CHAPTER 1:
Overview of Wireless Power Transfer

What is Wireless Power Transfer?

The transfer of electrical energy without using conductors as the transport medium

Examples of wireless power media:
- Electric fields
- Photons
- Magnetic fields

What is Wireless Power Transfer?

Energy can be transferred in many ways to yield a desired result. Cooking food is a good example of wireless power transfer in which an electric stove is used to heat food, but it is not very useful when trying to power portable electronic devices. To provide useful electrical energy for portable devices, without using electrical conductors, several media such as photons, electric fields, or magnetic fields can be used.

Each of these media has advantages and disadvantages. Photons are not efficient at transferring energy where the best-in-class may ultimately achieve only 40% – 50% when lasers are used [1.1], but typically fall around 10% [1.2]. Electric fields can be transmitted over a good distance, but can lead to high electrical potentials with associated risk of electrical shock. Magnetic fields offer a safer alternative, but yield shorter distances between the source and device due to their inherent loop characteristic (This characteristic is mathematically referred to as curl).

Considering the scenario where wireless power transfer is desired, most devices that need to receive power will be placed on a wireless power surface, which means there is some control over the distance between the source and the devices. And, the distance will not be excessive. Based on these comparative factors – electrical transfer, safety, and distance – the logical choice of a wireless power medium is the magnetic field.

[1.1] J-G. Werthen and M. Cohen, "The Power of Light: Photonic Power Innovations in Medical, Energy and Wireless Applications," *Photonics Spectra Magazine*, May 2006.

[1.2] A. Polman and H. A. Atwater, "Photonic design principles for ultrahigh-efficiency photovoltaics," *Nature Materials*, Vol. 11, March 2012, pp. 174–177.

Why Wireless Energy?

Mobile device charging

- Convenience of use
- Extended usable battery life

Medical implants

- Quality of life improvement
- Reduces risk of infection

Hazardous environments

- Explosive atmosphere
- Corrosive locations
- High voltage

Why Wireless Energy?

With the explosion of the variety and number of mobile devices, wireless power transfer offers convenience of charging batteries without the annoyance of cumbersome cables, and the inconvenience of "plugging in." Additionally, wireless power could potentially extend the working life of the battery by providing untethered power on demand.

Another end-use of wireless power transfer can be found in medical applications, particularly medical implants. These rapidly emerging applications can result in major quality of life improvements and have significant life-extending implications. Imagine not having invasive wires penetrating the skin to power artificial heart pumps, but rather being able to power the pump from a remote energy source as you sit in a chair, walk around, or lie in bed.

Wireless power transfer can also be used in safety-critical environments such as explosive or corrosive atmospheres (an electrical spark in the vicinity of a gas pump comes to mind), underwater, or any location where there is a safety risk when an electrical connection is made or broken with a corresponding spark.

Characteristics of a Magnetic Field

Magnetic fields:

+ Considered safe
+ Well understood – easy to generate and capture
– Have limited efficient transmission distance – depends upon transmitter and receiver diameters

Characteristics of a Magnetic Field

Having justified the practical need for wireless power transfer and the use of magnetic fields as the transfer medium, next we need to understand the relevant characteristics of magnetic fields. First, and most importantly, magnetic fields are considered safe for use even at the frequencies targeted for wireless power transfer [1.3]. Specific absorption rate (SAR) guidelines provide the required field density limits to ensure human safety when exposed to magnetic fields and are governed by well-researched standards [1.4-1.6].

Secondly, among electrical engineers, magnetic fields are well understood, making them easy to generate and capture.

Lastly, magnetic fields do not transfer energy well over long distances, which is primarily due to their divergent characteristics over distance. This makes it difficult to capture enough magnetic flux the further from the source the receiver is placed. This limitation is not severe, given that most wireless power transfer applications require relatively short distances (e.g., less than 18 inches).

[1.3] J. Nadakuduti, L. Lu, P. Guckian, "Operating Frequency Selection for Loosely Coupled Wireless Power Transfer Systems with Respect to RF Emissions and RF Exposure Requirements," *IEEE Wireless Power Transfer Conference*, May 15–16, 2013 Perugia, Italy, pp 234–237.

[1.4] *Class B–Human Exposure Limits*, FCC Part 1.1310.

[1.5] *Human Exposure Limits* – Recommendation 1999/519/EC.

[1.6] *Human Exposure Limits* – ICNIRP 2010.

Challenges to Wireless Power Transfer

High efficiency – limited power dissipation budget

Low profile – needed for the mobile market

Robust to dynamic operating conditions

Defined response to foreign metal objects

Compliance to regulatory standards

Challenges to Wireless Power Transfer

The implementation of a wireless power transfer system poses many challenges to power system designers. Some of the challenges are market-driven, while others are related to the practicality of the system. Today the mobile gadget market is driving the development of wireless power transfer, thus setting many of its requirements and challenges.

These requirements include high efficiency, particularly for the receiving devices due to limited power dissipation budgets, low physical profile, and robustness to all operating conditions. The need for robustness stems from the convenience-of-use factor that wireless power transfer offers – users do not want to be burdened with rules on device placement, limitations on the number of devices that can be powered at one time, and the size of the devices to be powered. Add to these requirements the need for systems to anticipate adverse operating conditions, such as the introduction of foreign objects that can drastically affect the operation and performance of wireless power transfer systems.

Lastly, these systems need to conform to EMI emissions standards such as FCC part 18 [1.7], and the equivalent EN standards such as EN 55011 [1.8] and EMC directive (2004/108/EC) [1.9].

[1.7] *FCC Code of Federal Regulations Title 47*, Vol. 1, Part 18 B (Industrial, Scientific, and Medical Equipment), 1998.
[1.8] European Norm. EN55011 Group 2 Class B.
[1.9] *Electromagnetic Compatibility (EMC)*, European Directive (2004/108/EC).

Wireless Power Transfer Standards Overview

Standard	rezence Alliance For Wireless Power	qi WIRELESS POWER CONSORTIUM	pma Power Matters Alliance
Frequency	6.78 MHz	~ 100 - 205 kHz	~ 201 - 315 kHz
Power	6.5 W*	5 W	5 W
Coupling	Loose < 50 mm Resonance	Tight < 5 mm Inductive	Tight < 5 mm Inductive
Communications	Bluetooth	In-Band	In-Band

* Closest device match

Wireless Power Transfer Standards Overview

Most of the older wireless power solutions focused on tight coupling, with induction coil solutions operating at relatively low frequencies from 100 kHz through 315 kHz. This is the basis of the Qi (Wireless Power Consortium) and Power Matters Alliance (PMA) standards.

The Alliance for Wireless Power (A4WP) standard, called Rezence [1.10], makes use of high-frequency (6.78 MHz) operation that allows resonance to be used to enhance the generation and transmission of magnetic fields for wireless power transmission [1.11, 1.12]. This use of high-frequency operation is the basis for the loosely-coupled, highly-resonant approach to wireless power transfer. There are many advantages to this approach that will become apparent as we delve more into the subject.

In all formats, power management and control between the source and device (that is, transmitter and receiver) is established using digital communications. In the case of the Wireless Power Consortium (WPC) Qi standard and the Power Matters Alliance (PMA) standards, the digital information is encoded on the power carrier. Whereas, in the Rezence standard, use is made of the Bluetooth standard, making it a more universal solution than the tightly-coupled, lower-frequency Qi standard.

[1.10] R. Tseng, B. von Novak, S. Shevde and K. A. Grajski, "Introduction to the Alliance for Wireless Power Loosely-Coupled Wireless Power Transfer System Specification Version 1.0," *IEEE Wireless Power Transfer Conference 2013, Technologies, Systems and Applications*, May 15–16, 2013.

[1.11] A. Karalis, J.D. Joannopoulos, M. Soljačić, "Efficient wireless non-radiative mid-range energy transfer," *Annals of Physics*, Vol. 323, No. 1, 2008, pp. 34–48.

[1.12] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, M. Soljačić, "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," *Science*, Vol. 317 No. 6, July 2007, pp. 83–86.

Criteria for the Selection of a Wireless Power Transfer Standard

What markets, less than 50 W, can the standard target?

- Mobile communications
- Computing
- Low-power medical

Does the standard address the “convenience factor” for the user?

- Only A4WP standard addresses this factor

Criteria for the Selection of a Wireless Power Transfer Standard

The choice of a wireless standard for the design of a specific power transfer system needs to consider many factors, with the power level and target applications being typically the two dominant factors. In the case of medical and mobile computing applications, key additional factors are safety and convenience of use.

The Qi and PMA standards have drawbacks, such as the need for precise placement of the device on the source, as well as the ability of the source to drive only one device at a time. Whereas, the Rezence standard uses magnetic resonance which makes it possible to have a single source capable of delivering power to multiple devices simultaneously, regardless of the orientation of the receiving devices. In addition, using resonance allows the system to deliver higher power than the inductive-based standards.

Wireless Power Transfer Selection

A4WP (Rezence®) was selected as the standard to be used because it is:

- Highly resonant – improves transmission of energy
- Allows loose coupling between source and device – addresses the convenience factor for the user
- Operates using unlicensed ISM band frequency of 6.78 MHz

Wireless Power Transfer Selection

Having compared various wireless power standards, the decision was made to adopt the A4WP Rezence standard as the primary subject of this handbook. This standard is characterized by being highly resonant, allowing loose coupling between the source and the device. Further, the A4WP standard operates in the open industrial, scientific and medical (ISM) frequency band at 6.78 MHz [1.13]. Operation at this frequency will require careful selection of an amplifier and deliberate consideration for other design choices to ensure high efficiency. Evaluating these wireless power transfer systems' design issues is the focus of this work.

[1.13] "ISM band." *Wikipedia: The Free Encyclopedia*. Wikimedia Foundation, Inc. January 2014. [Online] Available: http://en.wikipedia.org/wiki/ISM_band