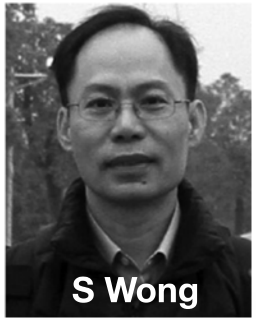
Part I: Overview

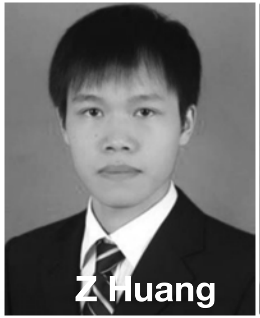
C K MICHAEL TSE
Department of Electrical Engineering
City University of Hong Kong
http://www.ee.cityu.edu.hk/~chitse

ACKNOWLEDGMENT

鳴謝

This set of slides has been rewritten, modified, and extended, based on an early set of material prepared by Dr S C Wong of HK Polytechnic University and Prof Qianhong Chen of Nanjing University of Aeronautics and Astronautics. My sincere gratitude is also due to Dr Xiaohui Qu, a former PhD student and now associate professor at Southeast University. Efforts of my former and current students and RAs, including Dr Wei Zhang, Dr Zhicong Huang and Dr Jia Hou, are gratefully acknowledged.





WIRELESS POWER TRANSFER

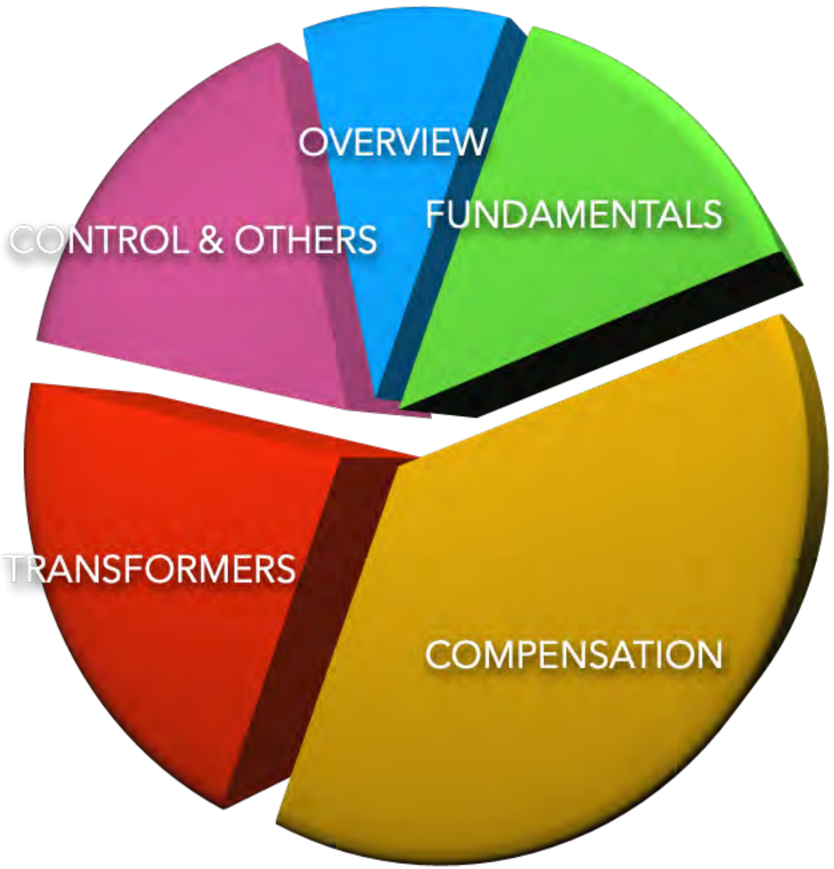
TAI CHI FANTASY

https://www.youtube.com/watch?v=EnbW7-uEJLs 警告： 純粹江湖賣藝 請勿信以為真

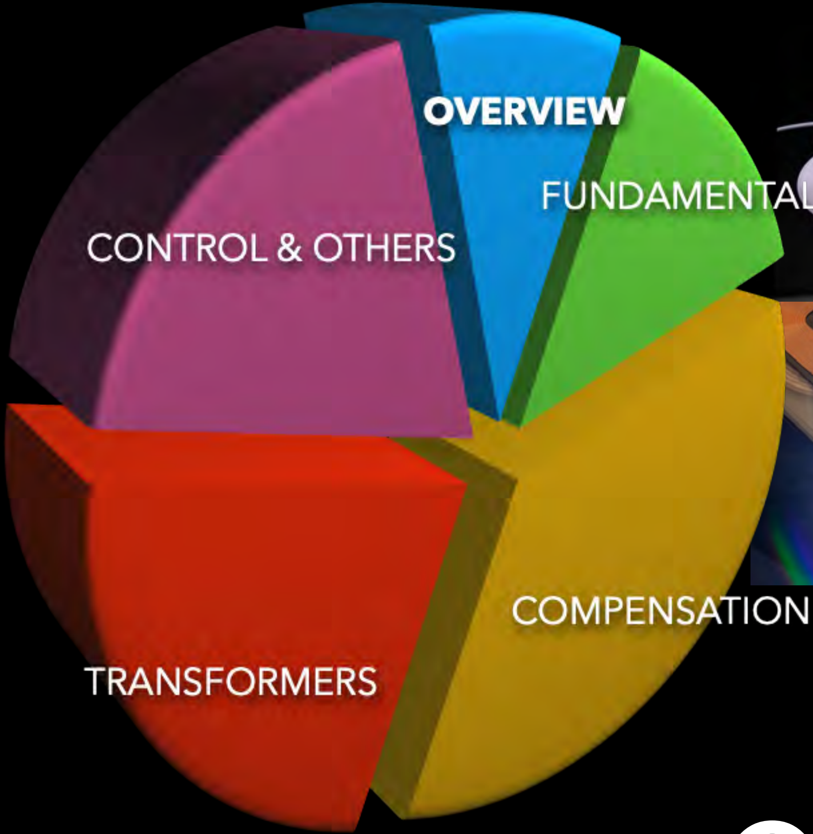
WIRELESS POWER TRANSFER

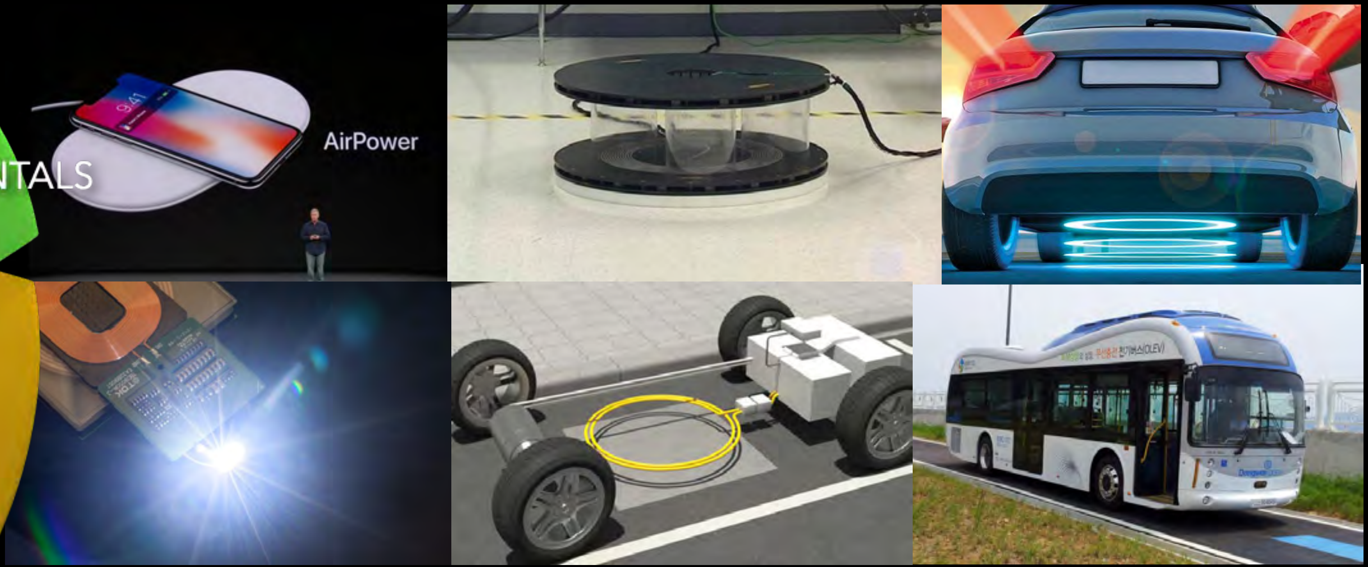
KUNG FU FANTANSY FILM “Buddha's Palm” 如來神掌，FEBRUARY 1964

CONTENTS



OVERVIEW
FUNDAMENTALS
CONTROL & OTHERS
TRANSFORMERS
COMPENSATION





PART I

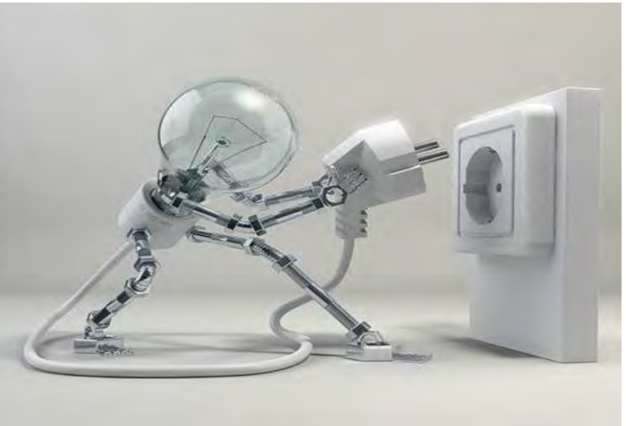
OVERVIEW

Electric Power Transfer

Very important process

Key design objectives:

- Convenient
- Safe
- Efficient



Conventional methods:

- Metal direct contacts
- Sockets
- Sliding contacts (commutations) for moving systems

Disadvantages

🙁 Metal contacts required

🙁 Possible sparks

🙁 Poses safety issues in certain environments, like premises with flammable gases, oil extraction plants, etc.

Electric Power Transfer

conventional contact type
Hong Kong trams (since 1904)

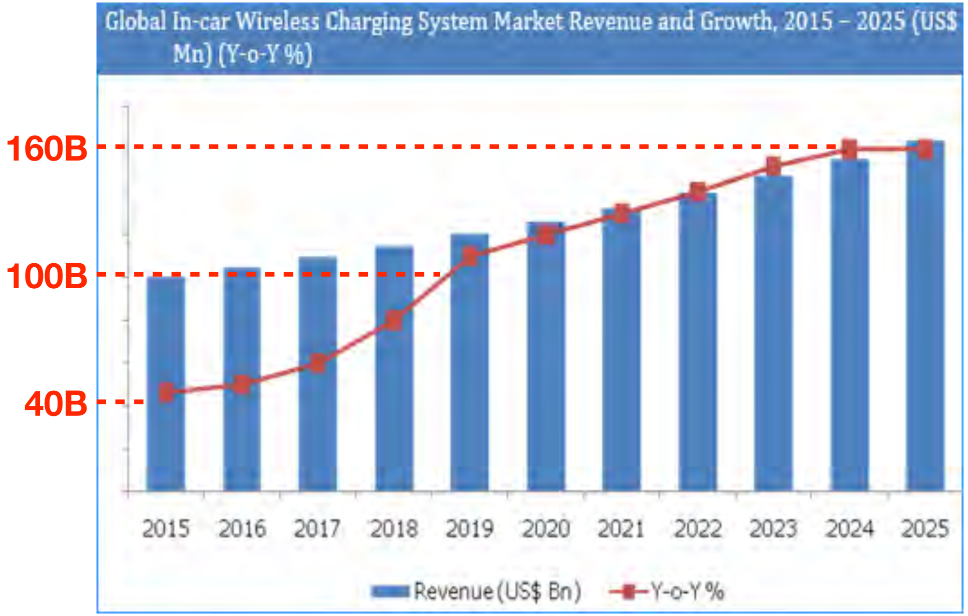
in-motion electric vehicle wireless power transfer

Advantages to go wireless

無線功率轉換的優點

- **Convenient to use:** contactless, not restrained by a wire, allowing mobility of the device powered
- **Safe to use:** no hazard of sparks or electric shocks due to contacts with high potential points
- **Readily used in adverse conditions:** good for hostile environments (presence of flammable gases) and bad weather (heavy rain) due to absence of metal contacts
- **Low maintenance cost:** free from dust and contact wearing
- **Easy to power movable devices:** moving objects can be powered without contacts

Market



The Global Wireless Charging Market is poised to grow at a ***compound annual growth rate*** (CAGR) of around 56.0% Over the next decade to reach approximately $160.2 billion by 2025.

Research and Markets, Nov 2017

https://globenewswire.com/news-release/2017/11/29/1210545/0/en/Global-In-car-Wireless-Charging-Market-2017-2025-Growth-Trends-Key-Players-Competitive-Strategies-and-Forecasts.html

First RPEV 1894

1894

Road

Powered

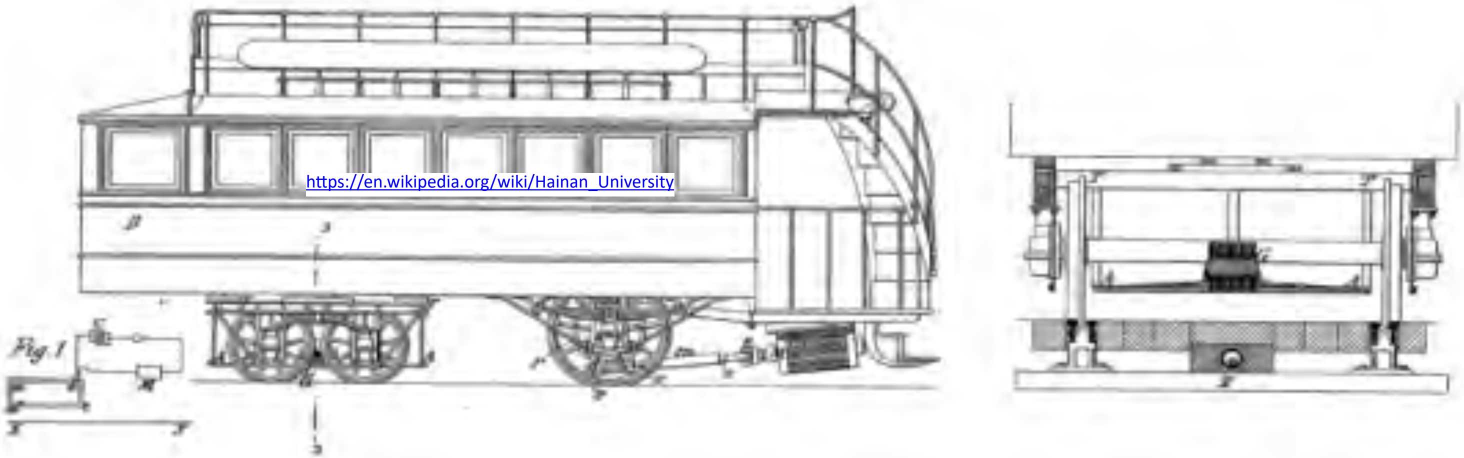
Electric

Vehicle

French Patent

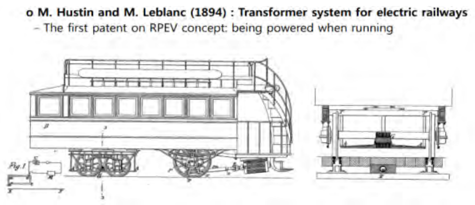
o M. Hustin and M. Leblanc (1894) : Transformer system for electric railways

- The first patent on RPEV concept: being powered when running



The first IPT design with high power pick-up coils patented, but was not implemented!

Timeline



FARADAY: Induction

1831

1891

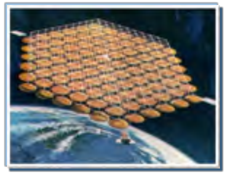
Tesla coil lighted up a gas lamp miles away

1894

First wireless powered train patented

1964, 1968

W.C. Brown Si rectenna power laser microwave transfer



1978

H. J. G. Bolger, F. A. Kirsten and L.S. Ng, "Inductive power coupling for an electric highway system," Vehicular Technology Conference, Vol. 28, pp.137-144, March 1978

1980s

1987– SHARP microwave-powered aircraft

1989-1996 PATH (transportation project) USA

1990s

University of Auckland launched first WPT charger for EVs

2007

Marin Soljacic of MIT lighted up a 60W bulb at 2 m distance

2008

WPC established

Wireless charging began commercial development from 2010

2010

WPC announced the Qi standard

2013

Society of Automotive Engineers (SAE) announced WPT charging standard "J2954" for power and frequency

2014

IEC61580 EV charging standard

2015

A4WP and PMA, 2 of the 3 consortia, merged

YEAR

RECENT KEY CONTRIBUTORS

Auckland Univ.
Michigan Dearborn, USA
Utah Univ., USA
Oak Ridge National Lab, USA
GIST, Korea
Hong Kong Univ.
Hong Kong Polytech. Univ.
Waseda Univ., Japan
Kyoto Univ., Japan
Sojo Univ., Japan
Nat. Yokohama Univ., Japan
Univ. Zaragoza, Spain
NTUST, Taiwan
NUAA, China
Southeast Univ., China
Harbin IT, China
SCUT, China
HUST, China
Tianjin UT, China
Zhejiang Univ., China

Surveyed by Qianhong Chen, NUAA, China

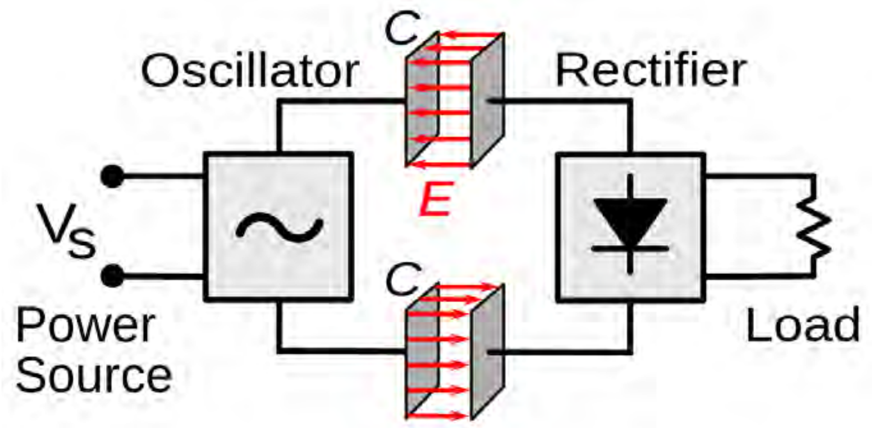
Types of WPT

Inductive coupling

Magnetic coupling
Low frequency
Short distance

MIT Resonant type
High frequency
Longer distance

Capacitive coupling



Others

- Laser
- Microwave
  Long distance

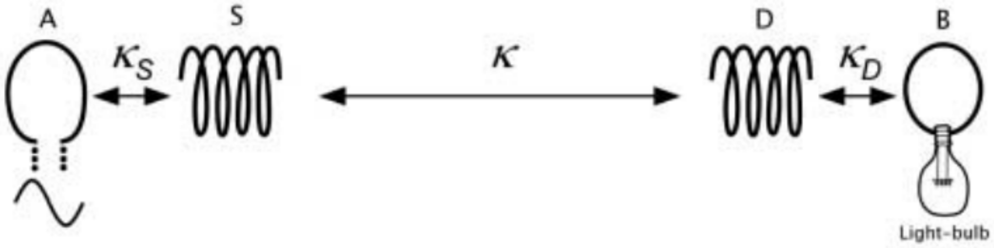
MIT Demo 2007

Wireless Power Transfer via Strongly Coupled Magnetic Resonances

André Kurs,[1]* Aristeidis Karalis,[2] Robert Moffatt,[1] J. D. Joannopoulos,[1] Peter Fisher,[3] Marin Soljačić[1]

Using self-resonant coils in a strongly coupled regime, we experimentally demonstrated efficient nonradiative power transfer over distances up to 8 times the radius of the coils. We were able to transfer 60 watts with ~40% efficiency over distances in excess of 2 meters. We present a quantitative model describing the power transfer, which matches the experimental results to within 5%. We discuss the practical applicability of this system and suggest directions for further study.

Two copper helices, with diameters of 60 centimeters, are separated from each other by a distance of about two meters. One is connected to a power source–effectively plugged into a wall–and the other is connected to a lightbulb waiting to be turned on. When the power from the wall is turned on, electricity from the first metal coil creates a magnetic field around that coil. The coil attached to the lightbulb picks up the magnetic field, which in turn creates a current within the second coil, turning on the bulb.



Resonant Power Transfer

Advanced devices

Improved understanding of electrical circuits

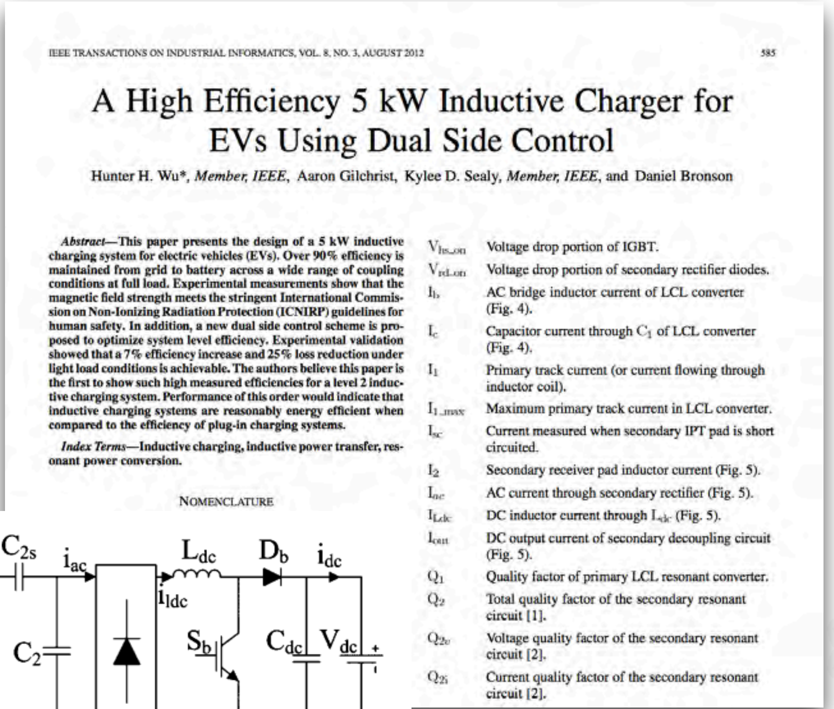
High-efficiency power converters

MIT demo : efficiency = 45% at 2 m distance

A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. Soljačić, "Wireless Power Transfer via Strongly Coupled Magnetic Resonances," Science, vol. 317:83~86, July, 2007.

With Power Electronics 2010–

Hunter H. Wu, Aaron Gilchrist, Ky Sealy, and Daniel Bronson, "A High Efficiency 5kW Inductive Charger for EVs using Dual Side Control." IEEE Trans. Industrial Informatics, vol. 8, no. 3, pp. 585-95. August 2012.



IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, VOL. 8, NO. 3, AUGUST 2012 585

A High Efficiency 5 kW Inductive Charger for EVs Using Dual Side Control

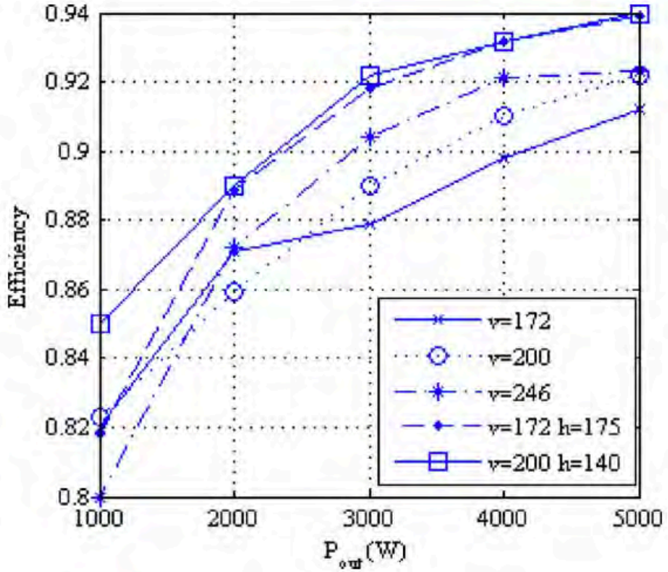
Hunter H. Wu*, *Member, IEEE*, Aaron Gilchrist, Kylee D. Sealy, *Member, IEEE*, and Daniel Bronson

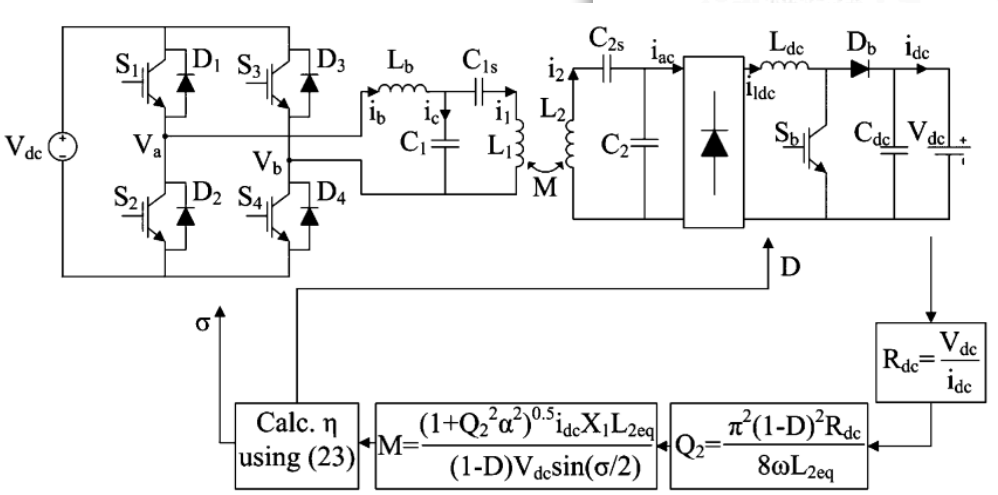
Abstract—**This paper presents the design of a 5 kW inductive charging system for electric vehicles (EVs). Over 90% efficiency is maintained from grid to battery across a wide range of coupling conditions at full load. Experimental measurements show that the magnetic field strength meets the stringent International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines for human safety. In addition, a new dual side control scheme is proposed to optimize system level efficiency. Experimental validation showed that a 7% efficiency increase and 25% loss reduction under light load conditions is achievable. The authors believe this paper is the first to show such high measured efficiencies for a level 2 inductive charging system. Performance of this order would indicate that inductive charging systems are reasonably energy efficient when compared to the efficiency of plug-in charging systems.**

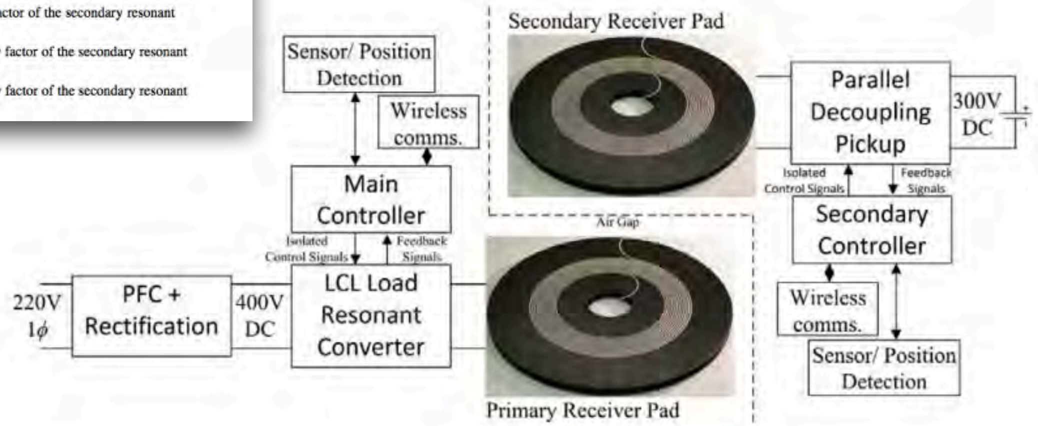
Index Terms—**Inductive charging, inductive power transfer, resonant power conversion.**

NOMENCLATURE

- V_{hs_on} Voltage drop portion of IGBT.
- V_{rd_on} Voltage drop portion of secondary rectifier diodes.
- I_b AC bridge inductor current of LCL converter (Fig. 4).
- I_c Capacitor current through C_1 of LCL converter (Fig. 4).
- I_1 Primary track current (or current flowing through inductor coil).
- I_{1_max} Maximum primary track current in LCL converter.
- I_{sc} Current measured when secondary IPT pad is short circuited.
- I_2 Secondary receiver pad inductor current (Fig. 5).
- I_{ac} AC current through secondary rectifier (Fig. 5).
- I_{Ldc} DC inductor current through L_{dc} (Fig. 5).
- I_{out} DC output current of secondary decoupling circuit (Fig. 5).
- Q_1 Quality factor of primary LCL resonant converter.
- Q_2 Total quality factor of the secondary resonant circuit [1].
- Q_{2v} Voltage quality factor of the secondary resonant circuit [2].
- Q_{2i} Current quality factor of the secondary resonant circuit [2].

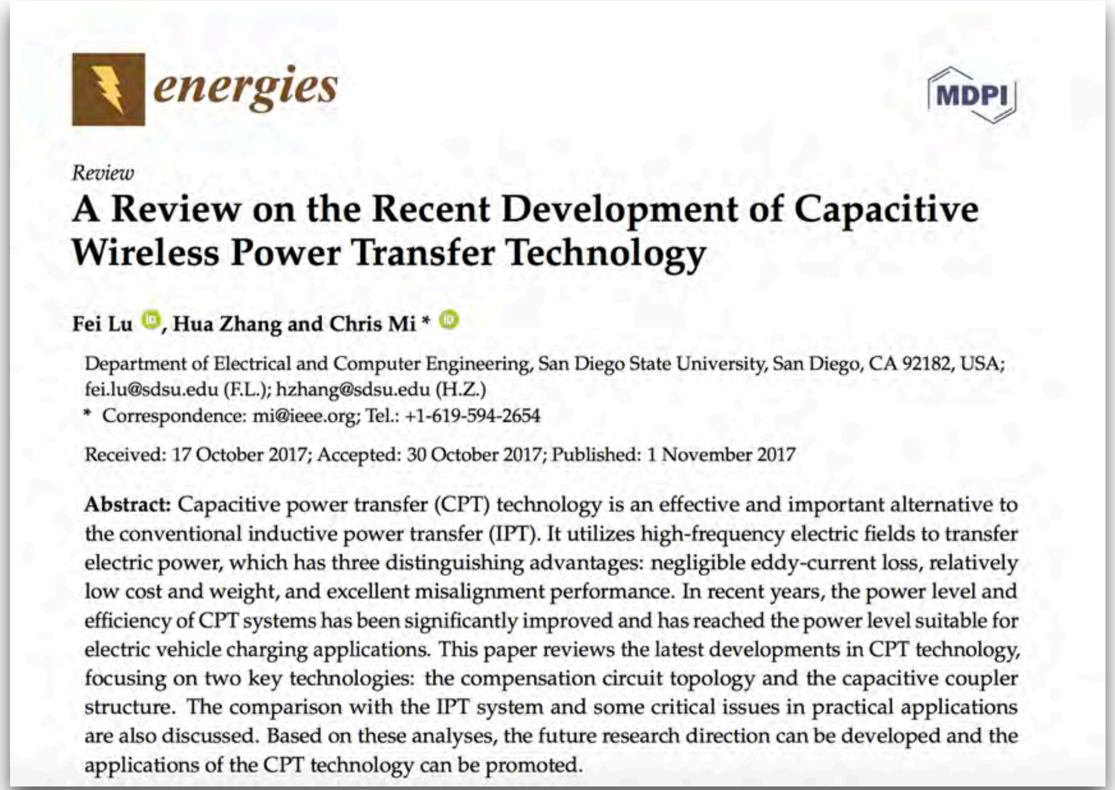






Capacitive Power Transfer

Fei Lu, Hua Zhang and Chris Mi, "A Review on the Recent Development of Capacitive Wireless Power Technologies," *Energies*, vol. 10, pp. 1752–1-30, November 2017.


energies

MDPI

Review

A Review on the Recent Development of Capacitive Wireless Power Transfer Technology

Fei Lu, Hua Zhang and Chris Mi *

Department of Electrical and Computer Engineering, San Diego State University, San Diego, CA 92182, USA; fei.lu@sdsu.edu (F.L.); hzhang@sdsu.edu (H.Z.)

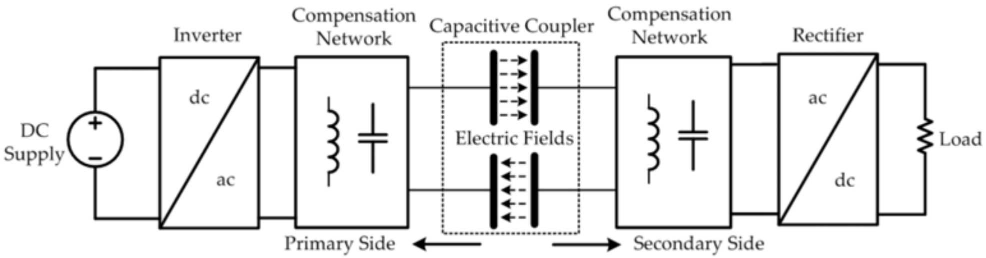
* Correspondence: mi@ieee.org; Tel.: +1-619-594-2654

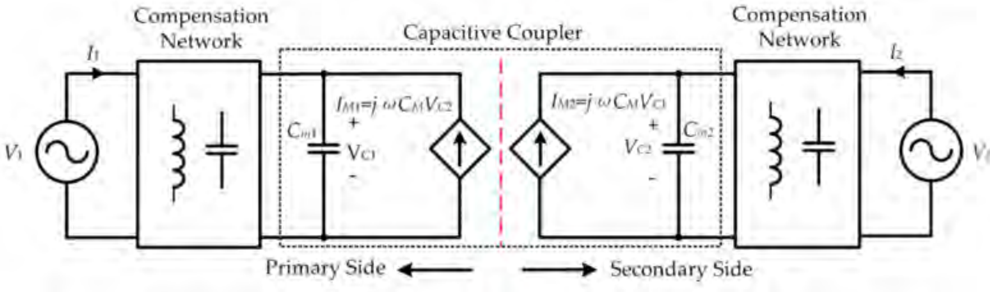
Received: 17 October 2017; Accepted: 30 October 2017; Published: 1 November 2017

Abstract: Capacitive power transfer (CPT) technology is an effective and important alternative to the conventional inductive power transfer (IPT). It utilizes high-frequency electric fields to transfer electric power, which has three distinguishing advantages: negligible eddy-current loss, relatively low cost and weight, and excellent misalignment performance. In recent years, the power level and efficiency of CPT systems has been significantly improved and has reached the power level suitable for electric vehicle charging applications. This paper reviews the latest developments in CPT technology, focusing on two key technologies: the compensation circuit topology and the capacitive coupler structure. The comparison with the IPT system and some critical issues in practical applications are also discussed. Based on these analyses, the future research direction can be developed and the applications of the CPT technology can be promoted.

Advantages:

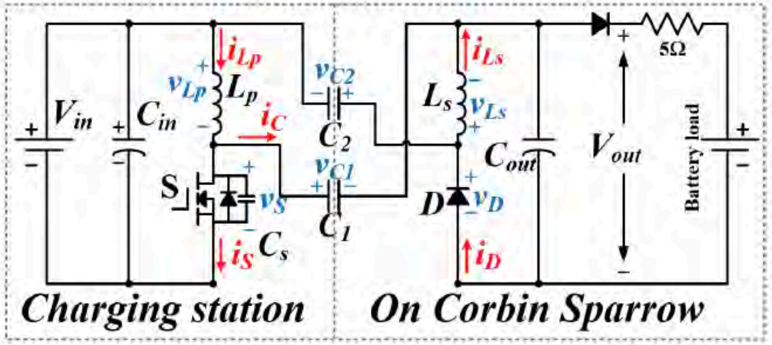
- Low cost
- Low weight
- Low eddy current loss in nearby metals





Capacitive Power Transfer

Jiejian Dai, Daniel C. Ludois, “Wireless Electric Vehicle Charging via Capacitive Power Transfer Through a Conformal Bumper,” IEEE APEC 2015.

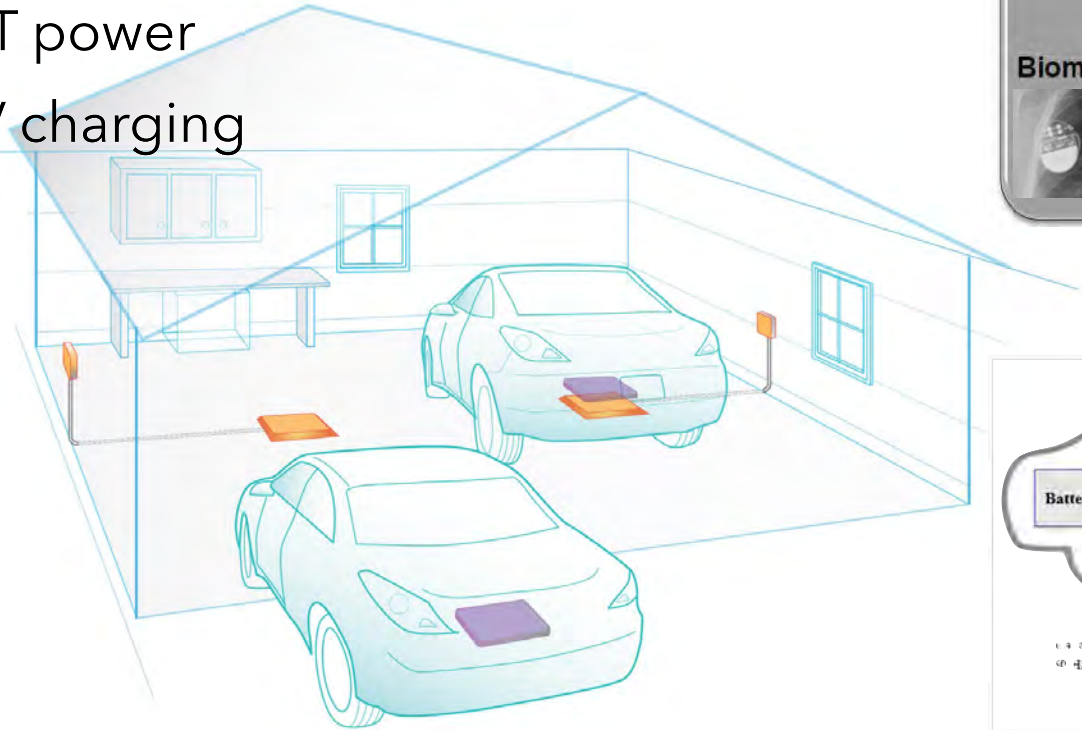


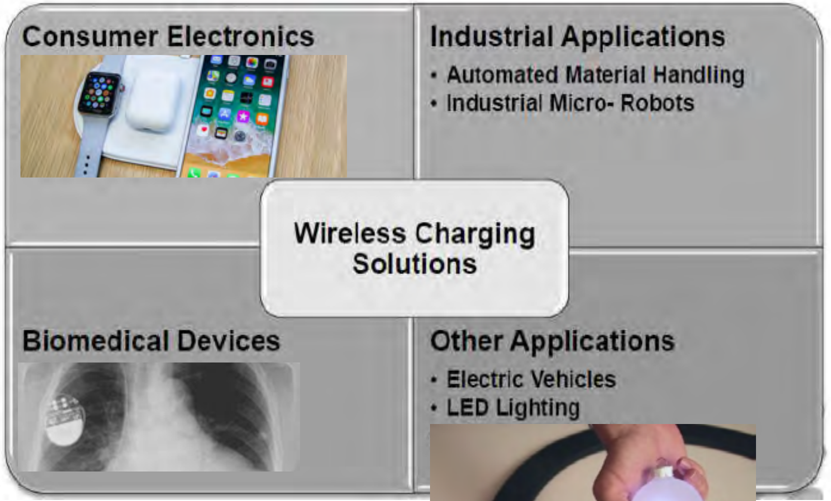
Buck-boost converter CPT circuit for EV charging

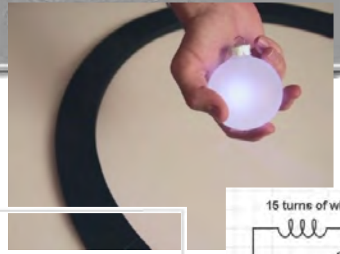
Input voltage: 340 V; Output voltage: 196 V
Output current: 5.21 A; Frequency: 540 kHz
Efficiency: 83%; Air gap: 100 μm (max coupling cap 20.4nF)

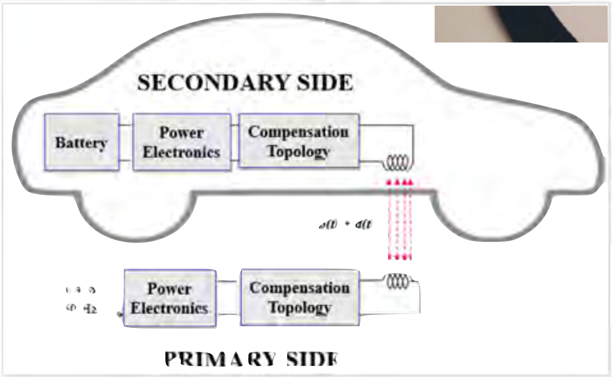
Inductive Power Transfer

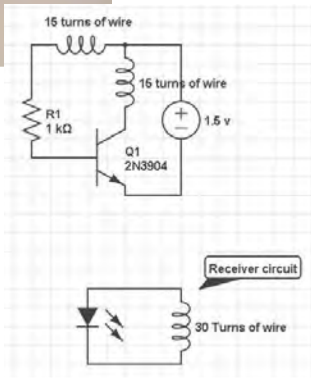
- Applications have rapidly become popular
  - Biomedical device charging
  - Portable device charging
  - IoT power
  - EV charging











Confusing Terminology

Wireless Power Transfer

Inductive Power Transfer

(short distance and low frequency)

Via a **transformer** (coupled inductors)

Well coupled

(very short distance)

inductive mode (Qi)

- Same circuit as resonant mode, but not at the compensation point
- Load reflected to the source side

Poorly coupled

(short distance)

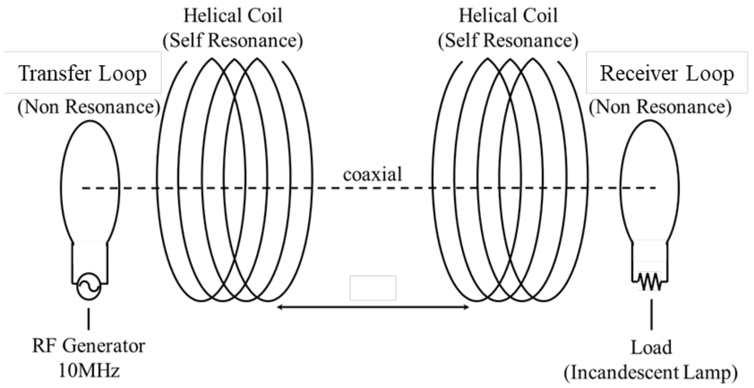
resonant mode (Qi)

- compensation designed for this mode using LC resonance to cancel reactive power
- Load reflected to the source side

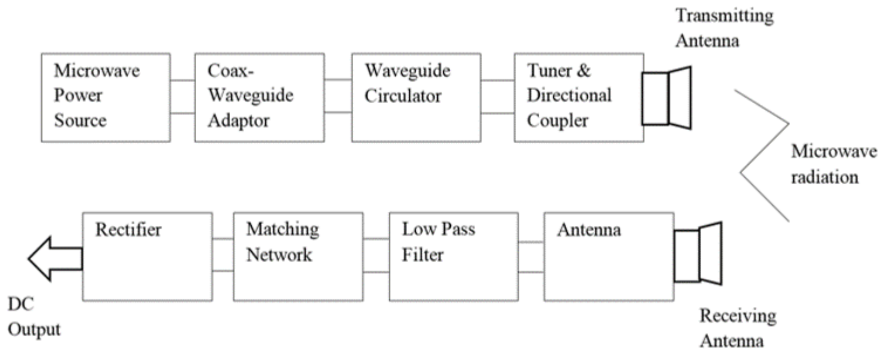
Resonance Power Transfer

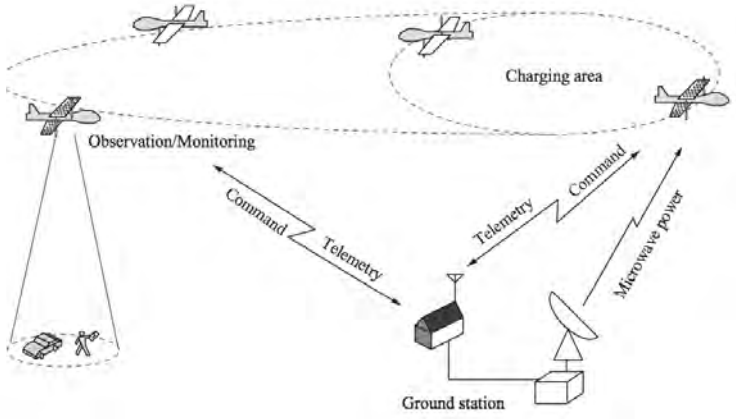
(long distance and high frequency)

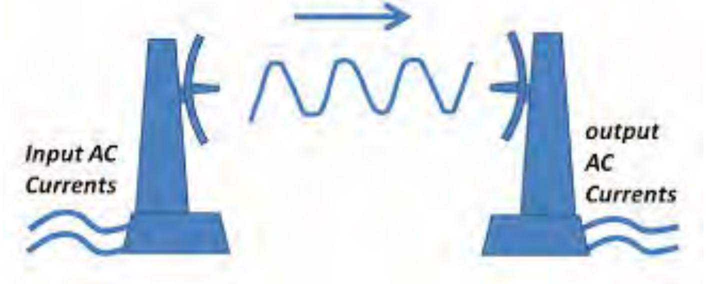
EM radio propagation

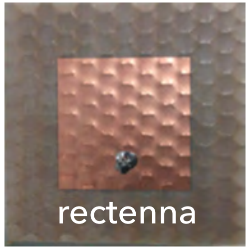


Microwave Power Transfer (Future?)









1996 University of Kyoto
MILAX project

Microwave Power Transfer is the most commonly **proposed** method for transferring energy to the surface of the Earth from solar power satellites or other in-orbit power sources. MPT is occasionally proposed for the power supply in beam-powered propulsion for orbital lift space ships.

Disadvantages

- 🙁 Large area of transmission medium
- 🙁 High frequency
- 🙁 High loss

Wireless Charging and EV

電動車何時可取代汽車

EV is going to make a big impact on the whole electricity supply infrastructure and market.

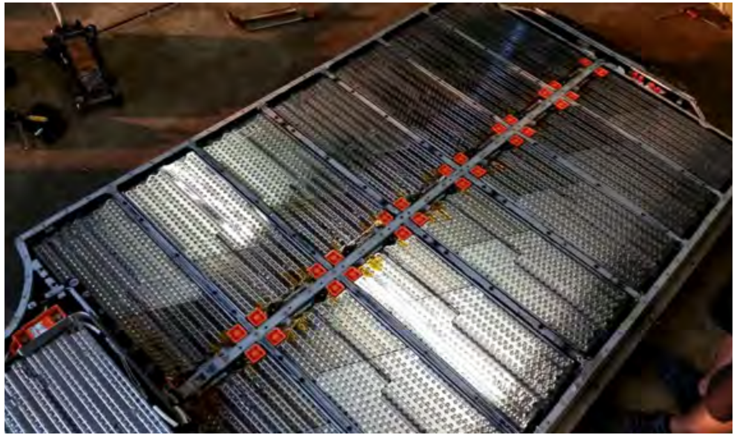
- The question is *when and how rapidly* EV will replace gasoline vehicles.
- EV is 6 times cheaper in running cost (USA: $0.02 per mile), and EV emits 20% less CO_2 (around 0.8 lb per mile from electricity generated from coal)
- But EV has very limited range (~1/3 of typical gasoline car)

UK MOVES CLOSER TO WIRELESS ELECTRIC VEHICLE CHARGING REALITY

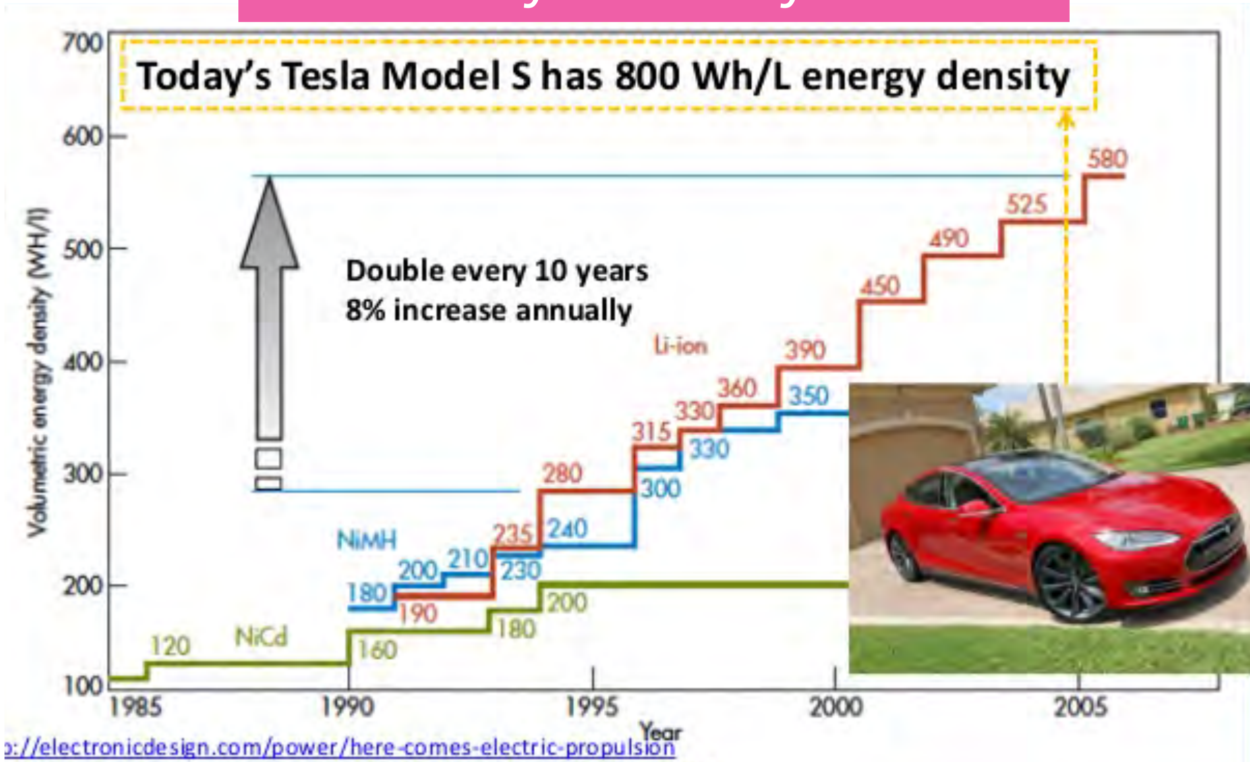
The UK has taken a step forward towards the deployment of wireless charging for electric vehicles with Qualcomm Incorporated, the California-based global mobile and wireless technology leader, investing in Chargemaster Plc, the UK's largest manufacturer and operator of electric vehicle charging points.

What limits its range?

- Battery too heavy
- Battery too costly
  - Tesla Model S battery 70kWh, making the vehicle weight around 2000kg



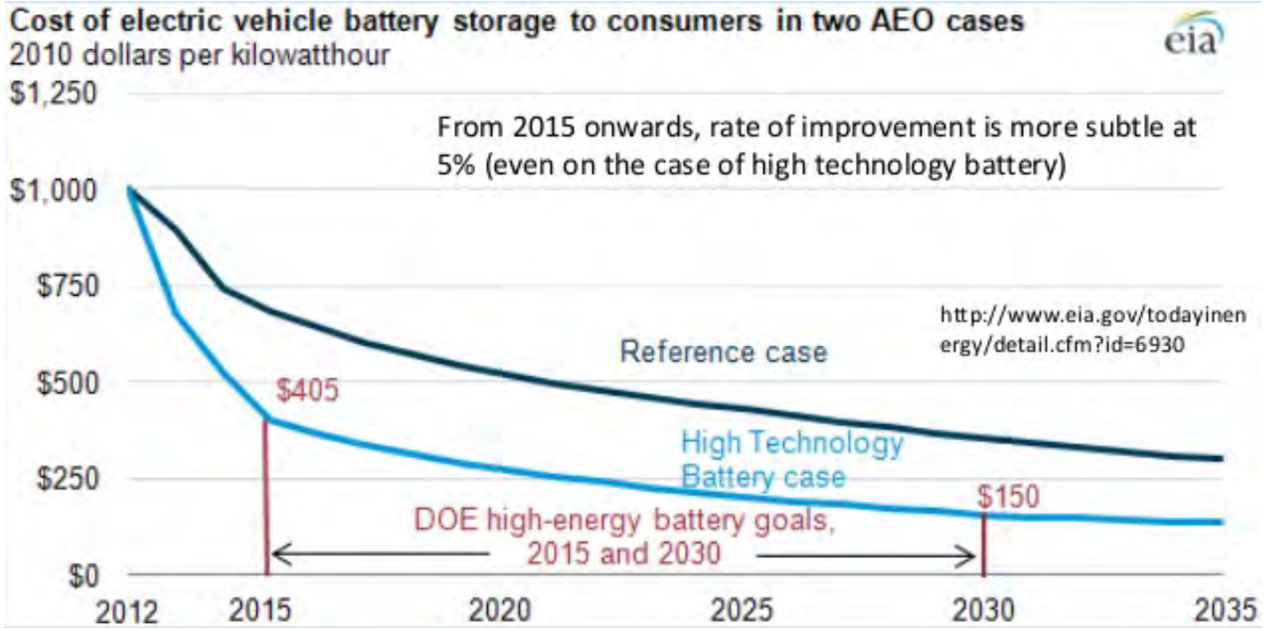
Battery Density Trend



At this rate, EVs will match gasoline cars in 2047!!

Cost of Battery

A 70kWh battery for 400km range EV costs 30,000 USD ≈ 220,000 HKD. It needs to drop 4 times to be competitive.



PREDICTION:

EVs won't match the price and range goal before 2035!!

Are there other factors that drive EV penetration?

Convenience of charging / charging stations is crucial

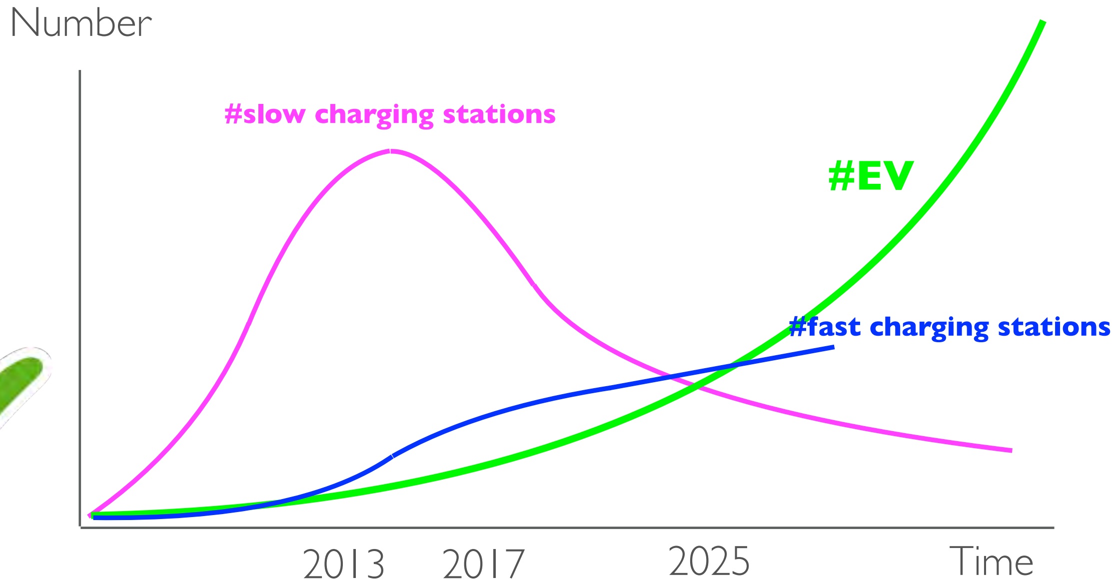
More charging stations encourages EVs with smaller batteries, hence lowering cost/ price.

Charging Level	Power Supply	Charger Power	Miles of Range for 1 Hour of Charge	Charging Times From Empty to Full*	
				BEV	PHEV
Level 1	120VAC Single Phase	1.4 kW @ 12 amp (on-board charger)	~3 - 4 miles	~17 Hours	~7 Hours
Level 2 $500-$3000	240VAC Single Phase up to 19.2 kW (up to 80 amps)	3.3 kW (on-board)	~8 - 10 miles	~7 Hours	~3 Hours
		6.6 + kW (on-board)	~17 - 20 miles	~3.5 Hours	~1.4 Hours
DC Fast Charge Level 2	200 – 450 VDC up to 90 kW (approximately 200 amp)	45 kW (off-board)	~50 - 60 miles (~80% per 0.5 hr charge)	~30 - 45 Minutes (to ~80%)	~10 Minutes (to ~80%)

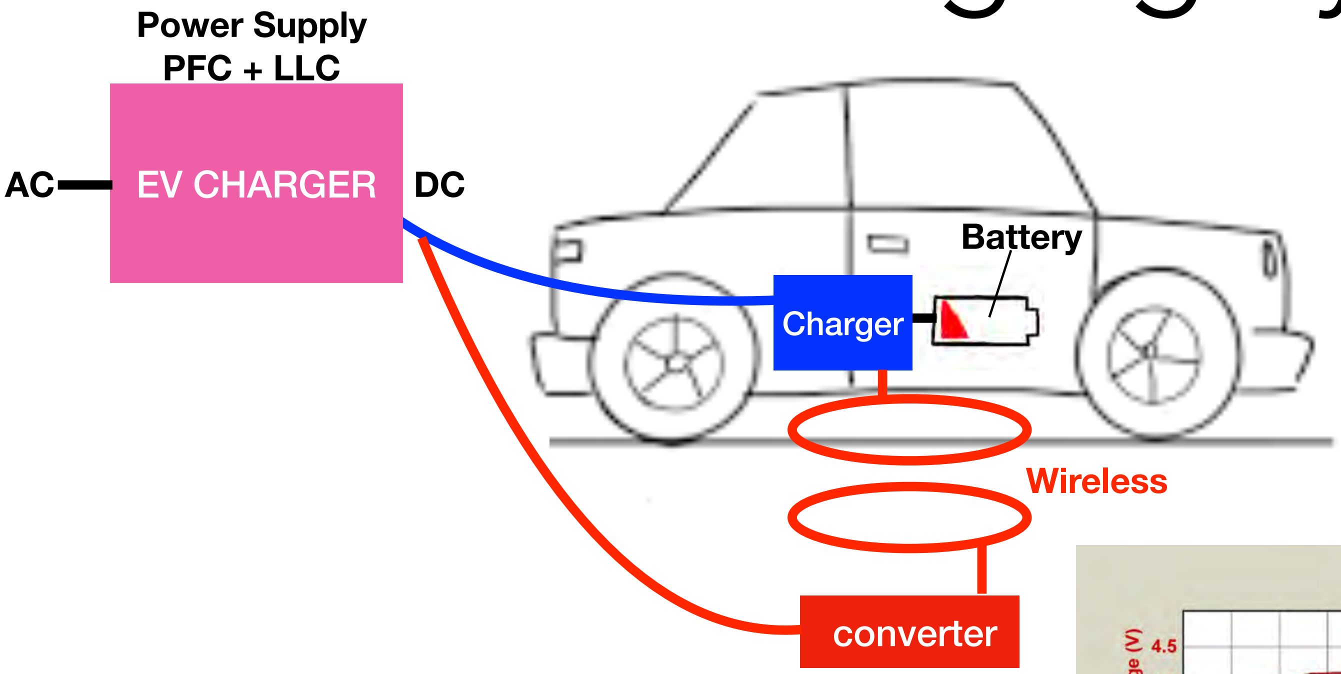
$12000-$15000

BATTERY IMPROVEMENT (2035 beyond)

Charging system improvement likely to come sooner as devices improve much faster! MOSFET – SiC

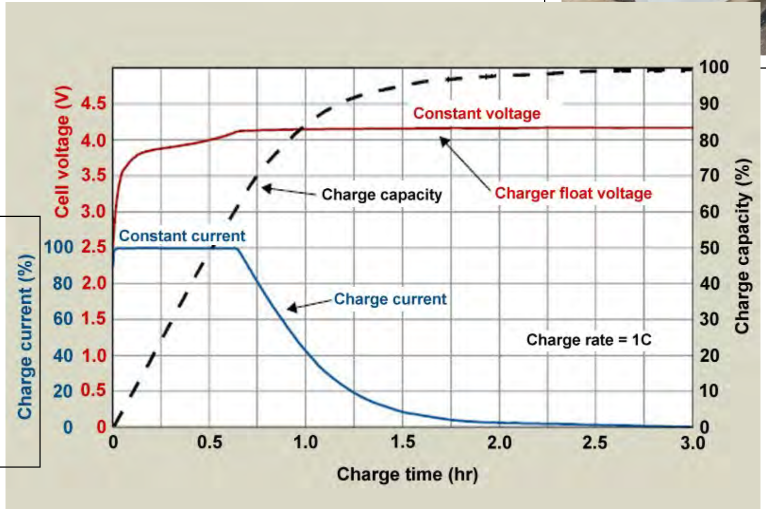


EV Charging System



More efficient way

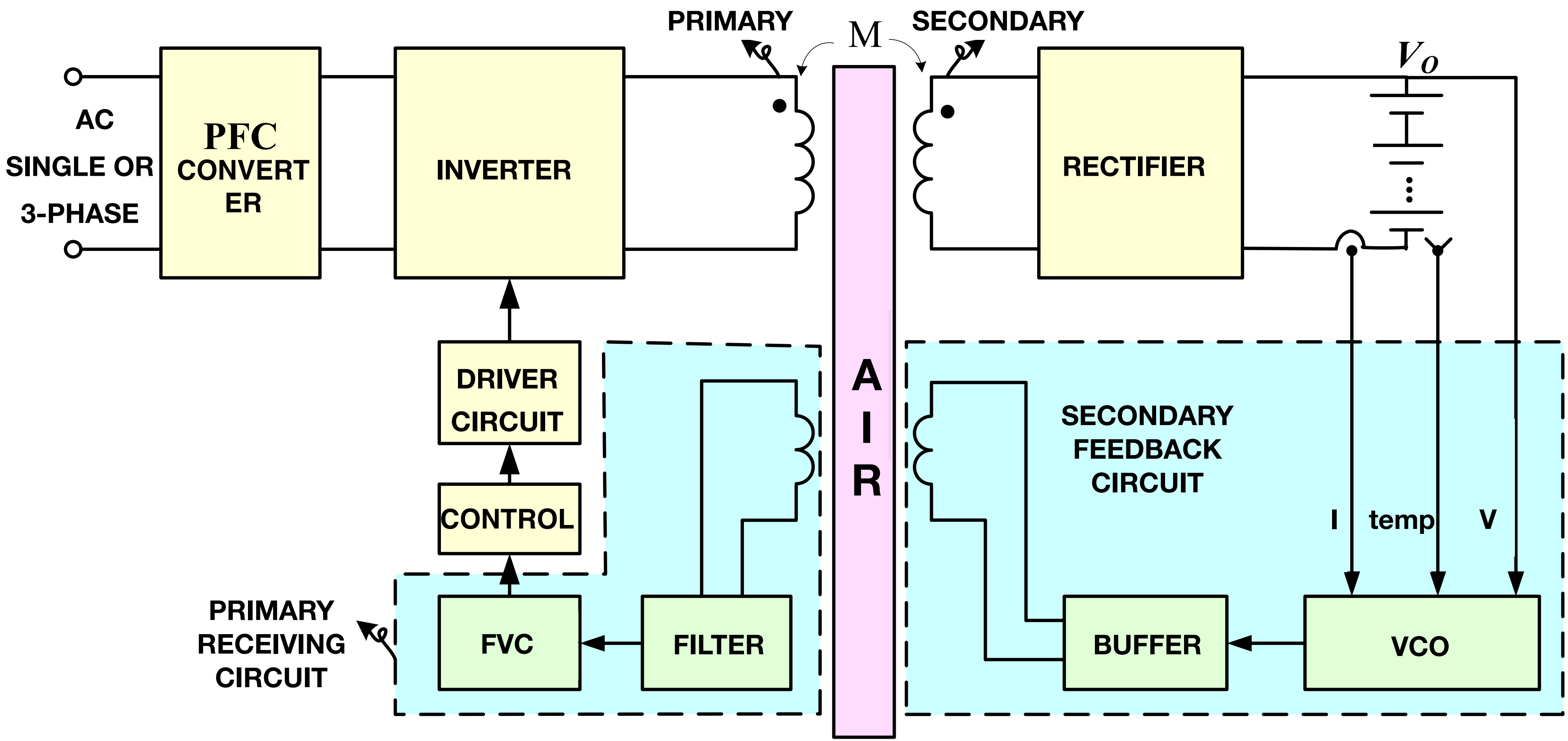
Direct charging:
Tesla supercharger



Charger is not a voltage source, but a complex converter that delivers current at the initial stage and voltage at the final charging stage, following a certain charging profile.

So, this arrangement is inevitably inefficient!!!!

General System Structure



Some developments

COMPANY	COLLABORATORS	POWER (kW)				
		3.3	6.6	10-22	22-60	100-250
Qualcomm (UK)	**Mercedes, BMW, Nissan**	X	X	X		
WiTricity (US)	**Toyata, Mitsubishi, Delphi**	X				
Evatran (US)	**Yazaki Corp., Google**	X				
Conductix (Germany)	**Factory/Bus**		X	X	X	
KAIST (Korea)	**SUV/Bus**			X	X	X
Bombardier (Canada)	**Factory/Bus**					X
Showa Denki Corp (Japan)	**Nissan**			X	X	X
ZTE (China)	**Dongfeng, Daewoo**	X	X	X	X	

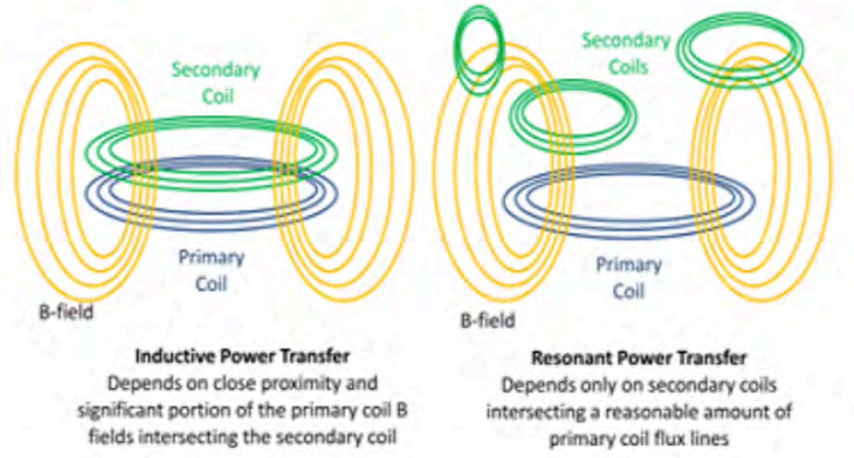
Some latest wireless charged buses

Toshiba, Japan
ANA Facilities at Haneda Airport
Air gap: 10 cm
Power: 44 kW
(2017)

KAIST, Korea
City of Gumi
Air gap: 23 cm
Power: 5x20 kW
(2013)

Industry Standards

Wireless Power Technologies: Inductive vs. Resonant



Inductive technology, which is a closely coupled solution, is the type of compliance used by Qi. This technology transfers power using low-frequency resonant tanks (100-205kHz) over very short distances (mostly anything under 10mm). In 2009, the first standard for Qi had a 5W power requirement ("Low Power"). In 2015, that was increased to 15W capability ("Medium Power"). This year, Qi is hoping for over 100W ("High Power"). Those are currently in testing and should be rolled out later this year.

The other wireless power technology, **resonant**, is considered a loosely coupled solution. Primarily championed by the AirFuel Alliance, this technology uses a high-frequency resonant tank (6.78MHz) to transmit power over long distances (multitudes of feet). Resonant technology offers the ability to charge multiple devices at the same time, with a capability of up to 22W for upcoming systems.

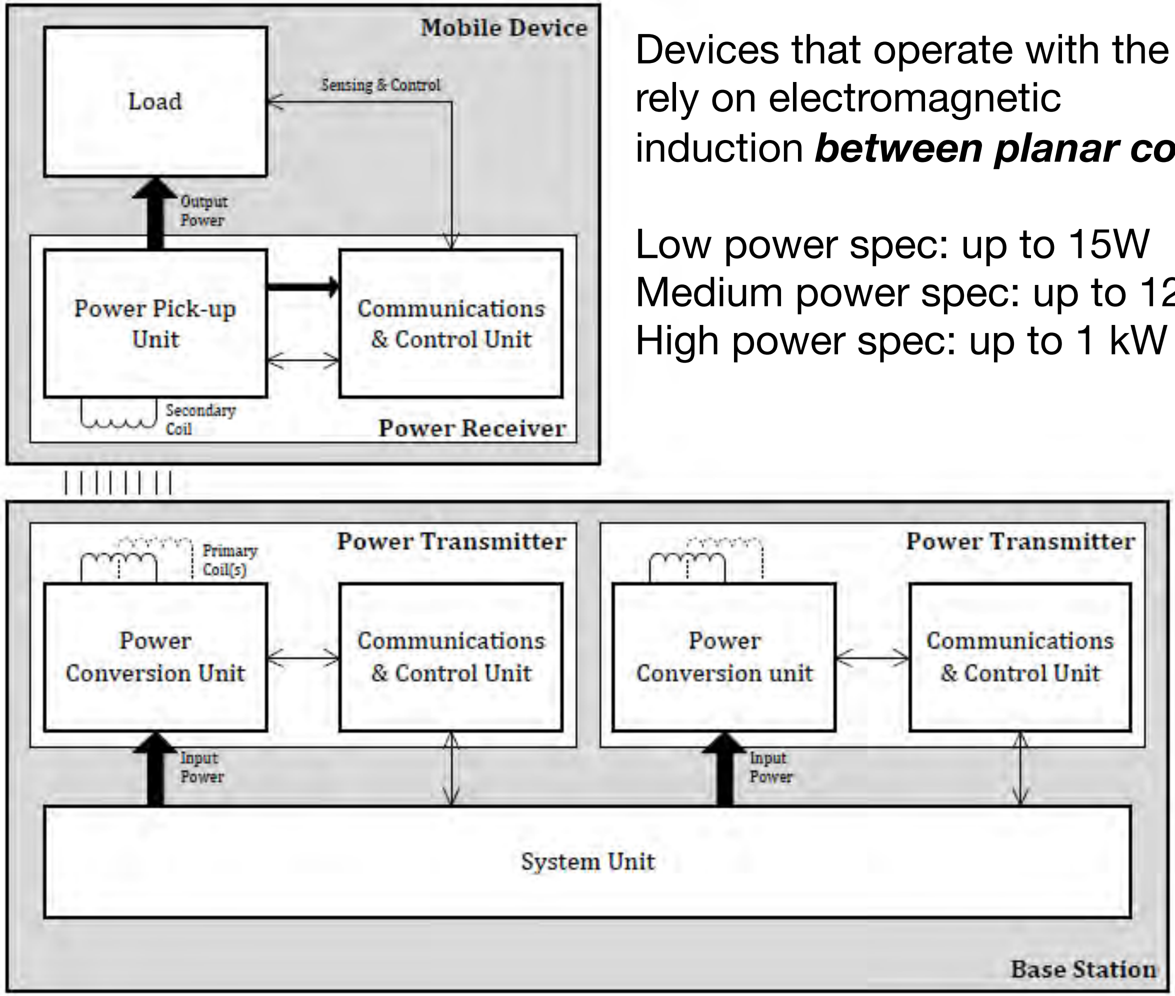
http://www.we-online.com/web/en/passive_components_custom_magnetics/blog_pbcm/blog_detail_electronics_in_action_100415.php

Standards

Qi Standard

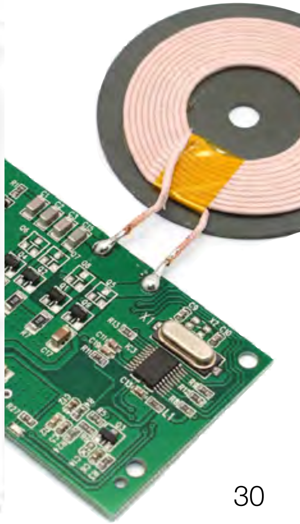
Wireless Power Consortium – formed in Dec 2008, based in Piscataway, New Jersey, USA. It officially published the Qi interface standard and the low-power specification in August 2010.

The company has over 235 companies as its members, with 24 of those companies in the official board of management, called the "Steering Group". When **Apple joined the WPC in February of 2017,** the number of board members was increased to 25.



Devices that operate with the Qi standard rely on electromagnetic induction ***between planar coils***.

Low power spec: up to 15W
Medium power spec: up to 120 W
High power spec: up to 1 kW



Standards

AirFuel Alliance (2015)

= Power Matters Alliance (PMA) + Alliance for Wireless Power (A4WP)

- PMA adopts the A4WP Rezence specification as the PMA magnetic resonance charging specification for both transmitters and receivers in both single and multi-mode configurations
- A4WP adopts the PMA inductive specification as a supported option for multi-mode inductive, magnetic resonance implementations
- A4WP to collaborate with PMA on their open network API for network services management

For a while, it's seemed like Apple's decision to join the WPC was the beginning of the end for PMA, and Powermat raising the white flag is as good a sign as any that resonant wireless will be the Betamax to Qi's VHS.

… … …

One of Powermat's biggest partners is Starbucks, which has installed wireless charging stations at many of its locations. In light of the news that the world's most popular phones would be Qi-enabled, Powermat announced back in September 2017 that it would push out a software update making its charging mats compatible with Qi in addition to PMA. The company switching its alliance to the WPC doesn't bode well for future backward compatibility.

NEWS

The Battle Between Wireless Charging Standards Comes to a Merciful End

Rhett Jones
1/08/18 12:20pm • Filed to: WIRELESS EVERYTHING

62.0K 49 4

Image: Apple

Wireless charging has been held back by poor tech for many years, but now we're seeing major manufacturers integrate it, and it's becoming a viable option. The biggest hurdle it currently faces is that there are two standard versions of the technology, making it difficult to offer chargers compatible with everyone's device. But in an announcement last week, one key player basically ended the debate over which standard is the future.

In a press release, wireless charger maker Powermat declared that it will join the Wireless Power Consortium (WPC), the group that backs the inductive tech of the Qi wireless ecosystem. Until now, Powermat has been the most prominent supplier of the other dominant standard, PMA resonant technology, which is supported by the Airfuel Alliance. A 2016 study by GM Insights found that Qi had claimed a little over half of the total market, with PMA sharing the rest of it with other players that don't have a chance. That was even before Apple threw its hat into the ring with the new generation of iPhones and its upcoming Qi-powered charging mat. For a while, it's seemed like Apple's decision to join the WPC was the beginning of the end for PMA, and Powermat raising the white flag is as good a sign as any that resonant wireless will be the Betamax to Qi's VHS.

Comparison

	WIRELESS POWER CONSORTIUM (Qi)	AirFuel Alliance: Alliance for Wireless Power	AirFuel Alliance: PMA Power Matters Alliance
Driver	**Many**	**Samsung/Qualcomm**	**Duracell-Powermat**
Members	**235**	**150**	**150**
Products	**>940**	**1**	**29**
Market Power class	**Multiple** 0-2.4kW	**Phone/Tablet** 0-20W	**Phone/Tablet** 0-20W
Technology	**Inductive**	**Resonant**	**Inductive**

Qi

There are 235 member companies and more than 940 certified products associated with Qi. Its power class reaches anywhere from 0W to 2.4kW of power. (It's important to note that 2.4kW isn't available yet; there are working solutions, but those are considered prototypes and are not yet certified to Qi's own standard). Qi uses inductive charging technology for its products.

AirFuel Alliance

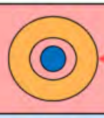
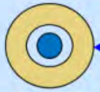
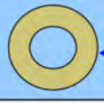
In order to compete with the much larger alliance of Qi, Rezence and PMA joined forces to create what they call the AirFuel Alliance. Together, they have 150 member companies.

Rezence, also known as the Alliance for Wireless Power (A for WP), is driven primarily by one or two large companies and have a more limited range of certified products. Rezence uses resonant technology and has only one certified product type, which is in the phone and tablet market. Thus, Rezence has a fairly limited scope in what it's looking to support.

The PMA, or Power Matters Alliance, is driven primarily by Duracell-Powermat. With its later entry into the market, the PMA has 29 certified products in the consumer market (which are almost all phones and tablets). Like Qi, the PMA uses inductive technology for its products.

http://www.we-online.com/web/en/passive_components_custom_magnetics/blog_pbcm/blog_detail_electronics_in_action_100415.php

Qi Compliance Specifications

Design	Inductance	Type	Voltage	Special Requirements	Visual
A1	24μH	Round	19	Magnet	
A5	6.3μH	Round	5	Magnet	
A6	11.5μH	Rectangular	12	Array	
A10	24μH	Round	19	No Magnet	
A11	6.3μH	Round	5	No Magnet	

Voltage classes for transmit coils

- 5V: USB applications
- 12V: Automotive applications, and
- 19V: Laptop power supplies

Qi Compliant Standards

Interface definition:

- transmitter and receiver design requirements, system control, and communications interface
    - foreign object detection so that the coils know whether another Qi coils are in the proximity to avoid mis-delivery of power
    - dictates the operating frequency of the ICs (100-205kHz), defines the resonant tank circuit, and defines coil construction with both mechanical and electrical parameters.

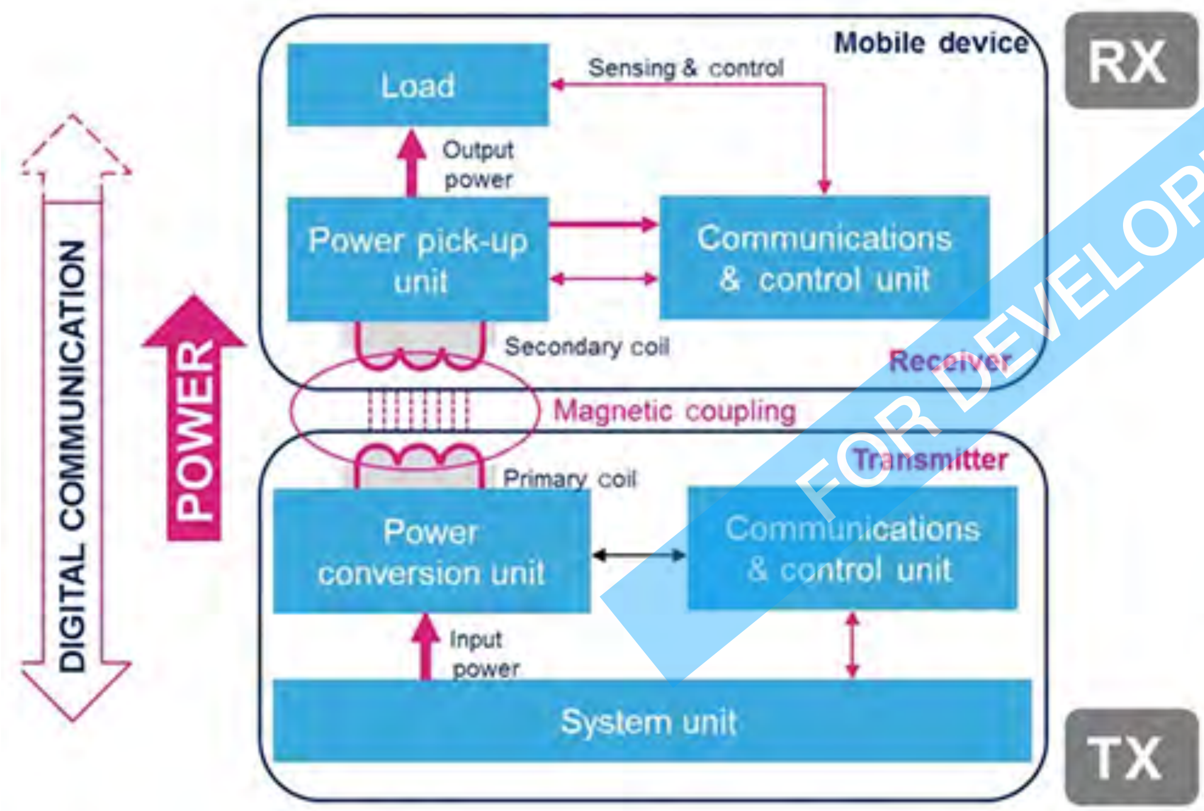
Performance requirements:

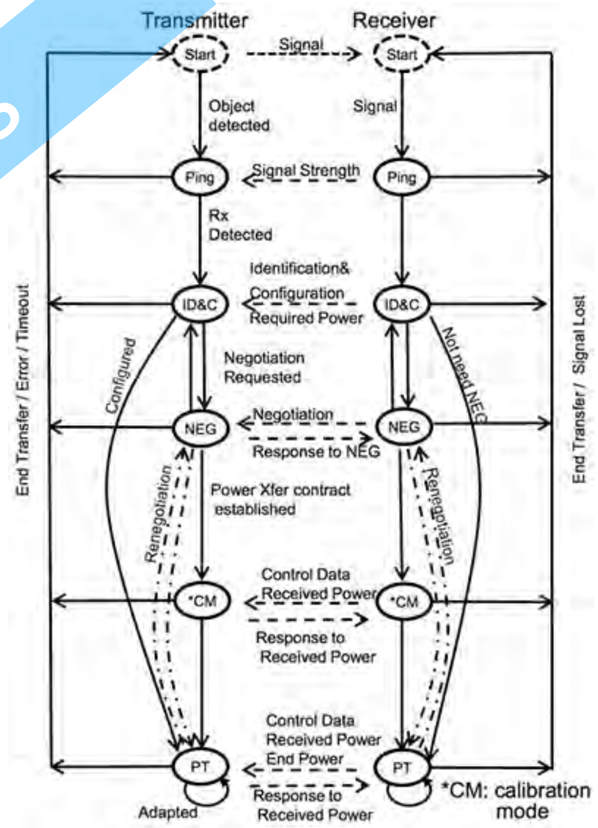
- transmitter and receiver design requirements, system control, and communications interface
    - ~70% efficiency at 1cm
    - If efficiency drops below 70%, the controller will shut off power and will not transmit until efficiency reaches 70% again.

Compliance testing:

- specify how products are to be tested for Qi compliance
    - four testing locations around the world: one in the U.S., one in Germany, and two in Asia.

Qi Compliance Specifications





http://www.digikey.hk/en/articles/techzone/2018/may/how-to-quickly-implement-qi-standard-compliant-wireless-charging-system

Qi Demo Video

This video shows a wireless charger that can power all standard Qi phones and tablets at any distance between 0 and 30 mm.

CAUTION:
So-called “inductive mode” and “resonant mode” within the Qi standard are imprecise terminology! From the circuit theory viewpoint, they have no difference, except in the extent of compensation performed. For “inductive mode”, the transformer is well coupled, and for “resonant mode”, the transformer is poorly coupled. Compensation in resonant mode suppresses the effect of reactive power due to poor coupling.

WIRELESS POWER CONSORTIUM

About Qi | Qi Blog | Qi Certified | Uses of Qi | Developers | The WPC | Membership

Login | Contact Us

Qi Components and Subsystems

Components

It is not possible to certify Qi components such as coils, shielding, and ICs. Compliance with the Qi specification can be determined only for products that are completely functional Qi transmitters or Qi receivers.

A product with components that have been used succesfully in a Qi Certified product is not automatically compliant. The use of different housing materials, different locations of coils and shielding, even differences in firmware can interfere with wireless power transfer.

Manufacturers of ICs usually demonstrate the suitability of their IC by certifying a demo product, the so-called "Evaluation Module". Products that use such IC must be tested for compliance. They are not automatically compliant.

Transmitter Subsystems

A subsystem is a completely functional transmitter product, with coils, shielding, and control system assembled together. It can be operated and tested without any additional assembly or construction.

Products with an embedded Qi Certified subsystem need not be tested for compliance with the Qi specification, provided the subystem is integrated correctly. Be careful. Incorrect integration, with the wrong coil-surface distance for example, will make the product non-compliant and require testing of product.

You can find a list of Qi Certified Subsystems in the **Qi Product Registration Database: "advanced search" and "Subsystem intended for integration into other products" = Yes**.

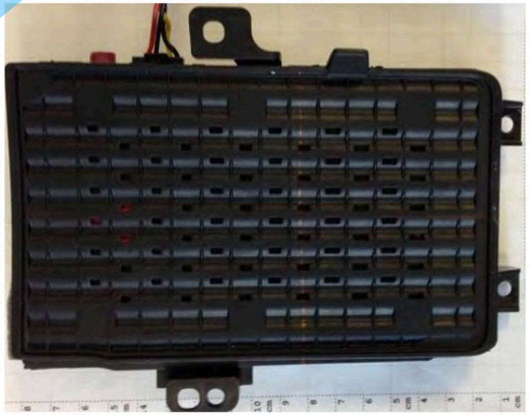
A Tx product can be Qi Certified as a "Subsystem intended for integration in other products" only when it meets these criteria:

1. The product must includes the means to attach the Tx into the complete system.
2. The position of coil(s) and shielding relative to the points of attachment must be fixed.
3. The minimum and maximum distance between the top of the sub-system and the surface of the complete system must be specified.

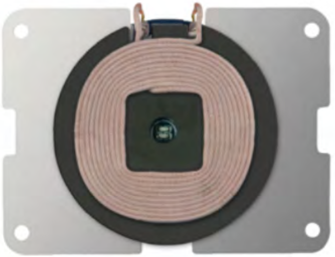
FOR DEVELOPERS

Example 1: Furniture Charger

Example 2: in-car charger



Example 3: a Tx module



https://www.wirelesspowerconsortium.com/developers/qi-components-and-subsystems.html

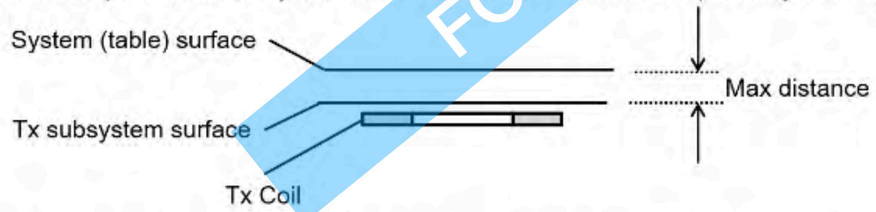
Receiver Subsystems

Products that contain a receiver subsystem, or module, must always be re-tested because materials used in the receiver product are likely to influence foreign object detection.

Products with an embedded Tx subsystem

Products that contain an embedded Tx subsystem can be registered with a simplified procedure. Testing of the product is not required when the product meets these criteria:

1. Brand name and type-number of the sub-system must be clearly visible on the sub-system.
2. Brand name and type-number of the sub-system do not have to visible on the system. Disassembly of the system may be need to determine brand name and type-number of the sub-system.
3. The sub-system must be in the product registration database with this brand name and type number.
4. The distance between the top of the sub-system and the surface of the complete system is within the tolerances specified during registration of the sub-system.



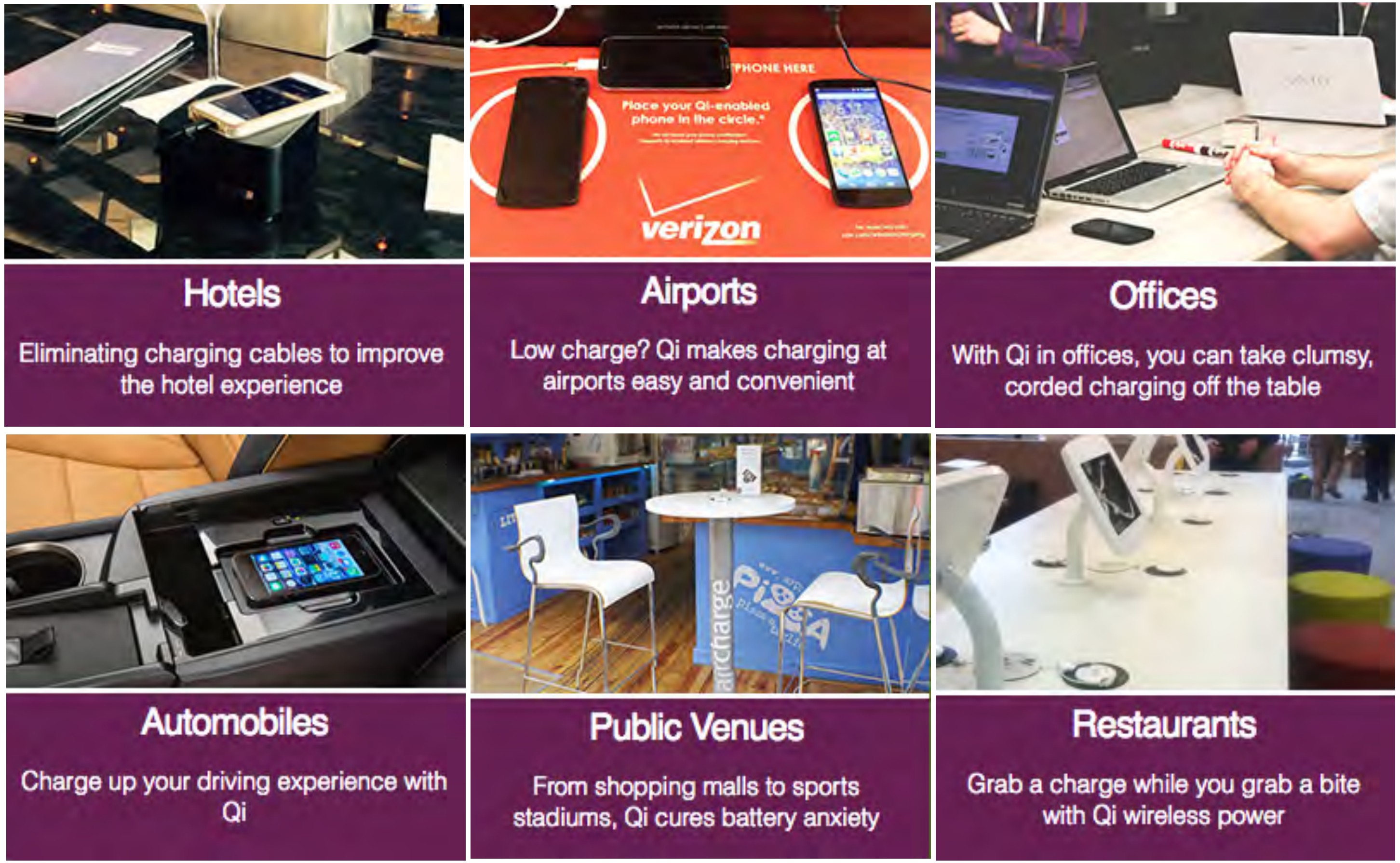
5. The power supplied to the sub-system must meet the specified minimum level.
6. Materials used in the complete system between the sub-system and the surface of the complete system do not influence the magnetic field.

FOR DEVELOPERS

https://www.wirelesspowerconsortium.com/developers/qi-components-and-subsystems.html

Uses of Qi Standard

The standard provides common specifications for transmitters and receivers.



Qi Low Power Specifications

- Transmitters to deliver up to **15 W power** and the option for receivers to obtain up to 15 W.
- Choose between 12 different transmitter specifications.
- Thermal test for transmitters.
- Possibility to power a Qi transmitter with a USB charger.
- Sensitivity of "Foreign Object Detection". This prevents heating of metal objects in the neighborhood of an active transmitter.
- Optional unique identifier for power receivers (WP-ID)

Interim Conclusion

- WPT will surely be the future main technology for charging and other contactless power transfer applications.
- Key elements:
  - ✶Transformer being leaky, i.e., high leakage inductance, low coupling
  - ✶Necessary **compensation** involving complete new circuit theory application
  - ✶**Optimization** of efficiency, offset sensitivity, minimal reactive power circulation
  - ✶Control methods under multiple constraints
  - ✶Contactless transformer pads design
    - ✶Future challenge for popularization: common standard vs. max efficiency