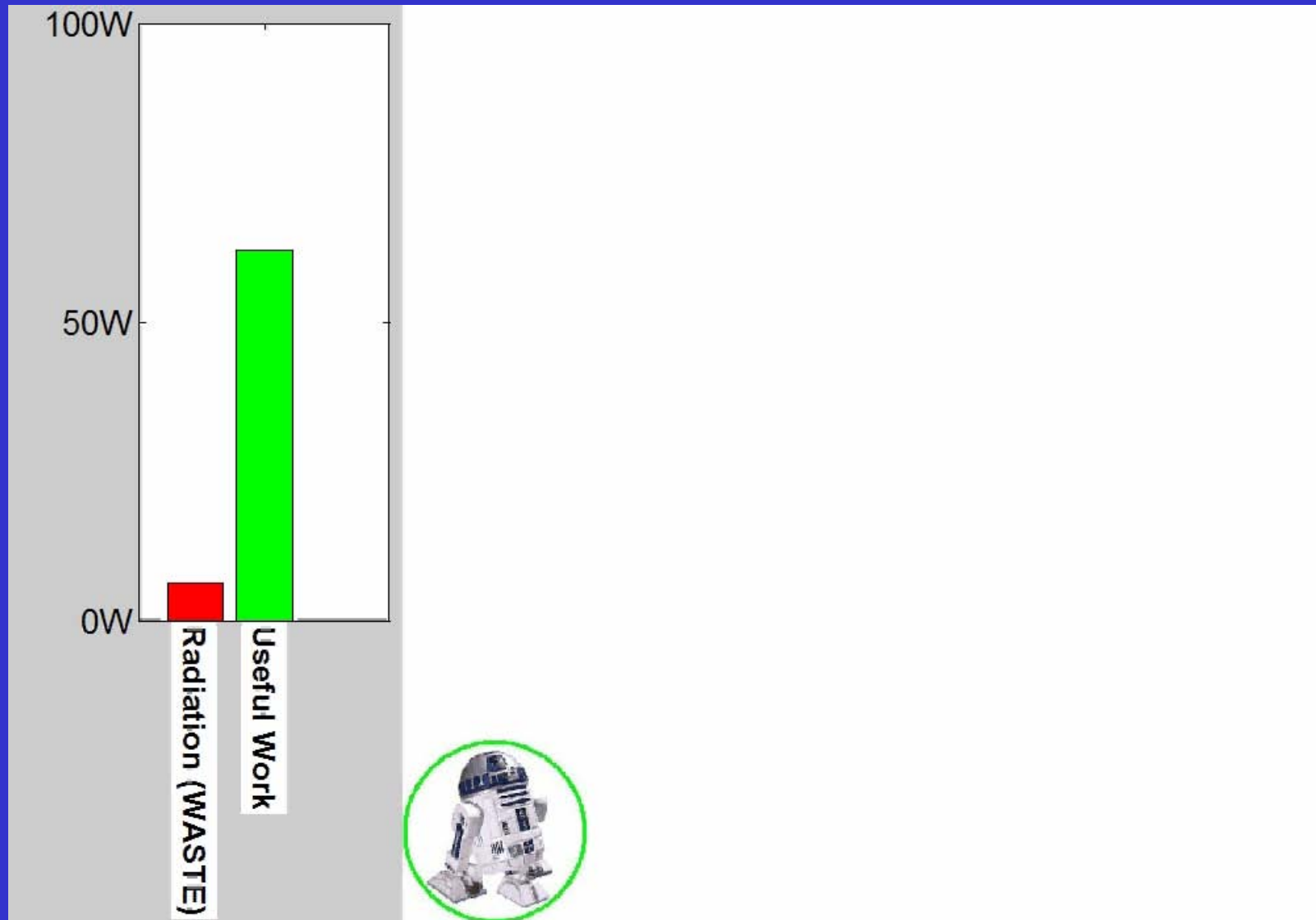
Robot & Office: simulation



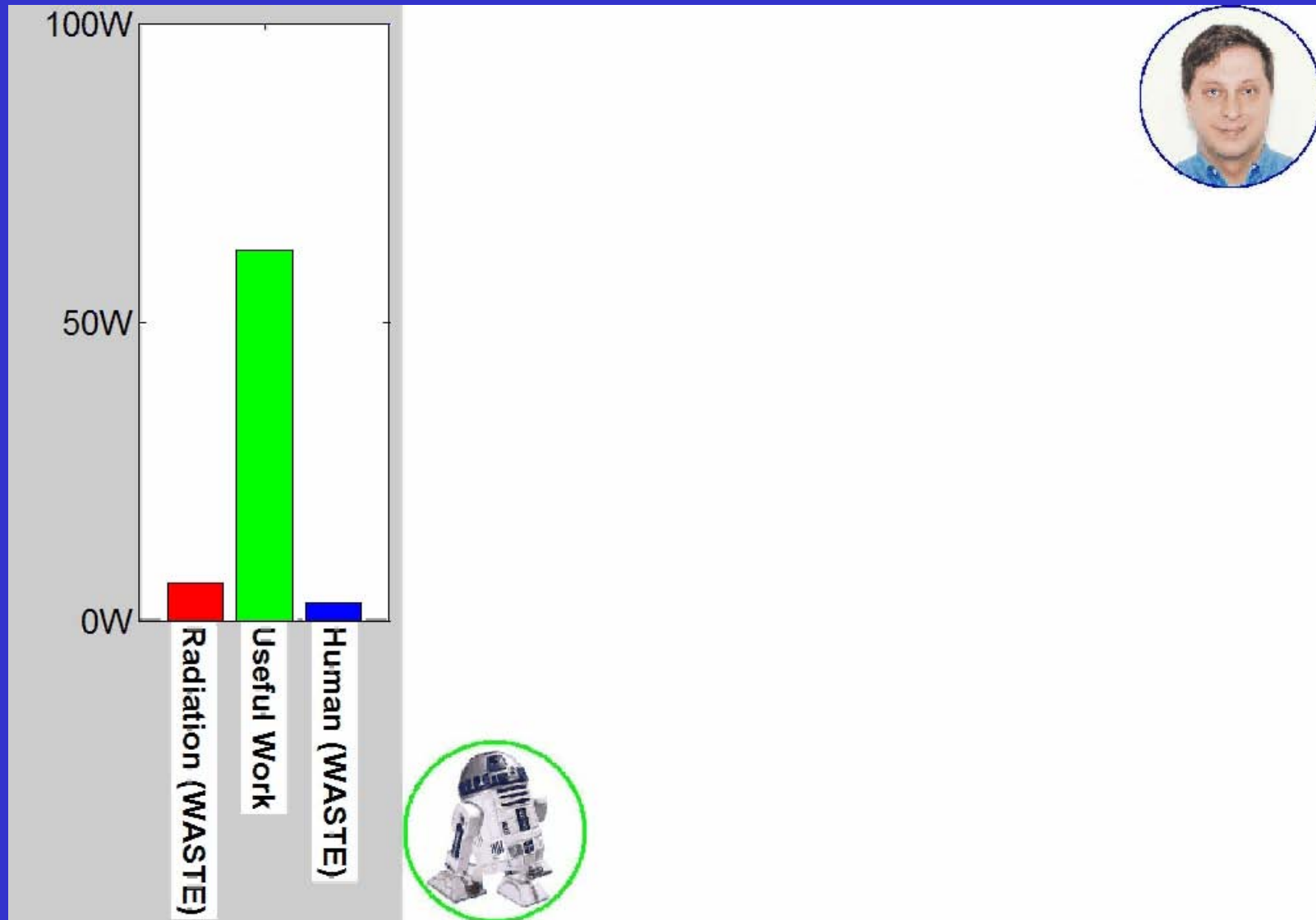
Robot & Office: *radiative* scheme



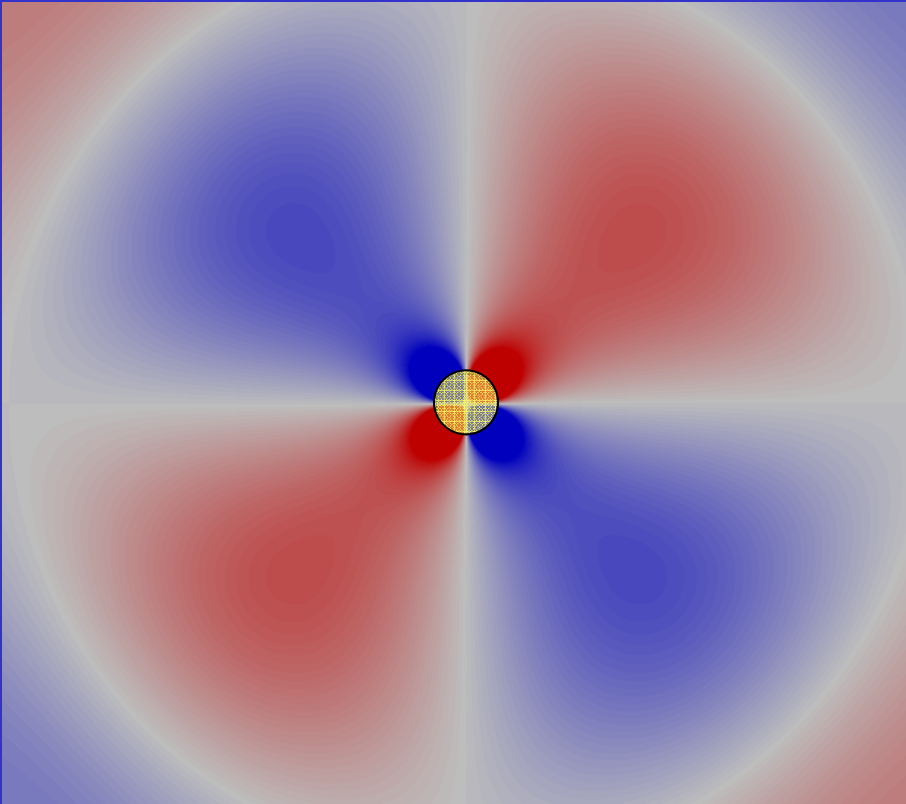
Robot & Office: non-radiative scheme



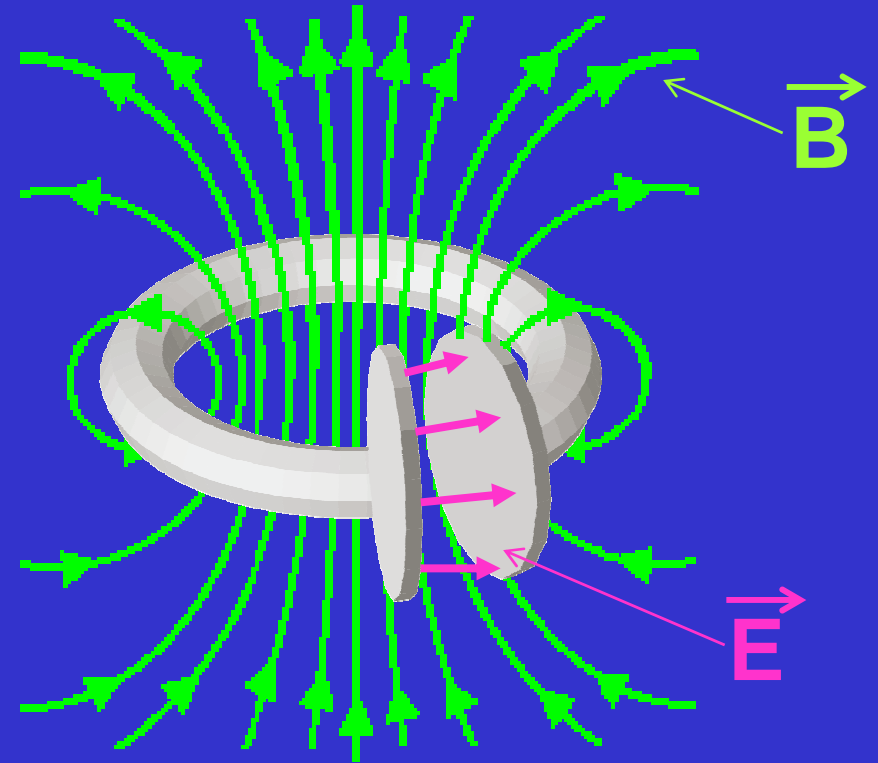
Robot & Office: non-radiative scheme



Magnetic resonances



Outside: $U_E \sim U_B$



Outside: $U_E \sim 0$

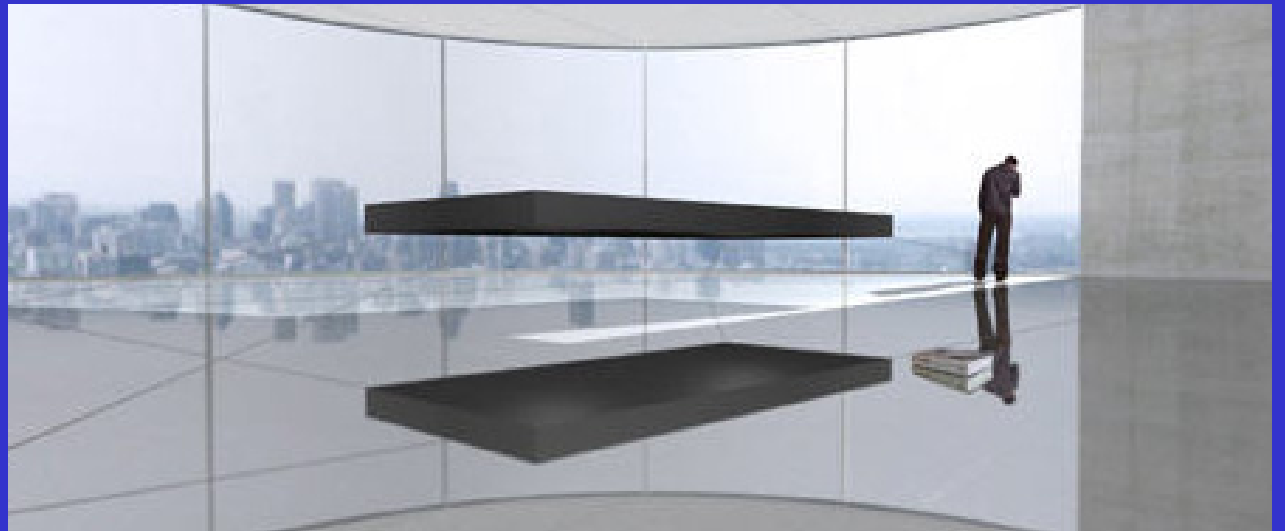
Most materials: $\mu \sim \mu_{\text{AIR}}$

\Rightarrow no interaction with the field!

Examples of “magnetic technology”

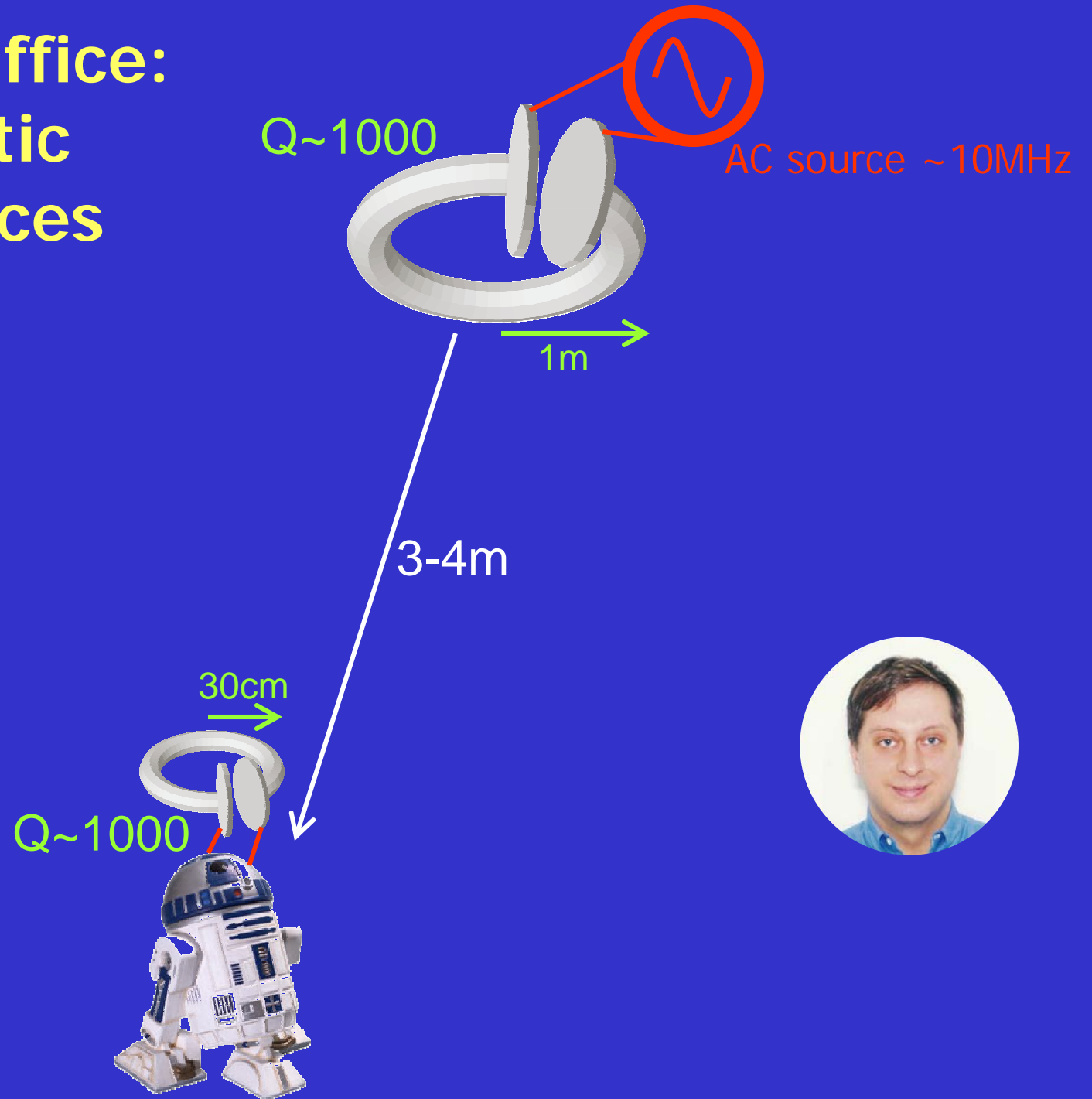


Maglev

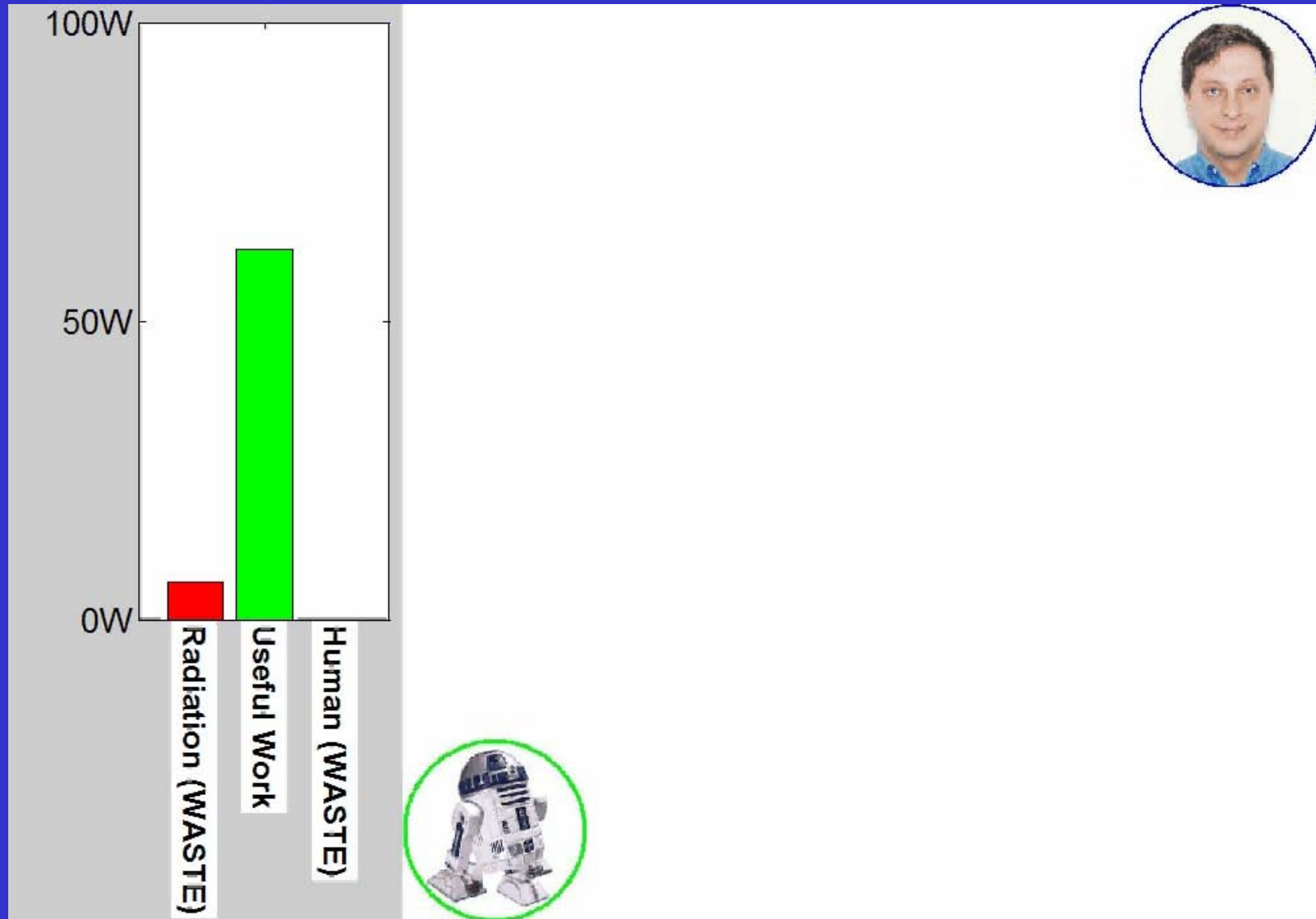


Magnetically levitating bed

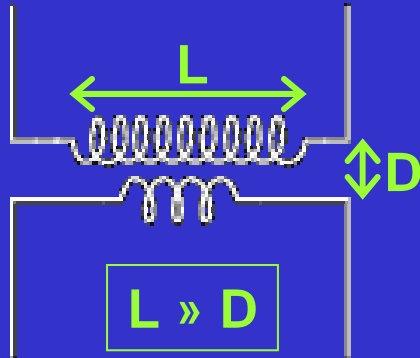
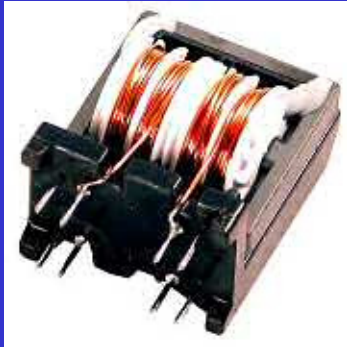
Robot & Office: magnetic resonances



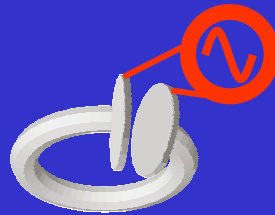
Robot & Office: magnetic resonances



Comparison with inductive coupling



$D \gg L$

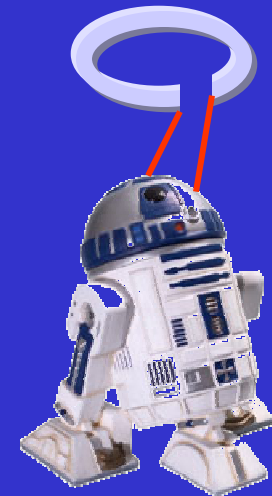


D



Efficiency $\equiv \eta_R$

Efficiency $\approx \eta_R/Q^2$
 $\sim \eta_R/1,000,000$



Some potential applications



Industrial, military, and household robots



Portable personal electronics



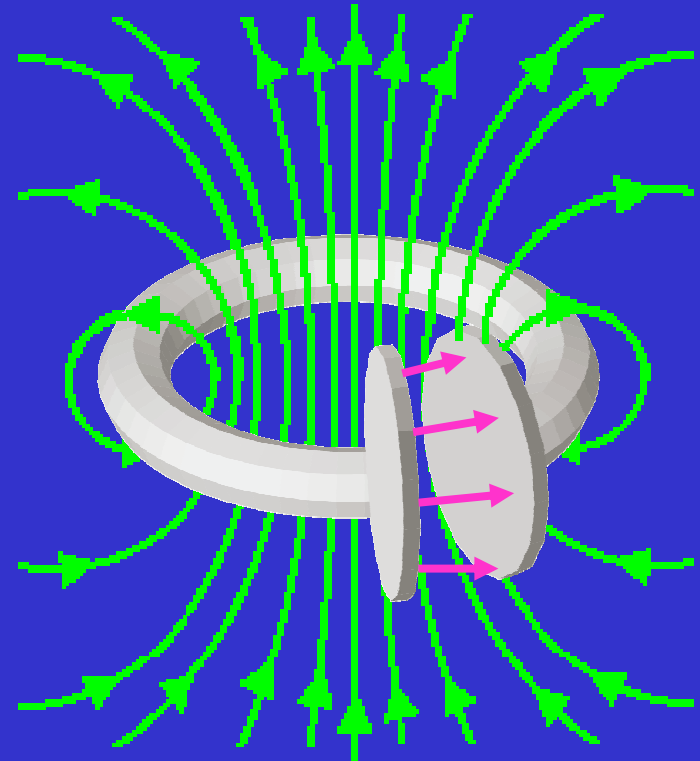
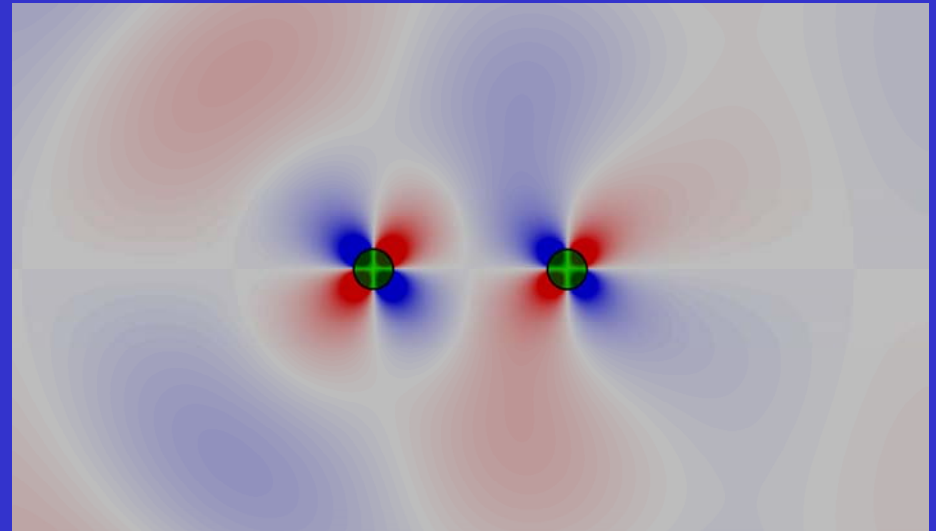
Electric vehicles

Other possible applications

- Confidential radio-communication
- Optical free-space interconnects for electronic logic circuits
- Energy supply for RFIDs and/or nano-robots

Conclusion

- mid-range *non-radiative* energy transfer scheme based on *resonances*
- even very simple designs have promising performance
- as a powerful concept, it could enable a wide range of applications



**Ok, but how come no one
thought of this before?**

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John Joannopoulos (MIT)

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Pre-print of this work:

<http://arxiv.org/abs/physics/0611063>