WiseHarbor Spotlight Report

By Keith Mallinson, 18th August 2015

Wireless Charging Ready for Burgeoning Mass Market in EVs

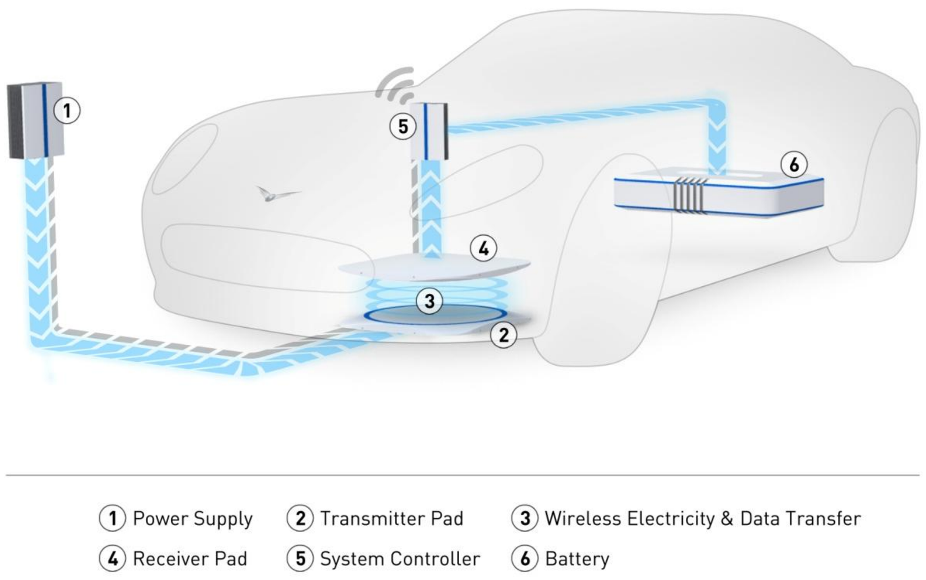
Bottom Line:	Wireless charging is effective and economic for mass market
Report Focus:	Increased WEVC pad efficacy with DD and BiPolar technology developments. Standardizing and commercializing these
Target Readers:	Product and engineering managers in automotive Tier 1 suppliers and OEMs including standard setting participants

Executive Summary

Wireless electric vehicle charging has progressed enormously in recent years: it is ready for widespread adoption in the burgeoning mass market for electric vehicles. Inductive power transfer is highly effective, compact, easy and safe to use, and economic for volume car production. Limited and specialized deployments, such as in bus fleets, have served as excellent proof-of-concept test beds for vehicle charging; but the circular coil technologies upon which these implementations are based have been developed about as far as possible.

Improvements including Double-D and BiPolar coil topologies have significantly increased power transfer, better positioning tolerance, less mass and are smaller while requiring lower-rated power electronics, which also reduces bill-of-materials costs. With environmental, technological and economic factors significantly increasing demand for EVs, time is ripe for standardization and implementation in mass-market production by automotive Tier 1 suppliers and OEMs.

Exhibit 1
Fast and Covert Wireless Charging with IPT



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I. Introduction

This is the first in a series of WiseHarbor Spotlight Reports, commissioned by Qualcomm Technologies Inc, on wireless EV charging (WEVC). This report focuses on developments in coil, pad and associated technologies employed in IPT including DD and BiPolar coil topologies. Subsequent papers will focus on systems aspects of wireless charging and on crucial ancillary safety technologies for living-object protection and foreign-object detection.

II. The rise of EVs

Supply and demand for plug-in electric and plug-in hybrid vehicles (EVs/PHEVs) is growing fast. There are increasing political and regulatory pressures to reduce carbon emissions and improve air quality – particularly in urban areas. Technological improvements, increasing numbers of public charging stations, tax incentives and consumer desires for cleaner and more efficient vehicle power are increasing adoption from a relatively low base. According to research from InsideEVs.com,[1] US sales of plug-in vehicles were 120,000 in 2014, a 23 percent increase from 2013 and 128% more than 2012. However, plug-ins still account less than one percent of total US vehicle sales of 16.5 million. Worldwide, 283,000 electric cars were sold in 2014. According to Scotiabank research, a total of 71 million cars were sold that year.[2] With rising car adoption, urbanization and ever-tighter exhaust emission requirements on internal combustion engines,[3] the proportion of vehicles which are primarily or exclusively electrically powered and need mains charging will increase enormously over the next decade.

III. EVs unplugged

A significant drawback with conventional EVs is that they need to be plugged in frequently. Whereas fuel tanks only need to be charged after driving at least a few hundred miles—typically once every week or two—EVs usually need to be topped-up every day and ideally whenever they are parked. Plug-in charging is obtrusive and a hassle: cables can be cumbersome and get dirty; public charging stations clutter the streets and are vulnerable to damage. Many PHEV drivers rarely bother to plug in, which negates the low exhaust

[1] http://insideevs.com/monthly-plug-in-sales-scorecard/
[2] http://www.gbm.scotiabank.com/English/bns_econ/bns_auto.pdf
[3] https://www.theaa.com/motoring_advice/fuels-and-environment/euro-emissions-standards.html

emission averages achievable and expected by legislators with their emission reduction target figures. These factors make WEVC indispensable.

IV. Meeting WEVC challenges

Maximizing charging rates is paramount with EVs. WEVC systems now regularly perform at levels not possible or even envisaged only five years ago. Wireless power transfer rates—from ground-submerged transmitter pad to receiver pad affixed underside the vehicle—are now similar to those with hefty cables, plugs, sockets and street-side pedestals. Developments in resonant induction technology and associated control electronics enable significant power transfer to be achieved safely over large and variable air gaps with wide positioning tolerances. This is has been made possible with sophisticated coil and pad configurations, and power electronics working in close coordination and optimization with vehicle battery management systems. It is now possible to charge vehicles including cars, buses and trucks at rates in the range of 3.3kW to 20kW or more with systems which can be manufactured in high volumes and at low cost, in a similar manner to other automotive components.

State-of-the-art WEVC systems including DD and BiPolar pads are effective, easy and safe to use. They provide the following capabilities:

- Highly efficient power transfer from 3.3kW to 20kW
- Wide tolerance to X (direction of travel) and Y positioning and to differing vertical Z-gaps from low ground-clearance sports cars to high-ride SUVs
- Unobtrusive designs with buried, flush or surface-mounted base pads and vehicle pads recessed and hidden underside
- Self optimising to achieve maximum energy transfer with communications between base and vehicle electronics for primary-side and secondary-side control
- Easy alignment of wireless pads while parking at home, at the office and in public places transforms EV charging with fully integrated positioning assistance
- Safe to use with foreign-object and living-object detection and protection systems
- Backward compatibility with Circular Rectangular vehicle pads by switching BiPolar base pads from simulating DD mode to CR mode operation

V. Long and extensive developments in IPT technologies

Some of the simplest-looking innovations have resulted from the most extensive and painstaking R&D efforts over many years. For example, Dyson's latest slot-in-a-box air-blade hand drier designs belie the painstaking development work undertaken. Similarly, according founder James Dyson's autobiography, 5,127 prototypes were made and tested over many years before for the company's patented dual-cyclone bagless vacuum cleaner design was commercialized, eventually with great success.

Likewise, the highly effective wireless charging technologies including coil designs and power electronics available today have also resulted from many years of "inspiration and perspiration," as Thomas Edison put it. The University of Auckland, for example, has pioneered IPT R&D since 1988 with commercialization by Auckland Uniservices Ltd since 1995 and more recently HaloIPT Ltd since 2010. They have developed technologies which are in commercial use for materials handling and in passenger transportation. This required extensive academic and industrial work with several dozen PhD students and staff researching and developing resonant magnetic induction technologies at the theoretical level, in computer simulations and with numerous prototypes prior to commercial implementation. Innovations include coil and ferrite configurations for pads with multiple coils, astute design layout of spacing and radii for Litz wire (overcomes skin effects at high frequencies used), and sophisticated control of multifarious elements in the power electronics.

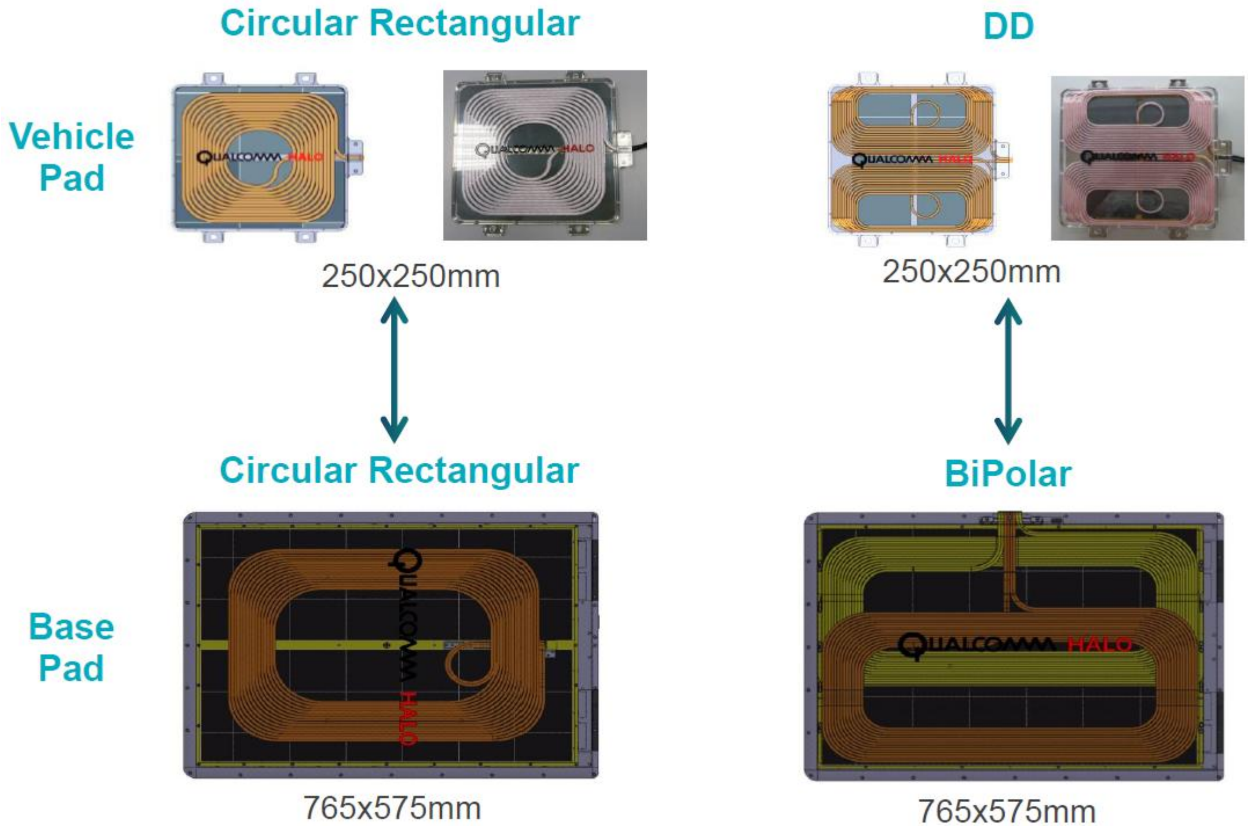
VI. DD and BiPolar coil technologies most effective

There has been a significant progression of performance advancements with these developments in coil and pad technologies over many years. Circular and CR coil configurations can achieve adequate power transfer rates in some cases, but these designs require relatively large pads and their non-polarized magnetic field patterns have been significantly improved upon. The next major step in technology developments was with various solenoid designs which provide higher power transfers for a given size or mass of pad; but these also result in unacceptably high flux losses which can cause excessive heating and harmful electromagnetic interference to other electrical systems.

Further developments over several years to employ DD coils in the vehicle and BiPolar pads in the base have provided the most effective and compatible designs today. With charging rates and efficiencies akin to wired charging rates, wireless charging with advanced DD and BiPolar coil technologies is superior CR and solenoid designs.

Exhibit 2

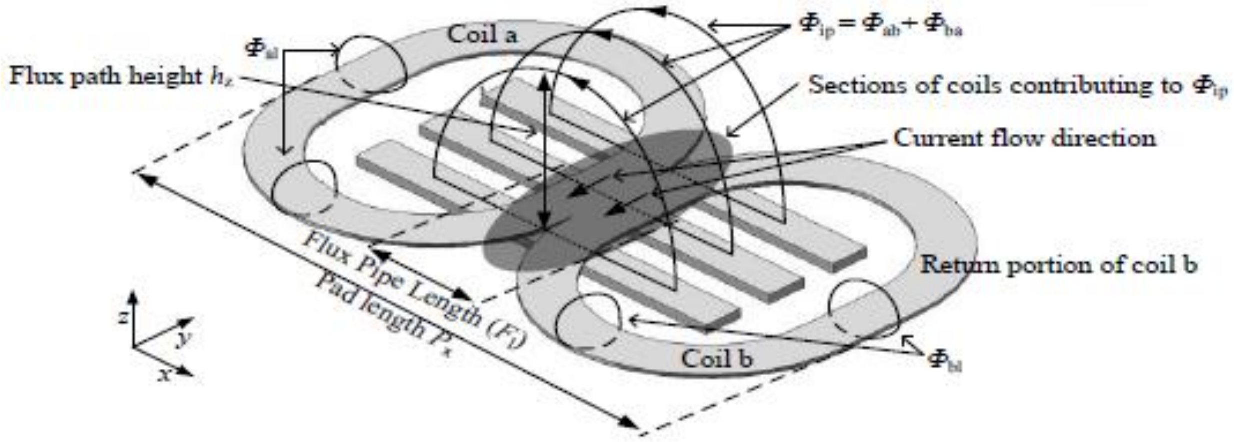
Improving on CR coils with DD and BiPolar topologies



Circular and CR coils create un-polarized flux which is relatively wide, shallow and shaped like a ring donut. Solenoid designs polarize and direct flux where required, but with some return flux on the wrong side of the pad, and flux also spills out from either end. DD and BiPolar configurations create a narrow and relatively tall "flux pipe". This allows more compact designs than CR and with low flux emissions. It allows coupling at full power between base and vehicle pads over large air gaps with wide positioning tolerances.

Exhibit 3

Improved flux pattern with DD coil topology



The technical characteristics and benefits of DD and BiPolar coil topologies translate directly into product performance and economic advantages over circular coil implementations. Qualcomm has quantified superior performance in extensive hardware testing.

Exhibit 4

Pad and coil topology performance comparisons

	Circular	DD	Comments
Transferrable power	-	++	With same pad sizes, DD delivers ~2x more power than circular at maximum X, Y & Z offsets
Vehicle pad size	-	++	DD pad is ~40% smaller for same transfer rating
Vehicle pad weight	-	+	DD pad is ~35% lighter (3kg saving) for same transfer rating
System material cost	-	+	DD is ~10% cheaper for same transfer rating, largely based on lower VA requirements with DD
X/Y offset tolerance	-	++	With same pad sizes, DD delivers full power at X = +/-100mm and at Y = +/-150mm. Circular only delivers full power at X = +/- 75mm and Y = +/- 100mm
Z-gap range	-	++	With same pad sizes, DD delivers full power across the entire 160 –220mm Z- gap range. Circular power much diminished at Z=220mm.
Flux emissions	++	+	Both meet threshold requirements for emissions which may cause electromagnetic interference

VII. Safe, complaint and ready for standardization

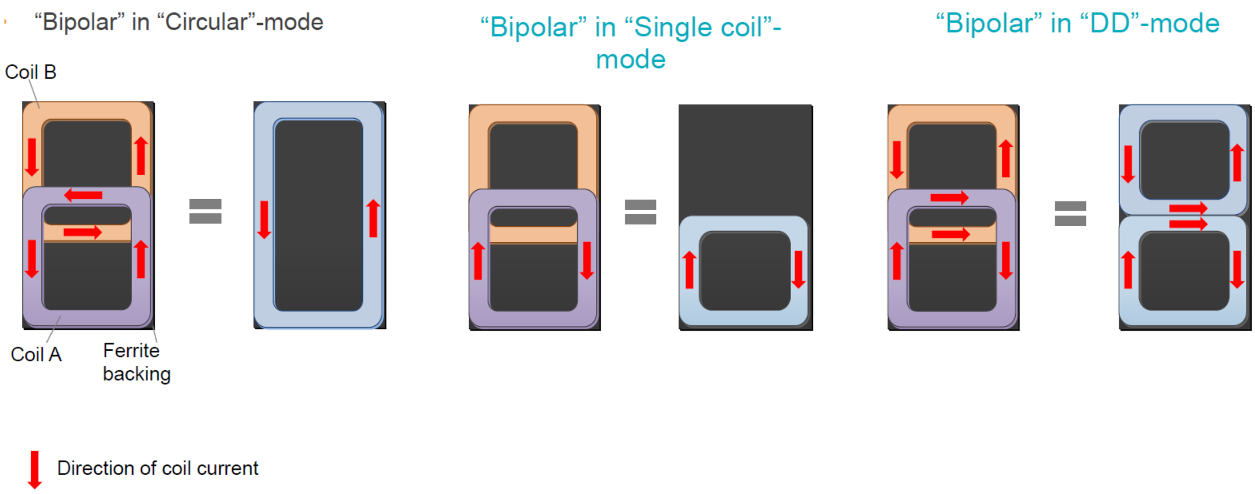
WEVC technologies enable compliance with a wide array of requirements and guidance on potentially harmful electromagnetic emissions including that from the International Commission on Non-Ionizing Radiation Protection (ICNIRP). WEVC systems also include ancillary systems which provide safety with living-object protection and foreign-object detection, as will be discussed in a subsequent Spotlight Report.

WEVC systems must also conform to international standards for most effective and interoperable technologies. As is the case with standards development organizations such as IEEE producing, for example, WiFi and Ethernet standards, many different ICT developers compete and collaborate to contribute the most-effective hardware and software technologies to the standards. These are then exploited by many different manufactures in high-performance and interoperable components, sub-assemblies and finished products. Similarly, SAE develops standards for effectiveness, quality and interoperability, as well as for safety in the automotive industry.

The high performance of WEVC systems based on DD coil technology makes DD technology a compelling candidate for standardization and adoption by the automotive industry including SAE, ISO and IEC standards organizations, as well as the Tier 1 suppliers and OEMs. This does not preclude use of other coil technologies including CR. One significant objective in standardization is in providing backward compatibility and interoperability among different technologies where possible. As indicated above, and also as the result of extensive development work including optimization in power electronics and software, BiPolar base pads can be switched between CR and DD modes of operation. This means that public charging stations can effectively charge vehicles fitted with either CR or DD pads.

Exhibit 5

Operational modes for BiPolar coupler



VIII. Ripe for implementation in mass-market production

WEVC technologies developed by a few expert specialists are ready to be implemented on a broad basis by multiple Tier 1s and OEMs.

WEVC systems are best suited to an industry supply structure with reference designs and technology transfer being provided under licensing agreements for product development and production by Tier 1 component and systems suppliers. The Tier 1s can then supply to the OEMs in their usual manner. The development of coil and pad, power electronics and ancillary technologies, as well as comprehensive integration of all sub-systems into high-performance and standards-compliant WEVC systems, is a major and ongoing yet specialized endeavor. As is the case in the ICT, where around 90% of PCs and 80% of smartphones employ the same software operating systems, there is increasing "horizontalization" with different types of firms specializing in different layers of the value chain in the automotive and other industry sectors. This is due to economies of scale and the need to focus on applicable core competencies in each and every layer of the value chain.

This horizontalized supply structure is the best approach technically and commercially for WEVC. Tier 1s and in turn their OEM customers receive a bundle of the best capabilities at a fraction of the cost of doing it all themselves, and with much accelerated time-to-market for initial and subsequent products and technologies. Meanwhile, WEVC technology licensors focus on:

- Ongoing development of core and ancillary technologies, and the optimized integration among these and with adjacent systems including battery management
- Compliance with national and international regulations including safety requirements
- Standardization for selection of best technology improvements and interoperability including extensive work in collaborating and contributing to various standards development organizations

This approach is efficient and effective in division of labor among companies with very different capabilities; while also fostering innovation and competition throughout the supply chain to produce the best and most cost effective WEVC systems. It is collaborative and means that many different companies can do what they do best while relying on partners to focus on their own core competencies. It enables Tier 1 suppliers to focus on differentiating their products based on cost, quality and functionality. This maximizes economies of scale at several levels. It minimizes overall cost, risk and time-to-market.

Further Reading

The Inductive Power Transfer Story at the University of Auckland. By John T. Boys and Grant A. Covic. IEEE Circuits and Systems Magazine, Second Quarter 2015 http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=7110451&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel7%2F7384%2F7110439%2F07110451.pdf%3Farnumber%3D7110451

Investigation of Multiple Decoupled Coil Primary Pad Topologies in Lumped IPT Systems for Interoperable Electric Vehicle Charging. By Adeel Zaheer, Hao Hao and Grant A. Covic. IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 30, NO. 4, APRIL 2015.
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=6827937

About WiseHarbor

Founded in 2006, WiseHarbor is an industry analyst and expert consultant in wireless and communications technology markets. WiseHarbor has many large and global companies among its clients. It frequently publishes articles in the trade press and for industry associations on various technical, commercial and regulatory issues. Engagements include commercial and financial analysis and expert witness testimony.