THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

ENGINEERING

ELECTENG 734 - Power Electronics

Wirelessly Powered RC Car Race

Project Brief – 2023

1. Project Overview

Inductive Power Transfer (IPT) technology, which has been used in a wide variety of applications, is currently the preferred technology for wireless electric vehicle (EV) charging. At present, IPT based EV chargers facilitate both uni- and bi-directional power transfer at power levels ranging up to tens of kilowatts, and efficiencies as high as 97 %. Over the last few years, specifications and guidelines for IPT based stationary wireless EV chargers, for example SAE J2954, have been introduced to ensure interoperability between various charging systems. The majority of IPT based EV charger technologies, developed to date, are for stationary charging applications, located in garages, public and on-street parking spaces, etc. However, with the maturity of IPT based stationary charging technologies, the focus has recently shifted towards the development of IPT based in-motion EV charging systems. They are also referred to as semi-dynamic and dynamic charging systems, where EVs are charged while driven along an electrified section of a road.

The goal of this project is to convert a radio-controlled (RC) model car, which is originally designed to operate with a 9.75 V NiCad battery pack, to a wirelessly powered car when driven along an electrified racing track. The project intends to introduce students to some key technologies used in dynamic IPT EV charging systems, offering valuable design experience. During the project, you are expected to work as a team of two students to design and develop a wireless power receiver system. The functionality and the performance of your prototype will be tested by driving the RC car, fitted with your wireless power receiver system, on both straight and oval electrified race tracks, each with a length of approximately 15 m and a width of approximately 180 mm. The race track has six wires buried under the surface that are driven by a three-phase IPT primary converter to generate approximately 30 A_{rms} at 38.4kHz producing a changing magnetic field above the roadway surface. The prototype wireless power receiver system, developed to replace the battery, will be mounted inside the battery compartment under the RC car to capture this magnetic field and wirelessly power the RC car while driven along these race track.

Teams that successfully construct a prototype will be given the option to compete with other teams in the 2023 Challenge Race event scheduled to be held on the last day of the semester.

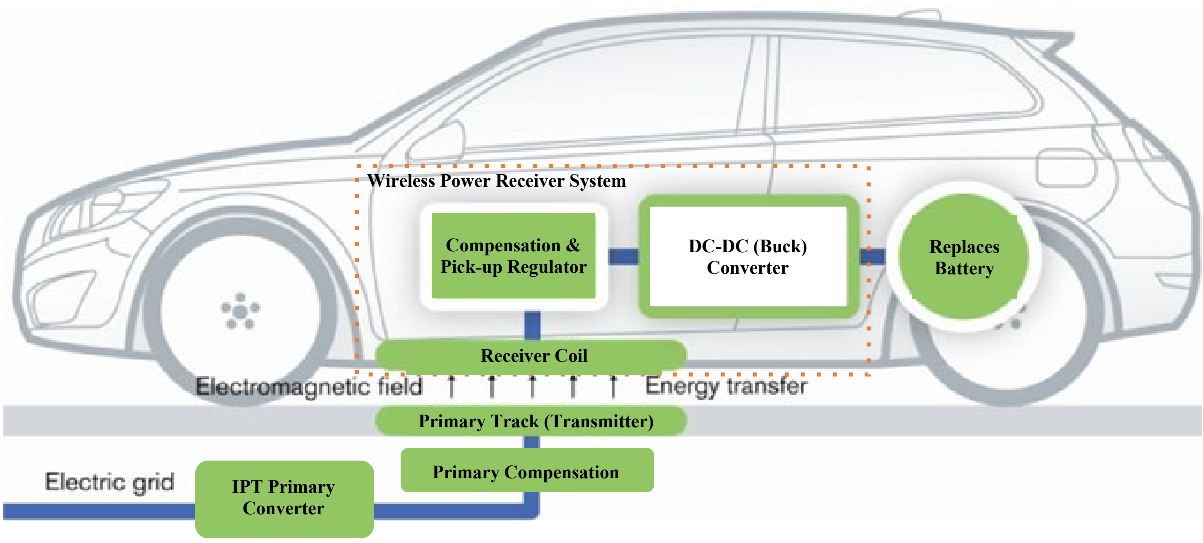

Fig. 1 A system diagram of the wirelessly powered RC car design

2. Design Specifications

As shown in Fig. 1, the wireless power receiver system that you will develop during the project has two stages that are operated together in series to emulate the functionality of the battery. The converter in the first stage is an IPT pick-up regulator, whose function is to extract power from the electrified track and generate a regulated output voltage to power the second converter stage. The second stage comprises a DC-DC Buck converter that provides the RC car with a regulated voltage of 9.75 V, emulating the Ni-Cad battery.

2.1 IPT Pick-Up Regulator

The pick-up regulator has a receiver coil, L_2, which is wound on a ferrite bar with N number of turns. When L_2 is placed near the electrified racing track (transmitter), a voltage is induced. As a result, when coil L_2 is shorted, a short-circuit current, I_{sc}, is generated. The short circuit current dictates the maximum amount of power that can be supplied to the RC car. The selection of compensation networks as well as the design of the receiver coil play a vital role in the performance of the overall system. Specifications limit the amount of power that is available to drive the RC car. Thus, your design should strictly comply with the design specifications listed in Table I. Note that under set primary operating conditions, a standard pick-up regulator design will only be able to deliver about 20 W to the DC-DC converter.

Table I Pick-up regulator specifications

Parameter	Symbol	Value	Unit
Nominal IPT track frequency	f_1	38.4	kHz
Dimensions of ferrite slab	LxWxD	100 x 60 x 20	mm
Minimum pickup inductance	L_2	24	µH
Minimum number of turns on pick-up coil	N	19	
Maximum average output voltage	$V_{o1,max}$	16	V_{dc}
Maximum output voltage ripple (peak to peak)	ΔV_{o1}	0.5	V_{pk-pk}
Maximum output current under short-circuit[1]	$I_{o1,max}$	1.4	A_{dc}
DC inductor core – type	L_{DC}	Drum core	
DC inductor core – inductance per square turn	A_l	52	nH
DC inductor core – winding area	A_w	36	mm^2
DC inductor core – mean turn length	l_e	31.5	mm
DC inductor core – effective core area	A_e	28.3	mm^2
Compensation topology	L_2 must be parallel compensated		
Controller architecture	Hysteretic controller		
L_2 coil assembly	Directly under chassis either side of front axel		

[1]When receiver coil is placed 10 mm above the racetrack (at the centre as well as 20 mm from the side of the track)

Table II DC-DC converter specifications

Parameter	Symbol	Value	Unit
Maximum switching frequency	f_s	150	kHz
Nominal average output voltage	$V_{o2,nom}$	9.7	V_{dc}
Maximum output voltage ripple	ΔV_{o2}	0.1	V_{pk-pk}
Maximum average output voltage	$V_{o2,max}$	9.80	V_{dc}
Nominal load range	R_L	2 to 10	Ω
Buck inductor core – type	L_{DC2}	EFD20	
Buck inductor core – material		N87	
Buck inductor core – supplier		TDK	
PWM controller		UC3843	
Over voltage protection	Independent active protection scheme to shut-down the PWM controller		

2.2 DC-DC Converter

The Buck converter receives power from the pick-up regulator and steps-down the input voltage to 9.7 V or lower to supply the RC car. The converter and the controller should be designed with fast acceleration and high speed in mind, while staying within the design specifications listed in Table II. It should be noted that the limited power throughput of the pick-up regulator and the limited controllability offered by standard peak current-mode controllers significantly impact the acceleration performance of the RC car. Thus, students are encouraged to explore innovative solutions to improve the peak current mode controller design and thus the performance of the DC-DC converter.

3. Project Assessment

The assessment components with associated weightings are shown in Table III. Note that all assessment components, except the Challenge Race, are compulsory for the course. Although this project will be undertaken in design teams of two, encouraging students to work together as a team, each student is required to learn all aspects of the design.

Table III Assessment components and associated weightings

Component	**Weighting**
Labs	10 %
Assignments	15 %
Test	30 %
Design report	25 %
Bench test and interviews	17 %
Time trials	3 %
Challenge Race	Optional

3.1 Test

One written test worth 30 % will assess your understanding of the fundamental power electronics and IPT concepts taught during the course. The tests will be held in closed book conditions with the restricted calculator (RC) policy and checked for academic integrity.

3.2 Labs

Each team must complete the DC-DC converter and pick-up regulator simulation lab assignments. The labs are worth 5% each and are designed help students gain an insight into the operating principles of power converters and their limitations. Partially completed PLECS simulation models will be provided for both the IPT pick-up regulator and the DC-DC converter through Canvas. As indicated in the course outline, support sessions will be conducted prior to lab assessments to help students complete these assignments.

At the completion of the lab assignment, each team must sign-up and attend a 20-minute interview for assessment by a graduate teaching assistant (GTA) or the lecturers who will assess each team member individually by asking questions relating to the lab assignment. Each team member will also be asked to run the simulations and satisfactorily explain the output waveforms obtained as well as the related design calculations. Therefore, you are expected to show the completed (team) PLECS simulation models and your own (i.e., individual) logbook (can be in a digital format such as OneNote). Your final grade will be mainly based on your (individual) understanding as well as completing the tasks in the lab assignments.

Note: You will not be allowed to change/re-do/work on your lab assignment during the interviews.

3.3 Assignments

Three assignments are required to be completed individually. The assignments will cover various aspects of the course to reinforce the course material. The assignments are based on the assigned text: *Erickson, R. and Maksimović, D "Fundamentals of Power Electronics", Second Edn (Springer, 2001)*.

3.4 Design Report

A team report, worth 25%, detailing the preliminary design, must be submitted strictly adhering to the report templates. The templates are provided to guide you through the design of your pick-up regulator and the DC-DC converter. You are expected to work on the report as a team, but must share the work evenly. Both team members must fully understand all aspects of the design as well as the design decisions/compromises that you have made. Your design report must include,

I. A cover page with a declaration of originality
II. Completed Excel design calculation sheets for both the pick-up regulator and the DC-DC converter
III. Formula sheets showing all equations (referenced to equation numbers indicated in the Excel sheets) used for the pick-up regulator and the DC-DC converter design calculations
IV. Detailed Altium schematic diagrams of your proposed pick-up regulator and DC-DC converter (including over voltage protection circuit) designs indicating appropriate component values and part numbers

You must combine the above documents into a single PDF file and electronically submit it via Canvas. The technical accuracy of your design calculations and the viability of the proposed solutions will be assessed to allocate your report marks.

3.5 Bench Test and Interview

A bench test (10% of total course) and a technical interview (7% of total course) will assess the functionality of your completed pick-up regulator and the DC-DC converters as well as your understanding of the subject matter. The pick-up regulator and the DC-DC converter will be tested individually to make sure that each design meets the specifications listed in Section 2 (under loaded conditions as well as no load conditions). Designs failing to meet the specifications will be given penalty marks (marked down) as appropriate. The designs will also be assessed for quality and innovation where appropriate. After demonstrating both designs to an assessor, they will interview both team members individually to assess the student understanding of the design. You must bring your logbook, updated schematics, and updated design report to the interview.

3.6 Time Trials

The performance of the pick-up regulator and the DC-DC converter will be tested in the laboratory. Marks (3% of the total course) are awarded based on the the time each car takes to reach the finish line. The performance of your team design will be graduated as a function of class performance. Designs failing to meet the specifications will be given penalty marks (marked down) as appropriate.

3.7 Challenge Race

Performance of the time trials will be used to select the top eight designs for the Challenge Race. If there are two or more groups of equal marks for the eighth position, then they will be required to race against each other to determine which group makes it to the top 8. The time trial rankings will automatically determine who races against each other in a series of knock-out races to determine the winner of the Challenge Race. The race will take place on a velodrome racing track, with top groups starting either side and having to complete 3 laps. RC cars will be provided to each of the teams, and guide rails are not permitted during these races.

3.8 Peer Assessment

At the conclusion of the semester, each member of the design teams MUST submit a confidential peer assessment. This should outline the work and contributions of your partner and yourself, commenting on how well the team worked as a team and the problems that were encountered, if any. Late submissions and poor work ethics or contributions to the project will lead to a penalty of up to 40% of your final grade.

4. Resources Available to Students

4.1 Staff

Lecturers:	Seho Kim, Jackman Lin, Matthew Pearce
Technician:	Howard Lu (Power Electronics Lab, Email: h.lu@auckland.ac.nz)
Teaching Assistants (TAs):	Brian Gu, Cody Liu, Aaron Wadsworth, Zhongzheng Lin, and Patrick Lawton

4.2 Assistance in Multi-disciplinary Learning Spaces (MDLS)

The Multi-disciplinary Learning Spaces are equipped with instrumentation and test fixtures required for the project and have been reserved for ELECTENG734 at specific time periods as laboratories as shown in the course outline. ***All students must attend these specified time periods.*** Staff/GTAs will be available during these designated time periods to assist with any project or course related issues.

4.3 Remote Learning Support

Software, such as MATLAB, PLECS and Altium that are required for this course is provided on FLEXIT. In case students want to run some of the software on their personal machines, steps on attaining the software are shown on Canvas.

4.4 Hardware and PCBs

A prefabricated PCB for both the DC-DC converter along with schematic and PCB files will be provided. A populated pick-up regulator will also be provided to you. You are encouraged to use these, with modifications if needed, to implement your prototype wireless power receiver. Each design team will be given a component pack containing specialised components required for the design. Other general components required for this project will be available through the ECE Stores. You will also be able to collect a load bank consisting of 2 Ω, 4 Ω and 10 Ω high-power resistors to test your DC-DC converter.

4.5 Notices/ Communication

The communications related to this course will be on university email, Canvas and Teams.

4.6 Lecture notes

OneNote is the primary method of note-taking in the class. Students will receive access to the class notebook and can use OneNote to keep up to date with the lectures. Students can also use OneNote as a digital logbook.

5. Logbooks

All students are expected to maintain a logbook in which their design decisions, calculations, simulation results, hardware test results, etc. should be recorded. You are expected to use the logbook during interviews and lab assessments to support your answers. Logbooks can be in a digital format such as OneNote.

6. Project Groups

You are allowed to choose your own project partner. However, make sure that both of you are available to attend most of the support session together as a group. Once you know your project partner, you should register your group details on Canvas under People -> Teams. This should be done as soon as possible or before the end of second teaching week of Semester 1. Otherwise, all remaining students will be teamed up randomly.