Magnetic Resonance and Magnetic Induction

What is the best choice for my application?

Architects of wireless power transfer systems face a couple of choices in the configurations of coils and the magnetic transfer technique. The best choice depends on the application:

Choice 1: Loose coupling or tight coupling between the Tx and Rx coils?

Inductive power transfer works by creating an alternating magnetic field (flux) in a transmitter coil and converting that flux into an electrical current in the receiver coil. Depending on the distance between the transmit and receive coils, only a fraction of the magnetic flux generated by the transmitter coil penetrates the receiver coil and contributes to the power transmission. The more flux reaches the receiver, the better the coils are coupled.

A higher coupling factor improves the transfer efficiency, and reduces losses and heating. Applications with a larger distance between the transmit and receive coils operate, by definition, as a loosely coupled system. In loosely coupled systems, only a fraction of the transmitted flux is captured in the receiver. That means that loosely coupled systems have higher electromagnetic emissions, making them less suitable for applications with tight EMI or EMF requirements.

Loosely coupled systems trade-off larger distance at the cost of lower power transfer efficiency and higher electromagnetic emissions. This may be suitable choice in applications where tightly aligned coils is impractical, but less suitable for applications with tight EMI or EMF of efficiency requirements.

Tightly coupled systems, because of their higher efficiency, tend to produce less heat which is an advantage in products with tight thermal budgets such as modern smartphones.

For the definition of coupling factor see: http://www.wirelesspowerconsortium.com/technology/coupling-factor.html

The transmit and receive coils are tightly coupled when (a) the coils have the same size, and (b) the distance between the coils is much less than the diameter of the coils.
Loosely coupled coils or operate with significantly different coil sizes,

\[\text{receiver coil diameter } D_2 \]
\[\text{transmitter coil diameter } D_1 \]

or operate at larger distance.

\[\text{coil diameter } D \]
\[\text{coil distance } Z \]

loosely coupled coils: \( D \) similar to \( Z \)
Choice 2: Operate the coils at resonance or off-resonance?

From the beginning of inductive power transmission, resonant circuits have been used to enhance the efficiency of power transmission. As early as 1891, Nicola Tesla used resonance techniques in his first experiments with inductive power transmission. Systems with a low coupling factor generally use a resonant receiver and resonant transmitter to improve power transfer efficiency.

For technical details see: http://www.wirelesspowerconsortium.com/technology/resonant-coupling.html

You might expect that operating tightly coupled coils at resonance offers the best performance. That combination, however, is not used in practice because two tightly coupled coils cannot be both in resonance at the same time. This is one of the counter-intuitive effects that make power electronics such an interesting subject.

Most Qi transmitters use tight coupling between coils. In that configuration, the best results are achieved by operating the transmitter at a frequency that is slightly different from the resonance frequency of the Qi receiver. Off-resonance operation gets you the highest amount of power at the best efficiency.

Choice 3: Single coil or multi-coil?

Tightly coupled coils are sensitive to misalignment. That’s why most Qi transmitters use multiple coils. This increases the complexity of the transmitter design, but improves the horizontal (X, Y) freedom of positioning. Coil arrays can cover large areas. See, for example, ConvenientPower’s WoW5 transmitter.

Another advantage of multi-coil systems is that they help localize the magnetic flux, reducing EM emissions, and make it possible to charge multiple receivers concurrently.
Here are some examples of transmitters that use overlapping coils

Coils don’t need to overlap either. Solutions with non-overlapping coils can be easier to assemble.

Multi-coil transmitters can charge several receivers at the same time, simply by powering the coils underneath the receiver.

Multi-coil transmitters also allow the wireless power ecosystem to scale with increasing power levels that devices demand, by powering multiple coils underneath the receiver. The first smart phones needed 3W, todays require over 7.5W and growing. We also now have tablets, ebooks readers, ultrabooks which need from 10-30W. Multi-coil systems transmit the power exactly where it is needed in a safe, efficient and controlled manner guaranteeing scalability as devices get more and more power hungry.
A loosely coupled system can achieve multi-device charging with a single transmitter coil, provided it is much larger than the receiver coils and the provided the receivers can tune themselves independently to the frequency of the single transmitter coil.

The table below provides a summary of the possible transmitter configurations:

<table>
<thead>
<tr>
<th>Transmitter Architecture</th>
<th>example product</th>
<th>Efficiency</th>
<th>Horizontal (X-Y) freedom</th>
<th>Vertical (Z) freedom</th>
<th>EMI/EMF</th>
<th>Multi-device charging</th>
</tr>
</thead>
<tbody>
<tr>
<td>single coil, tightly coupled, non-resonant multi-coil</td>
<td>Qi A1 type, Powermat</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Most Qi transmitters</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>single coil, loosely coupled, resonant multi-coil</td>
<td>A4WP prototypes, Qi resonant prototypes</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>multi-coil, loosely coupled, resonant</td>
<td>Qi resonant prototypes</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

As you can see, there is no optimum design. The choice of architecture will depend on the application requirements. Is efficiency important? Is EMI (electromagnetic interference) a concern? Do you need a large Z distance? Is cost the key issue? Depending on your priorities, the optimum will be different.

**Qi gives you the possibility to choose what is best for your application**

All Qi receivers have a well-defined resonance frequency and can operate at resonance. The Qi transmitter products that are in the market today operate off-resonance, with tight coupling, because that combination provides both high power transfer and high efficiency. Most Qi transmitter products use multiple coils because they provide a better user experience.

At the Consumer Electronics Show in January, and at Mobile World Congress in February, you could see the first Qi transmitter products that operate at larger distance, loosely coupled, and at resonance. These resonant Qi transmitters are compatible with all Qi phones out there today. Otherwise we would not call it a Qi transmitter: If you see the Qi logo, you can be sure that the product is compatible with all other Qi products.
The Alliance for Wireless Power offers only one choice: “single coil, loosely coupled, resonant”. That configuration is not optimal for all applications. The WPC believes that product developers need more options to choose from. The solution “single coil, loosely coupled, resonant” is just one of the options offered by the Wireless Power Consortium.

The solution offered by the A4WP is not compatible with the millions of Qi phones and tablets that are already in the market. The WPC has demonstrated that it is possible to make loosely coupled resonant transmitters that are compatible with all these of Qi phones and tablets. There is no technical justification for incompatibility.