Designing a Qi-compliant receiver coil for wireless power systems, Part 1

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Overview

The implementation of the Wireless Power Consortium's (WPC's) Qi standard[1] brings wireless power to many different end applications. The receiver (Rx) coil for each application may have different geometries and/or power requirements. Since the Rx coil is a key component in a successful and efficient design of a Qi-compliant Rx and there are many design options and trade-offs to consider, the designer must take a careful and methodical approach when realizing a solution. This article provides the technical insight needed to realize a successful Rx-coil design. It covers the Qi-compliant system model as a basic transformer; Rx-coil measurements and system-level influences; and methods of qualifying a design for successful operation. It is assumed that the reader has a general understanding of the Qi-compliant inductive power system. Background information can be found in Reference 2.

Qi-compliant system as a transformer

For many near-field wireless power systems such as the one specified by the WPC, the behavior of the magnetic power transfer can be modeled by a simple transformer. A traditional transformer usually has a single physical structure with two windings around a core material that is highly permeable compared to air (Figure 1). Since the traditional transformer uses a highly permeable material to carry the magnetic flux, most (not all) of the flux produced by one coil couples to the second coil. This coupling, which can be measured through a parameter known as the coupling coefficient, is denoted as k (a measure that can have a value between 0 and 1).

Three parameters define a two-coil transformer:

L_{11} is the self-inductance of coil 1.

L_{22} is the self-inductance of coil 2.

L_{12} is the mutual inductance of coils 1 and 2.

The coefficient for coupling between the two coils can be formulated as

$$k = \frac{L_{12}}{\sqrt{L_{11}L_{22}}}. \quad (1)$$

The ideal transformer then can be modeled by using a coupled inductor as shown in Figure 2.

Using the voltage and current relationship of an inductor can provide the nodal equations of this two-coil transformer:

$$V_1 = L_{11}\frac{di_1}{dt} + L_{12}\frac{di_2}{dt} \quad (2a)$$

Figure 1. Traditional transformer with one physical structure

Figure 2. Ideal model of a traditional transformer

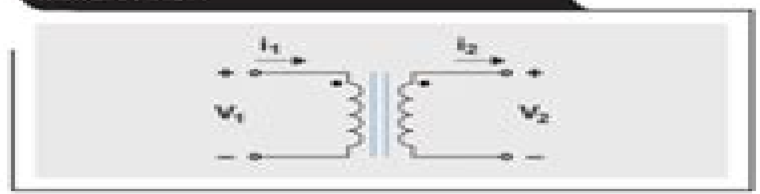
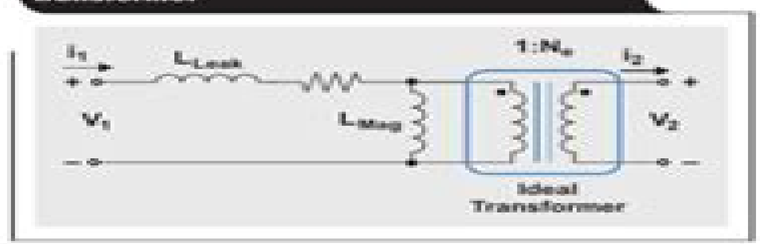


Figure 3. Cantilever model of a traditional transformer



$$V_2 = L_{22}\frac{di_2}{dt} + L_{12}\frac{di_1}{dt} \quad (2b)$$

For circuit analysis, the model in Figure 2 can be represented by what traditionally is referred to as a cantilever model, shown in Figure 3. Here the magnetic coupling and mutual inductance are simplified to leakage and magnetizing inductances. This allows the physical nature of the

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Designing A Qi Compliant Receiver Coil For Wireless Power:

Wireless-Powered Communication Networks Dusit Niyato,Ekram Hossain,Vijay Bhargava,Lotfollah Shafai,2017 A comprehensive introduction to architecture design protocol optimization and application development **Battery Power Management for Portable Devices** Yevgen Barsukov ,Jinrong Qian,2013-05-01 The introduction of Li ion batteries in 1991 created a tremendous change in the handheld devices landscape Since then the energy stored and put to use in palm sized electronic devices has quadrupled Devices are continuously getting more power hungry outpacing battery development Written by leading engineers in the field This cutting edge resource helps you overcome this challenge offering you an insightful overview and in depth guide to the many varied areas of battery power management for portable devices You find the latest details on optimizing charging circuits developing battery gauges that provide the longest possible run time while ensuring data protection and utilizing safety circuits that provide multiple independent levels of protection for highly energetic batteries This unique book features detailed design examples of whole systems providing you with the real world perspective needed to put this knowledge into practice You get the state of the art know how you need to perfect your device designs helping you make them strong competitors in the fast growing portable device marketplace *Modern Stroke Rehabilitation through e-Health-based Entertainment* Emmanouela Vogiatzaki,Artur Krukowski,2015-09-08 This book describes a new e Health approach to stroke rehabilitation The authors propose an alternative approach that combines state of the art ICT technologies ranging from Augmented and Virtual Reality gaming environments to latest advances in immersive user interfaces for delivering a mixed reality training platform along with advanced embedded micro sensing and computing devices exhibiting enhanced power autonomy by using the latest Bluetooth Smart communication interfaces and energy saving approaches These technologies are integrated under the umbrella of an online Personal Health Record PHR services allowing for delivery of personalized patient centric medical services whether at home in a clinic or on the move Describes innovative ways for achieving mixed reality gaming environments Enhances immersive experience by combining virtual projections with user interfaces based on body motion analysis Offers cost effective body motion capture by hybridizing wearable sensor data Utilizes energy efficient micro embedded sensors for wearable physiological and sensing and activity monitoring applications Includes innovative power autonomous sensing using Body Area Networks Describes the prototype of the portable integrated rehabilitation training solution **Modern Standardization** Ron Schneiderman,2015-03-27 This book includes a collection of standards specific case studies The case studies offer an opportunity to combine the teaching preferences of educators with the goals of the SEC Standards Education Committee providing students with real world insight into the technical political and economic arenas of engineering Encourages students to think critically about standards development and technology solutions Reinforces the usage of standards as an impetus for innovation Will help understand the dynamics and impacts of standards A curriculum guide is available to instructors who have adopted the book for a course To obtain the guide please send a request to ieeeproposals wiley com

Artificial Intelligence-Empowered Modern Electric Vehicles in Smart Grid Systems Aparna Kumari,Sudeep Tanwar,2024-05-23 Artificial Intelligence Empowered Modern Electric Vehicles in Smart Grid Systems Fundamentals Technologies and Solutions is an essential reference for energy researchers graduate students and engineers who aim to understand the opportunities offered by artificial intelligence for the integration of electric vehicles into smart grids This book begins by building foundational knowledge for the reader covering the essentials of artificial intelligence and its applications for electric vehicles in a clear and holistic manner Next it breaks down two essential areas of application in more detail energy management from to energy harvesting to demand response and complex forecasting and market strategies including peer to peer vehicle to vehicle and vehicle to everything trading plus the cyber security implications A final part provides detailed case studies and close consideration of challenges including code and data sets for replication of techniques Providing a clear pathway from fundamentals to practical implementation Artificial Intelligence Empowered Modern Electric Vehicles in Smart Grid Systems will provide multidisciplinary guidance for implementing this cutting edge technology in the energy systems of the future Supports fundamental understanding of artificial intelligence and its opportunities for energy system specialists Collects the real world experiences of global experts Enables practical implementation of artificial intelligence strategies that support renewable energy integration across energy systems markets and grids Parkinson's Disease: Technological Trends for Diagnosis and Treatment Improvement Joan Cabestany,Antonio Suppa,Gearóid ÓLaighin,2023-03-20 **Low-Cost Sensors and Biological Signals** Frédéric Dierick,Fabien Buisseret,Stéphanie Eggermont,2021-05-31 Many sensors are currently available at prices lower than USD 100 and cover a wide range of biological signals motion muscle activity heart rate etc Such low cost sensors have metrological features allowing them to be used in everyday life and clinical applications where gold standard material is both too expensive and time consuming to be used The selected papers present current applications of low cost sensors in domains such as physiotherapy rehabilitation and affective technologies The results cover various aspects of low cost sensor technology from hardware design to software optimization **Electronics World** ,2016 *Scientific American* ,1907 **Index to IEEE Publications** Institute of Electrical and Electronics Engineers,1994 Effect of Receiver Coil Diameter on the Power Transfer Capability for 5 KHz Wireless Power Transfer System Muhammad Najmul Fadli,2022 This study was conducted to design and construct a WPT system The WPT system uses a 5 kHz of frequency The circuit converts a DC source to an AC voltage by a single phase half wave bridge inverter consisting of 12 transistors TIPC35C 6 transistors each polarity Furthermore this study only uses the PIC16F628A microcontroller in the pulse driver to generate a frequency of 5 kHz not NE555 IC The technique used is an electromagnetic field inductive resonance technique by making a solenoid shaped copper coil used to produce a mutual inductance Mutual Inductance M that showed on the picture is the interaction of one coil s magnetic field on another coil as it induces a voltage in the adjacent coil Nataraj et al 2017 The 5 kHz WPT system in this study uses a receiving coil varied in 3 different diameters some of them are a receiver coil with 50 cm of diameter coil 50 receiver coil with 16 cm of diameter coil 16 and 9 cm of diameter coil 9 Although the diameter is different the inductance value for each receiver coil is the same While the transmitter coil only uses a coil with a diameter of 50 cm Furthermore The study was conducted by comparing the simulation results and the results of direct data measurements of the WPT system by multimeters WPT system simulation was carried out using PSIM and then the resulting data were processed using MATLAB and Microsoft Excel This study does not use LTSpice as an application to perform simulations When the simulation can be run hardware is built for the WPT system with a system frequency of 5 kHz Moreover in this study multi receiver settings are also used to compare the effect of adding a receiver coil to the WPT system output The receiver coil is arranged in alignment with the transmitter coil which means the distance between the transmitter coil and the receiver coil or multi receiver coil are the same Dual-Band Coil Module Design for Near-Field Wireless Power Transfer Systems □□□,2017 **Design Methodologies for Low Flux Density, High Efficiency, KW Level Wireless Power Transfer Systems with Large Air Gaps** ,2013 The objective of this work is to investigate resonant circuit and magnetic component design methodologies for multi kW MHz frequency over 95% coil to coil efficiency and large distance 20 40cm wireless power transfer systems that achieve very low flux density in the air gap Design methodologies for resonant circuits as a part of a magnetically coupled system using lumped parameter equivalent circuit models have been proposed A new design concept the feasible design space has been proposed which shows the combinations of the transmitter and receiver coils reactances that satisfy given voltage and current limits of the circuit Using the feasible design space the transmitter and receiver coil geometries which result in low flux density high efficiency high control stability etc have been calculated The trade offs between the system performances vs transmitter and receiver coil geometries design have been demonstrated graphically The optimal transmitter and receiver coils geometries have been selected from a new objective function The proposed design methodology has been evaluated by means of FEA and experimental analysis As a second focus of this research a new magnetic component design methodology for improving power transfer efficiency at MHz operation has been investigated in this research A new conductor layout methodology called surface spiral winding SSW was proposed and FEA models showed that it is effective in decreasing Ohmic losses and in increasing coupling coefficient between the transmitter and receiver Design methodologies for the SSW coils have been proposed using analytical equations and FEA results The proposed design methodologies have been evaluated via FEA and experimental analysis Thermal modeling of the SSW coils has been developed and experimentally evaluated In the last part of this research the impact of coil misalignment is investigated By assuming the transmitter and the receiver coils as filaments the mutual inductance of large air gap wireless power transfer systems has been calculated The analytical mutual inductance calculation was evaluated by FEA and experiments The impacts of coil misalignment on the magnetic flux density resonant frequency power capability and efficiency have been investigated and the theoretical analyses were evaluated by means of FEA and experimental results *Inductive Wireless Power Transfer for RFID & Embedded Devices* Kyriaki Fotopoulou,2009 **Design of a Wireless Power Supply Receiver for Biomedical Applications** Noorul Amin Abdul Samad,Tharshan Valthlanathan,Syed Mahfuzul Aziz,Christopher Eric Brander,2006 **Efficient Wireless Power Transfer with Capacitively Segmented RF Coils** Sebastian Stöcklin,Adnan Yousaf,Gunnar Gidion,Leonhard M. Reindl,2020 Abstract Wireless power transfer systems have been widely applied in the field of portable and implantable devices featuring contact free and reliable energy supply Novel implant systems such as brain computer interfaces impose the challenges of strong miniaturization and operation under loosely coupled conditions Therefore maximizing power transfer efficiency while decreasing the size of transmitter and receiver structures becomes a central research question This paper presents a unified design strategy of modeling analyzing and optimizing planar spiral coils with integrated capacitive elements so called capacitively segmented coils for operation in wireless power transfer interfaces It mathematically analyzes and experimentally verifies that the combination of capacitive coil segmentation increased operational frequencies and geometrical coil optimization can be used to establish wireless power transfer links with comparatively high efficiency small size and limited detuning effects in lossy dielectric environments The paper embraces the formulation and verification of a broadband analytical link model based on partial element equivalent circuits which is subsequently used to determine dominant coupling and loss mechanisms and to optimize the coils geometries for high efficiency Moreover an extended analysis shows how the capacitive coil segmentation can effectively suppress dielectric losses and non uniform current distributions by canceling the inductive contribution of every coil segment at the frequency of operation Utilizing these methods an exemplary 40 68MHz wireless power link with a 30mm primary and a 10mm secondary coil is designed and evaluated With a maximum efficiency of up to 31% in biological tissue at 20mm separation distance it features efficiency levels which are up to ten times higher and a specific absorption rate which is up to five times lower compared to non segmented systems When operated at 150MHz in air efficiency levels are up to 1 5 times higher than in state of the art systems of the same size *An Interface Design of Wireless Power Transfer Receiver with Impedance Adjustment for Maximum Power Transfer* Yi-Chia Chen,2016 **Design, Analysis, and Application of Multiple-frequency Multiple-receiver Wireless Power Transfer** □□□,2019 **Time-domain Modeling of Wireless Power Transfer in Motion Using Inductively Coupled Flat Spiral Coils** Joshua Nathan Turnbull,2020 In current commercial technologies wireless power transfer WPT occurs when the item charging and the charger are not in motion Products such as wireless chargers for cell phones cars and some internet of things IoT devices have stationary wireless chargers A limiting factor of these chargers is in a single transfer coil system the coils need to be aligned perfectly and the device must be physically touching the charger If it is not minimal or no power is transferred and the device is not charged

This set up allows manufacturers to simplify design and modeling as a steady state system In this thesis the receiving coil is in motion over the embedded transfer coil The industrial standard to discern how the system would react uses finite element analysis FEM which is very resource intensive and time consuming The point of this thesis is to model and approximate the potential of a WPT system to help discern the viability of designs therein reducing the number of resources and time necessary to find an optimum solution A Series Series Compensated Wireless Power Transfer circuit was solved using Thevenin Equivalent Circuits and converted into a state space equation Using MATLAB and Simulink the circuit was modeled and compared to another study to validate the results Variables such as frequency load resistance vertical and horizontal offset were then changed to see how the output voltage waveform and power transfer changed Due to the receiving coil s motion a steady state is not reached and the system has transient states The effects on the waveforms thoughts about optimization and possible future studies are discussed **Large Area Wireless Power Transfer with Coupled Relay Resonators** Xingyi Shi,2019 Emerging wireless charging technologies will become essential for medical implants which currently require cables passing through patients skin in order to provide power or force the patient to undergo costly surgery operations to replace dead batteries Likewise makers of sensors and devices used on the factory floor are increasingly looking towards wireless power to eliminate the need for battery changes and eliminate downtime Even the ever increasing number and diversity of consumer electronics such as smartphones laptops wearables and VR headsets will benefit from wireless power solutions that make battery charging more convenient Commercially available wireless chargers such as those implementing the Qi standard partially address the problem Qi chargers can typically charge only one device at a time and require precise alignment of transmitter and receiver and so are not effective as the number of electronics that need to be charged increases Magnetic resonance wireless power transfer systems which use resonant coils as transmitters have greater range and tolerance to misalignment However the size of the transmitter cannot be arbitrarily increased to fit any large area because large transmitter to receiver size ratios result in extreme inefficiency As an enhancement on magnetic resonance phased array transmitters explored in academic research can extend transmission range However they have the tradeoff of increased cost and complexity because each array element requires an independent RF source Non magnetic methods of wireless power transfer such as radiative ultra high frequency beaming and tracking laser systems have more extended power transfer range but much less efficiency and they both have lower output power limits due to safety regulations So whereas these methods may be useful for devices that only need small amount of energy and require long separation distances they cannot be used for systems that require high power output while still being safe for use near humans and animals This dissertation focuses on the design of a wireless power transfer solution that can provide efficient wireless charging over a large area can tolerate some amount of separation and misalignment can charge multiple devices at the same time at a reasonable complexity and cost and can do all of this while staying well within safety regulations To achieve this we introduce an adaptive passive wireless relay system to extend power transfer range A prototype of a centrally controlled array of reconfigurable relays CARR is implemented that can deliver power to multiple moving receivers We show that the relay system is much more efficient at delivering power to small receivers over a large area than a single transmitter system and has better uniformity of coverage The CARR prototype can identify and adaptively route power to a new or moving receiver in as little as 120 microseconds Additionally a method for enabling large area power transfer without a large transmitter is introduced which proposes to use receivers themselves as relays when many receivers are in close proximity We demonstrate a key step towards realizing this receivers as relay system by showing that a suitable routing configuration for delivering power to receivers can be identified using a load modulation technique Finally in evaluating the safety of magnetic resonance systems we conclude an interesting feature of coupled resonator systems which reduces safety concerns by reducing the SAR a measure of the energy absorbed by biological tissue

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