WiTricity: non-radiative wireless power transfer
OUTLINE:

- Background and motivation
- Resonant coupling as energy transfer
- Magnetically coupled resonators
- Experimental results
- Path forward
- Potential applications
Motivation

Tesla tower: cca. 1904
Wi-Fi (wireless internet) concept: radiation
Radiative energy transfer

Omni-directional radiation

Directed radiation
Resonant coupling as energy transfer
Resonances in quantum mechanics – nonradiative transfer

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

Schrödinger equation

\[ -c^2 \nabla^2 E = \omega^2 E \]

Maxwell equation

Hydrogen atom

quantum tunneling

proton
Electromagnetic resonances

Optical fiber

$\varepsilon = 147.70, \quad Q_R = 1992$

![Graph showing E field](image)
Example of resonant coupling

Diagram showing two green circles labeled 'Device' and 'Source' with a wave pattern connecting them.
Coupled mode theory

\[ \frac{da_s}{dt} = -i(\omega - i\Gamma) a_s + i\kappa_D \]

\[ \frac{da_D}{dt} = -i(\omega - i\Gamma) a_D + i\kappa_S \]

\[ Q = \frac{\omega}{2\Gamma} \]
"Strong Coupling":

\[ \frac{\kappa}{\Gamma} \gg 1 \]

\[ \Rightarrow \text{efficient energy transfer} \]
“Strong Coupling” \(\Rightarrow\) efficient transfer
Resonant coupling vs. distance

\[
\frac{\kappa}{\Gamma} \text{ vs. } \frac{\text{Distance}}{\text{Object Radius}}
\]

Source

Device

<table>
<thead>
<tr>
<th>Distance / Object Radius</th>
<th>6</th>
<th>8</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\kappa / \Gamma)</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
Aside: Paris Hilton connection

Aristeidis Karalis

Prof. J.D. Joannopoulos
Robot & Office: simulation

Source

Device (robot)
Robot & Office: *radiative* scheme
Robot & Office: non-radiative scheme
Robot & Office: *non-radiative* scheme
Magnetically coupled resonators
Magnetic resonances

Outside: $U_E \sim U_B$

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

$\Rightarrow$ weak interaction with B-field!
Examples of “magnetic technology”

Maglev

Magnetically levitating bed
Robot & Office: magnetic resonances

Q~1000

AC source ~10MHz

3-4m

30cm

1m
Robot & Office: *non-radiative* scheme
Comparison with inductive coupling

Efficiency $\equiv \eta_R$

$\eta \approx \eta_R / Q^2$

$\sim \eta_R / 1,000,000$
Experimental results
same thing, different viewing angle
Experimental proof of strongly-coupled regime
efficiency ~50%
source is behind board

25 cm radius copper coil

200 cm

another geometry
Path forward: physics part
Learning from atomic physics
An oscillating resonator radiates a bit

Much smaller than the wavelength: $\lambda_{\text{RES}} \approx 30 \text{ m}$
“Dicke effect” – atomic physics

two excited, same atoms

strong radiation

OR

NO radiation
Coupling of resonators

EVEN MODE

ODD MODE

Coupling \Rightarrow f_{\text{EVEN}} \neq f_{\text{ODD}}
Transmission vs. frequency (gedanken system)

Collaborators:
A.Karalis, R.Hamam, and J.D.Joannopoulos
Playing David Copperfield with energy
Direct transfer
Mediated transfer
Comparison: direct vs. mediated
Time-dependent coupling strength

Collaborators:
R. Hamam, A. Karalis, and J.D. Joannopoulos
Comparison: mediated vs. time-dependent

(1)                              (3)

(2)                              (4)

(1) is mediated, (2) is time-dependent. The graphs illustrate the energy distribution over time for different energy components.
Time-dependent coupling strength

"Dark" state:

\[
\mathbf{V}_1 = e^{-i\omega t - \Gamma_A t} \begin{pmatrix}
\frac{-\kappa_{23}}{\sqrt{(\kappa_{12})^2 + (\kappa_{23})^2}} \\
0 \\
\frac{\kappa_{12}}{\sqrt{(\kappa_{12})^2 + (\kappa_{23})^2}}
\end{pmatrix}
\]

\[
\frac{d}{dt} \begin{pmatrix}
a_1 \\
a_2 \\
a_3
\end{pmatrix} = \begin{pmatrix}
-(i\omega + \Gamma_A) & i\kappa_{12} & 0 \\
i\kappa_{12} & -(i\omega + \Gamma_B) & i\kappa_{23} \\
0 & i\kappa_{23} & -(i\omega + \Gamma_A)
\end{pmatrix} \begin{pmatrix}
a_1 \\
a_2 \\
a_3
\end{pmatrix}
\]
In atomic physics, this effect is known as STIRAP.

STIRAP: "Stimulated Raman Adiabatic Passage"
...also happens in "Electromagnetically Induced Transparency" (EIT)
Potential applications
Some potential applications

Industrial, military, and household robots

Portable personal electronics

Electric vehicles
Vision: less dependence on batteries
Other possible applications

- Implanted medical devices
- Power supply for MEMS or nano-robots
- Sensors with difficult access
- Electrically heated clothes
Conclusion

• mid-range non-radiative energy transfer scheme based on strongly-coupled resonances

• even very simple designs have promising performance

• as a powerful concept, it could enable a wide range of applications
Epilogue: what about Paris Hilton?

Press coverage of WiTricity

Wall Street Journal
New York Times
USA Today
BBC News: front page of news.bbc.co.uk *2
BBC World Service Radio *3
The Economist *2
Associated Press
NPR
...600 other newspapers, TVs, radio stations around the world

>2,000,000 hits for “WiTricity” on Google (~10th June 2007)
It’s electric!

MIT team claims wireless power demo

Breakthrough step

The truly new step, which is what was described in the paper in Science, was that the MIT team carried the concept out. The scientists were able to light up a 60-watt bulb that had "no physical connection" with the power-generating appliance.

The innovation is being called "WiTricity" by the scientists.

The concept of sending power wirelessly isn’t new, but its widespread use has been dismissed as inefficient because electromagnetic energy generated by the charging device would radiate in all directions.

It's similar to how an opera star can break a wine glass that happens to resonate at the same frequency as her voice.

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G8 leaders agree to climate deal

Germany's chancellor says the leaders of the G8 nations have agreed a compromise deal on climate change.

Putin offers joint missile shield

In pictures: G8 summit protests

Climate change: In graphics

Kenyan police shoot sect suspects

Moscow 'to cut migrant workers'

Kenyan police say they have shot and killed 12 more people during a crackdown on the banned Mungiki sect.

Moscow city authorities plan to reduce the number of migrants working in the Russian capital.
Ok, but how come no one thought of this before?

“We explore. What path to explore is important, as well as what we notice along the path.

And there are always unturned stones along even well-trod paths.

Discovery awaits those who spot and take the trouble to turn the stones.”

-- Charles H. Townes
Collaborators:

Robert Moffatt
Andre Kurs
Rafif Hamam
Dr. Aristeidis Karalis
Prof. Peter Fisher
Prof. John Joannopoulos

More info and reprints: www.mit.edu/~soljacic