By Keith Mallinson, 2nd September 2015

Wireless EV Charging made Safe with Foreign Object Detection and Living Object Protection Systems

Bottom Line:	FOD and LOP make WEVC safe as well as effective
Report Focus:	Ancillary systems which alleviate safety hazards in WEVC
Target Readers:	Product and engineering managers in automotive Tier 1 suppliers and OEMs including standard setting participants

Executive Summary

Safety is paramount while replenishing energy stored in all types of vehicles because very large energy transfers are required to fill fuel tanks and charge EV batteries. For example, filling stations are governed by regulations to make fuel pumps intrinsically safe from the risk of fire which can have fatal consequences for forecourt staff, drivers and passengers.

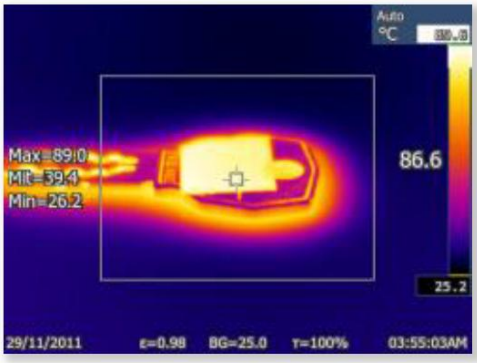
Wireless EV charging using inductive power transfer presents two types of safety hazard:

- Excessive heating of stray objects which are energized by the inductive power transfer magnetic field between base and vehicle pads with the risk of skin burns or fire
- Direct exposure of humans, animals and implantable medical devices to magnetic and electrical fields which may cause potentially adverse health effects, or erratic operation of IMDs

The best FOD and LOP ancillary systems, sensing with an array of electrical loops and radar respectively, conform to regulations which make WEVC safe, are reliable including minimizing false alarms and missed detections, and preserve the efficacy of IPT technologies.

Exhibit 1

Safety threats during Wireless EV charging with FOD & LOP



Key heating up on base pad

Dog and human arm below a vehicle

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I. Introduction

This is the third in a series of WiseHarbor Spotlight Reports, commissioned by Qualcomm Technologies Inc, on wireless EV charging. The first report focuses on developments in coil, pad and associated technologies employed in IPT including DD and BiPolar coil topologies. The second report examines systems aspects of wireless charging. This third report focuses on crucial ancillary safety systems technologies for FOD and LOP.

II. Safety first

Safety is paramount in replenishing the energy stored in all types of vehicles because very large energy transfers are required to fill fuel tanks and charge EV batteries. For example, filling stations are governed by various regulations to make fuel pumps intrinsically safe from risk of fire which can have fatal consequences for forecourt staff, drivers and passengers.

FOD and LOP safety systems are crucial ancillary capabilities in WEVC along with positioning systems which make WEVC also quick and easy to use. FOD and LOP systems must conform to safety regulations, while also being reliable, including minimizing false alarms and missed detections, and preserving the efficacy of IPT technologies.

III. Foreign object detection

a. FOD safety requirements and challenges

A wide variety of metallic and magnetic objects pose potential safety hazards to WEVC systems. These objects tend to heat when energized by IPT magnetic fields, potentially causing excessive "parasitic" heating. Even small objects such as coins and paper clips can rapidly heat to temperatures which could cause skin burns or even fires, for example, when flammable materials such as paper are present. It is essential that these and a wide variety of other common objects, including those in the following exhibit, can be reliably detected.

ISO regulations set acceptable threshold levels for potential human contact with heated surfaces.[1] These levels are much more conservative than those which could cause fire in contact with flammable materials.

[1] ISO 13732-1-2006, Ergonomics of the thermal environment – Methods for the assessment of human responses to contact with surfaces – Part 1: Hot surfaces, First Edition, Sept. 2006. In addition, SAE J2954 is one of the WEVC standards currently being drafted: it specifies compliance with UL 2750 surface temperature limits

Different objects can have disparate characteristics in terms of heating and detection. The rate and extent of heating depends on the size, mass, shape and position of the foreign object near or between the charging pads. Relatively large objects tend to be easier to detect than small objects. Objects with metallic loops including paper clips and electrical extension cords can couple particularly strongly with magnetic fields and heat most significantly. Most stray objects between the base and vehicle pads rest with all or most of their metal in contact with the base pad's surface. This tends to make detection relatively straightforward. In contrast, for example, the foil in cigarette packaging and plastic yoghourt pots with thin metal foil tops present a particular detection problem. In the very unlikely event a yoghourt pot is standing in an upright position on a charging pad with its lid still attached, the metal will be several centimeters off the ground.

Exhibit 2

Some common or garden foreign objects from among many which might end up on a base pad and which must be detected (not to scale)

The large metallic underbody of a car makes it impractical to detect metal at every vertical position all the way up the Z-gap between the base and vehicle pads. Nevertheless, FOD must work reliably in sufficient "use cases," including the example of an upright and lidded yoghourt pot, such that OEMs, together with their component and system suppliers, deem WEVC acceptable for commercial implementation.

b. FOD methods

Detection methods attempting to measure temperatures directly have significant limitations and commonly do not detect some foreign objects due to the above factors despite heating above 80 degrees Celsius. Detection can be unreliable with these missed detections, and false detections or erratic behavior as sensitivity is increased to mitigate missed detections. For example, thermocouples sensing temperature in the base pad may not detect small objects and will not detect the heating of a yoghourt pot top. Infrared camera temperature sensors are vulnerable to being made inoperable by dirt, water and snow that drops from vehicles overhead.

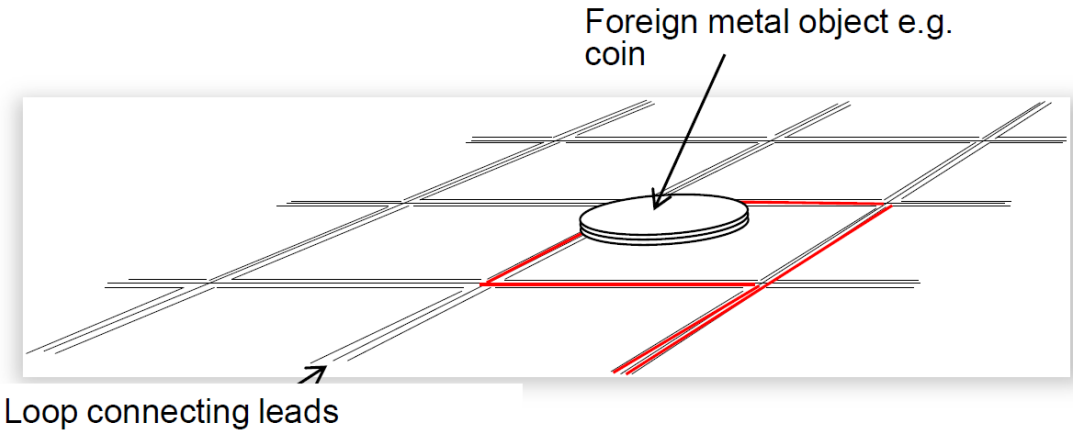
Parasitic heating can also be detected by indirect methods such as in measuring the unexpected power loss between the primary (base) and secondary (vehicle) charging pads.

However, whereas a typical 0.5 watts of potentially hazardous parasitic heating represents a significantly detectable 10 percent on a 5 watt smartphone charging system, it represents only a tiny 0.015 power fluctuation on a 3.3kW WEVC system, which would not be reliably detectable given variability with positioning, vibration and other factors.

Most sensitive and effective FOD can be achieved without direct temperature measurement by employing an array of multiple electrical loops embedded in the base pad above the IPT coil. Associated electronics to drive and monitor the loops can also be integrated in the base pad. The presence and changing temperature of conductive or ferromagnetic materials affects the electrical characteristics of the nearby loops. This enables reliable detection of metallic objects, or their metallic parts, resting on the pad or in the Z-gap.

Exhibit 3

FOD with an array of electrical loops



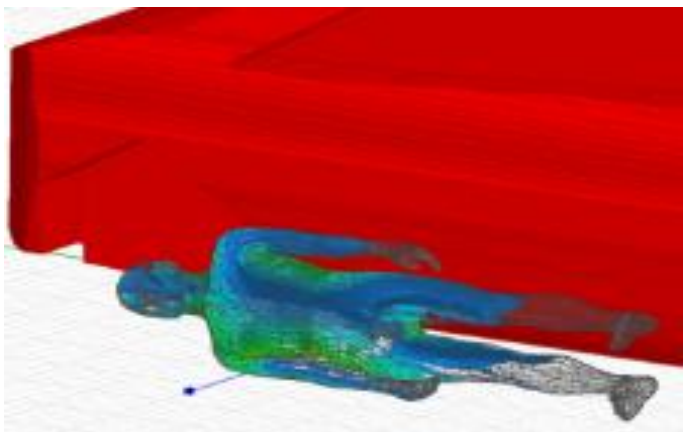
IV. Living object protection

a. LOP safety requirements and challenges

IPT systems can produce electromagnetic fields which exceed the regulated levels for humans and implantable medical devices such as heart pacemakers. Between and around the pads, these emissions may cause potentially adverse health effects to humans and other vertebrates including pets, or erratic operation of IMDs could occur. The human exposure hazards are greatest when somebody lies on the ground by the side of the car and reaches into the gap between the pads with their arm.

Exhibit 4

Human exposure to EMF



EMF radiation must comply with the international safety regulations. International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines have been established to limit human exposure to time-varying EMF with the aim of preventing adverse health effects. The guidelines provide reference safety restrictions of both electric field and magnetic field for occupational exposure and general public exposure.[2] Regulators refer to the ICNIRP guidelines in their development of safety regulations. IMD immunity regulations are set by the American National Standards Institute and the Association for the Advancement of Medical Instrumentation.[3] Automotive OEMs impose more stringent limits in various places around the car (e.g. by the sills) than those in ICNIRP guidelines, in some cases.

Effective LOP systems must ensure that WEVC is immediately shut down when parts of the human body (e.g. a hand, arm or foot) and animals approach the Z-gap zone where field strengths exceed safety limits. Safety regulations are set for humans, including those with IMDs. However, systems must also protect various animals including household pets.

b. LOP methods

Some LOP systems have also suffered from various limitations. These include a tendency to false trigger due to incidental movements around the vehicle or vehicle vibrations, and missed detections: for example, no provisions for sleeping animals (i.e. not moving). Some systems have been located on the vehicle: OEMs now specify that LOP systems must be located off vehicles.

Extensive development of radar technology-based LOP systems significantly improve system operation by eliminating or significantly reducing false triggers. Sensing and signal processing electronics is conveniently contained in the base pad and provides information on object speed and distance from the base pad. The coverage includes a defined area around the perimeter of the base pad and directly above the base pad surface. The coverage will vary depending on the properties of the WEVC system and the vehicle model being charged. Vehicle-specific coverage areas can be defined and then programmed into the LOP system. The LOP system sensitivity is configurable and limits for the minimum size of living objects to be detected can be defined. This balances risks of missed detections with risks of false triggers.

Exhibit 5

Radar detects hand entering zone adjacent to base pad and Z-gap

[2] ICNIRP guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (1hz to 100khz), *Health Physics,* vol. 99, pp. 818-836, 2010
[3] ANSI/AAMI PC69: 2007

V. Safe, trustworthy and future-proof technology supply

Ancillary systems for safety as well as positioning along with core IPT technologies are all required for legally and commercially viable WEVC. And, everything including battery management and other in-vehicle systems needs to be integrated to work well together.

Technology improvement roadmaps must accommodate changes to safety regulations and advances in interoperability standards. For example, WEVC is currently available for parked vehicles but will soon enable charging while vehicles are in motion. Ancillary systems must also be developed accordingly.

Technology supply from an expert systems provider who has all this covered is essential for automotive OEMs and their Tier 1 suppliers. This is the most effective way of ensuring highest-performing and compliant capabilities are available on an ongoing basis. It enables OEMs and Tier 1s to focus on what they do best – developing differentiated and cost-effective products for mass market production.

Further Reading

Wireless Charging Ready for Burgeoning Mass Market in EVs. WiseHarbor Spotlight report, by Keith Mallinson, 18th August 2015
http://www.wiseharbor.com/pdfs/WiseHarbor%20Spotlight%20Report%201%20Efficacy%202015Aug18.pdf

WEVC Requires Many Technologies with Well-Integrated Systems and Supply. WiseHarbor Spotlight report, by Keith Mallinson, 24th August 2015
http://www.wiseharbor.com/pdfs/WiseHarbor%20Spotlight%20Report%202%20System%202015August24.pdf

Loosely Coupled Transformer Structure and Interoperability Study for EV Wireless Charging Systems. By Wei Zhang, Jeff C. White, A.M. Abraham and Chunting Chris Mi. IEEE TRANSACTIONS ON POWER ELECTRONICS, Volume 30, Issue: 11
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=7108053&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel7%2F63%2F4359240%2F07108053.pdf%3Farnumber%3D7108053

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