Charge Your Cell Phone in Your Pocket

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Wireless Charging

Today: zero distance & highly sensitive to orientation
A small increase of charging distance and a flexible orientation → Big gain in user experience
A small increase of charging distance and a flexible orientation → Big gain in user experience
MagMIMO

and obviously in your pocket.
How Does It Work?
Wireless Charging Primer
Wireless Charging Primer

Magnetic field generates a current in Rx → Power in Rx
Wireless Charging Primer

Magnetic field doesn’t cross Rx \(\rightarrow\) No Rx current
Wireless Charging Primer

Magnetic field doesn’t cross Rx  ➔  No Rx current

➔ Existing chargers fail with distance or orientation
Can We Borrow from Wireless Communications?

SNR too low → no signal!
Can We Borrow from Wireless Communications?

Rx

SNR too low \(\rightarrow\) no signal!

MIMO Tx
Can We Borrow from Wireless Communications?

Beamforming focuses the signal
Can We Borrow from Wireless Communications?
Can We Borrow from Wireless Communications?

Magnetic Beamforming
How Do We Beam-form the Magnetic Field?

Steer the beam with Rx
Derivation of Magnetic Beamforming
Derivation of Magnetic Beamforming

\[ y = (h_1 + h_2)x \]
Derivation of Magnetic Beamforming

\[ y = (h_1 + h_2) \times x \]

\[ I_{Rx} = C \times (M_1 + M_2) I_{Tx} \]
Derivation of Magnetic Beamforming

\[ y = (h_1 + h_2) \cdot x \]

\[ I_{Rx} = C \cdot (M_1 + M_2) \cdot I_{Tx} \]
Derivation of Magnetic Beamforming

\[ y = (h_1 + h_2) x \]

\[ I_{Rx} = C \cdot (M_1 + M_2) I_{Tx} \]

Channels \( \rightarrow \) Magnetic Coupling
Symbols \( \rightarrow \) Currents

Same Mathematical Framework
Beamforming
Beamforming

RF Beamforming
Beamforming

$$\alpha_i = \frac{h_i^*}{\sqrt{\sum |h_j|^2}}$$
Beamforming

RF Beamforming

$$\alpha_i = \frac{h_i^*}{\sqrt{\sum |h_j|^2}}$$

Magnetic Beamforming

$$\alpha_i = C' \frac{M_i^*}{\sqrt{\sum |M_j|^2}}$$

→ Shape the magnetic field in a beam
Are we done?

RF Beamforming

• Tx needs the channels, $h_i$, to compute $\alpha_i$
• Rx measures the channels and send them to Tx

Magnetic Beamforming

• Tx needs the magnetic coupling, $M_i$, to compute $\alpha_i$
• Rx is out of power \(\rightarrow\) Can’t measure and send the $M_i$

Magnetic Coupling can be measured locally at the transmitter
Performance
Implemented MagMIMO

- 6 Tx coils controlled by programmable logic, which applies the beamforming multipliers to Tx currents

- Experimented with iPhone 4S
## Compared Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Input Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Witricity Wit-2000M</td>
<td>24 [W]</td>
</tr>
<tr>
<td>Energizer Qi</td>
<td>22 [W]</td>
</tr>
<tr>
<td>Duracell</td>
<td>18 [W]</td>
</tr>
<tr>
<td>MagMIMO</td>
<td>20 [W]</td>
</tr>
</tbody>
</table>
MagMIMO supports much longer distances.

Charging Time vs. Distance

MagMIMO
Dealing with Phone Orientation

Phone Orientation (Degree)

Received Power (W)
Dealing with Phone Orientation

![Graph showing the relationship between received power and phone orientation for different brands and thicknesses.]

- **Energizer** (0.7cm)
- **WiTricity** (2cm)
- **Duracell** (0.4cm)

The graph plots received power (W) against phone orientation (Degree) for various phone orientations, demonstrating how power decreases as the phone orientation deviates from the optimal perpendicular position.
Dealing with Phone Orientation

![Graph showing the received power (W) vs. phone orientation (Degree) for different phone brands: Energizer (0.7cm), WiTricity (2cm), and Duracell (0.4cm). The graph illustrates how power decreases as the orientation deviates from the vertical.
Dealing with Phone Orientation

Received Power (W) vs. Phone Orientation (Degree)

- MagMIMO (2cm)
- Energizer (0.7cm)
- WiTricity (2cm)
- Duracell (0.4cm)
Dealing with Phone Orientation

- MagMIMO (2cm)
- Energizer (0.7cm)
- WiTricity (2cm)
- Duracell (0.4cm)
- MagMIMO (40cm)
Conclusion

• MagMIMO charges your phone in your pocket
Conclusion

- MagMIMO charges your phone in your pocket
- Even more critical for wearables