Wireless Power Transfer to Moving Vehicles

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Resonant Inductive Power Transfer

In recent years there has been renewed interest in wireless power transfer. In particular, a recent experiment, conducted at MIT, has demonstrated that two high-Q resonances, with their magnetic fields strongly coupled in the near-field regime, allows highly efficient power transfer over a distance of approximately two meters.

Efficient transfer requires:
- Source and receiver in resonance
- Resonant mode of high quality factors
- Strong coupling rate

Complex EM environment (metallic car body).

Strong coupling rate due to absorption and radiation.

The dynamic equations for the system are:

\[ \begin{align*}
\dot{a}_1(t) &= (\omega_1 - \gamma_1) a_1(t) + i \omega_2 a_2(t) + \sqrt{\gamma_1} s_1(t) \\
\dot{a}_2(t) &= (\omega_2 - \gamma_2) a_2(t) + i \omega_1 a_1(t) \\
s_1(t) &= -s_{1-}(t) + \sqrt{\gamma_1} a_1(t) \\
s_{1-}(t) &= \sqrt{\gamma_2} a_2(t)
\end{align*} \]

The transfer efficiency is given by:

\[ \eta = \frac{\sqrt{\gamma_1} \sqrt{\gamma_2} \kappa}{|i(\omega - \omega_1) + (\gamma_1 + \gamma_2) i(\omega - \omega_2) + (\gamma_1 + \gamma_2) + \kappa|^2} \]

Simulation Results

Advantages:
- Increase driving range.
- No CO2 emission.
- Good isolation.

Challenges:
- Complex EM environment (metallic car body).
- High power (on the order of 10kW).
- Safety concerns (radiation, strong EM field exposure).
- Moving on an array of source resonators (tolerance of misalignment, economy).

Coupled Mode Theory Model

The mechanism for the wireless energy transfer can be described by the coupled mode theory:

\[ \begin{align*}
\dot{a}_1(t) &= (\omega_1 - \gamma_1) a_1(t) + i \omega_2 a_2(t) + \sqrt{\gamma_1} s_1(t) \\
\dot{a}_2(t) &= (\omega_2 - \gamma_2) a_2(t) + i \omega_1 a_1(t) \\
s_1(t) &= -s_{1-}(t) + \sqrt{\gamma_1} a_1(t) \\
s_{1-}(t) &= \sqrt{\gamma_2} a_2(t)
\end{align*} \]

Operation frequency \( f = 10 \text{MHz} \)

\[ \begin{align*}
\eta &= \text{transfer efficiency} \\
\Delta t &= \text{transfer time}
\end{align*} \]

Experiment Results

Maximum transfer efficiency vs distance:

System configuration

Maximum transfer efficiency

96% 46% 95%

Conclusion

We demonstrated numerically and experimentally that efficient wireless energy transfer can be achieved between two high Q resonators in a complex electromagnetic environment. In particular, in the close proximity of metallic planes, efficient wireless energy transfer can be achieved with proper system designs. The time scale of the energy transfer is in microseconds, which is much smaller than the moving time scale of a car. Static result can be applied to moving vehicles.

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