

Training in CERN (CMS Agreement with SQU)

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1 Introduction

"CERN, located near Geneva in Switzerland, is the European Organization for Nuclear Research, the world's largest particle physics centre. Here physicists come to explore what matter is made of and what forces hold it together. CERN exists primarily to provide them with the necessary tools. These are accelerators which accelerate particles to almost the speed of light and detectors to make the particle visible. Founded in 1954, the laboratory includes now 20 Member States." [1]

During my stay in CERN for building the CMS Robot Wireless Charging Station, several tasks were researched, studied thoroughly and implemented.

Wireless Transmission is a technology that has been studied since 1819, when

H.C.Oersted discovered that electric current generates magnetic field. As a concept point of view, it is the transfer of energy from one object to another without being them in contact. laws of energy states that the energy is reserved and

changing from one form to another considering the losses.

Technically,[1] defines wireless charging as power transmitting power through air gap to electrical devices for the purpose of energy replenishment.

As this project focuses on harvesting energy from two forms, inductive coils as magnetic field and RF energy, the constant method to be discussed is the flat spiral coils, where design comparison will be applied, for quality and efficiency studies.

The reason for choosing wireless transfer of energy is the user-friendliness as having contact-less energy transfer, as less wires are used in the cavern where a need of shield for magnetic field and cost resources are cut. In addition to adding the flexibility and spatial freedom for charging more than one battery at a time placed in different positions on the inspection robot in CMS cavern.

Different consortium standards were studied as an option, such as Wireless Power Consortium (WPC), Power Matters Alliance (PMA), and Alliance for Wireless Power (A4WP). Based on these standards, different techniques were adopted mainly subdivided to non-radiative coupling based and radiative RF-based, examples of non-radiative coupling are: inducting, magnetic resonance and capacitive coupling. Examples on RF coupling are: RF power beamforming. Technologies introduced based on application and shapes of coils and coupling method including:

a) Witricity Systems, b) Tesla coils, c) Wardencliff Tower, d) JPL's Foldstone Facility, e) Qi Charging, f) Magnetic MIMO System, g) Microwave-Powered Airplane, h) Directional, Array and loop Antennas, i) Powercaster transmitter and harvester.

A complete paper study on the wireless charging technologies: fundamentals, standards, and network applications can be referred to in reference [2].

The most common standards and techniques used in induction harvesting are: Qi, Power Matters Alliance PMA, Alliance for Wireless Power A4WP, simultaneous wireless information and power transfer (SWIPT), Wireless Power Consortium (WPC) and wireless powered communication network (WPCN).

The phenomena of air coupled (energy induced harvesting) started in 1819 when the investigation into electromagnetism by H.C. Oersted leading to the discovery of magnetic field generated by electric current in a wire. Progressing to Ampere's law, Biot-Savart's law and Faraday's law to derive a model representing the properties of magnetic field, however, the biggest study to characterize how electric and magnetic fields are generated and altered by each other was implemented in Maxwell's equations in 1864.[3]

2 Objectives and Tasks

The Tasks are:

- 1- Research on CMS cavern.
- 2- Different required courses to access CMS cavern at point 5.
- 3- Research on best batteries to be used in CMS cavern.
- 4- Research on Wireless Charging techniques to find the most appropriate for use.
- 5- Visiting p.5 and studying the cavern to allocate the station requirements and base.
- 6- Research and testing on some simple electro-magnetic circuits as toroidal inductance.
- 7- Design Comparison between Induction and RF Harvesting in Building Wireless Charging Station for CMS Inspection Robot As A Summer Student Project.

3 Aim

To build a wireless charging station inside CMS cavern, which is capable to charge fast and couple from a distance.

4 Tasks

1. Research on CMS cavern

"The Compact Muon Solenoid (CMS) is a general-purpose detector at the Large Hadron Collider (LHC). It has a broad physics programme ranging from studying the Standard Model (including the Higgs boson) to searching for extra dimensions and particles that could make up dark matter. Although it has the same scientific goals as the ATLAS experiment, it uses different technical solutions and a different magnet-system design.

The CMS detector is built around a huge solenoid magnet. This takes the form of a cylindrical coil of superconducting cable that generates a field of 4 tesla, about 100,000 times the magnetic field of the Earth. The field is confined by a steel "yoke" that forms the bulk of the detector's 14,000-tonne weight.

An unusual feature of the CMS detector is that instead of being built in-situ like the other giant detectors of the LHC experiments, it was constructed in 15 sections at ground level before being lowered into an underground cavern near Cessy in France and reassembled. The complete detector is 21 metres long, 15 metres wide and 15 metres high.

The CMS experiment is one of the largest international scientific collaborations in history, involving 4300 particle physicists, engineers, technicians, students and support staff from 182 institutes in 42 countries (February 2014). [4]"

5 Introduction CMS cavern

Compact Muon Solenoid (CMS) is an experiment to explore particle physics at TeV energy scales, for proton-proton collisions delivered by Large Hadron Collider (LHC) at CERN. It was officially full readiness for first LHC beams in September 2008. CMS solenoid magnet detector operate at field of 3.8T, 100 m underground. Picture below shows the experiments operating in CERN, also the location of the intended training in CMS.

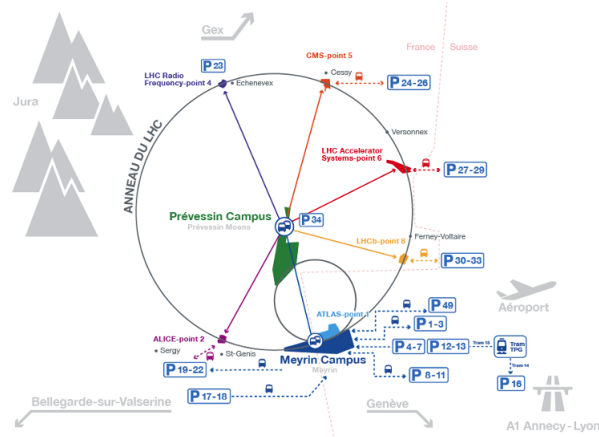


Figure 1: CERN experiments

General view of the CMS detector. The major detector components are indicated, together with the acronyms for the various CMS construction modules in figure below:

“description of the CMS experiment, illustrated in Fig. above. The central feature of the CMS apparatus is a superconducting solenoid of 6m internal diameter, 13m length, and designed to operate at up to a eld of 4T. The magnetic ux generated by the solenoid is returned via the surrounding steel return yoke—approximately 1.5m thick, 22m long, and 14m in diameter—arranged as a 12-sided cylinder closed at each end by endcaps.

To facilitate pre-assembly of the yoke and the installation and subsequent maintenance of the detector systems, the barrel yoke is subdivided into ve wheels (YB0, YB1, and YB2, as labeled in Figure above) and each end cap yoke is subdivided in to three disks (YE1, YE2, and YE3). Within the eld volume are the silicon pixel and strip trackers, the lead tungstate crystal electromagnetic calorimeter (ECAL), and the brass-scintillator hadronic calorimeter (HCAL). Muons emerging from the calorimeter system are measured in gas-ionization detectors embedded in the return yoke. CMS uses a right-handed coordinate system, with the origin at the nominal interaction point, the x-axis pointing

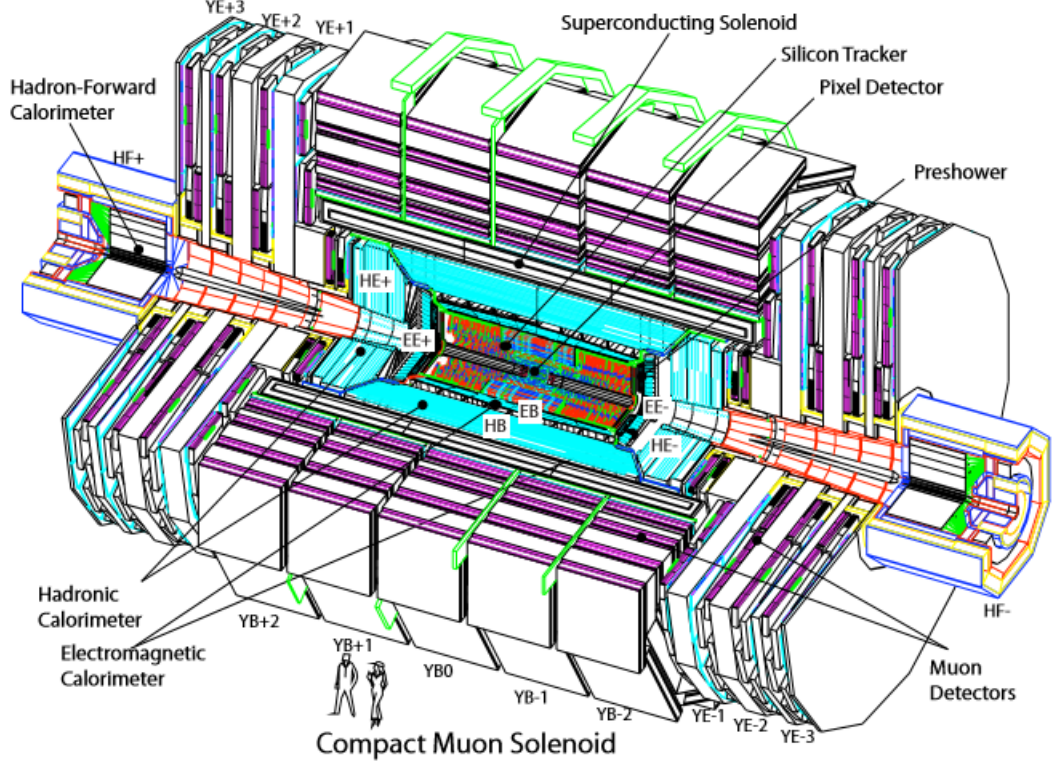


Figure 2: CMS

to the centre of the LHC, the y-axis pointing up (perpendicular to the LHC plane), and the z-axis along the anticlockwise-beam direction. The polar angle, θ , is measured from the positive z-axis, and the pseudorapidity is defined as $\eta = \ln \tan(\theta/2)$. The azimuthal angle, ϕ , is measured in the x-y plane.

Charged particles are tracked within the pseudorapidity range $|\eta|$ less than 2.5. The silicon pixel tracker consists of 1440 sensor modules containing a total of 66 million 100150 μm^2 pixels. It is arranged into three 53.3cm long barrel layers and two endcap disks at each end.

The crystals in the endcap have a transverse area of 33cm² at the rear and a longitudinal length of 24.7 radiation lengths. Scintillation light from the crystals is detected by avalanche photodiodes in the barrel region and by vacuum phototriodes (VPT) in the endcaps. A preshower detector comprising two con-

secutive sets of lead radiator followed by silicon strip sensors was mounted in front of the endcaps in 2009, after the CRAFT period, and has a thickness of three radiation lengths. The HCAL barrel (HB) and endcaps (HE) are sampling calorimeters composed of brass and scintillator plates with coverage $-\pi < \eta < \pi$. Their thickness varies from 7 to 11 interaction lengths depending on η ; a scintillator “tail catcher” placed outside of the coil at the inner 3 most muon detector extends the instrumented thickness to more than 10 interaction lengths everywhere.

In the HB, the tower size is $\Delta\eta = 0.087$. Each HB and HE tower has 17 scintillator layers except near the interface of HB and HE. The scintillation light is converted by wavelength-shifting fibres embedded into the scintillator tiles, and is then channeled to hybrid photodiodes (HPD) via clear optical fibres. Each HPD collects signals from up to 18 different HCAL towers. The Hadron Outer (HO) calorimeter comprises layers of scintillators placed outside the solenoid cryostat to catch the energy leaking out of the HB. Its readout is identical to that of the HB and HE. Quartz fibre and iron forward calorimeters (HF), read out by photomultipliers, cover the $|\eta| < 3.0$ range between 3.0 and 5.0, which corresponds to the conical central bore of each endcap yoke. Three technologies are used for the detection of muons: drift-tubes (DT) in the central region ($|\eta| < 1.2$), cathode strip chambers (CSC) in the endcaps ($1.2 < |\eta| < 2.4$), and resistive plate chambers (RPC) throughout barrel and endcap ($|\eta| > 2.4$ and less than 1.6). The DT system comprises 250 chambers mounted onto the η wheels of the barrel yoke and arranged into four concentric “stations” interleaved with the steel yoke plates. Each chamber is built from a sandwich of 12 layers of drift tubes with 4.2cm pitch, and is read out with multiple hit capability. Eight layers have wires along z and measure the z coordinate; four layers have wires perpendicular to the z -axis and measure η (except for the outermost DT station where there are no z measuring layers).

The CSC system is made of 468 chambers mounted on the faces of the endcap disks, so as to give four stations perpendicular to the beam pipe in each endcap. Each chamber has six cathode planes segmented into narrow trapezoidal strips projecting radially from the beam line, and anode wires aligned perpendicularly to the strips (wires for the highest- η chambers on YE1 are tilted by 25 to compensate for the Lorentz angle). The barrel RPC system is mounted in the same pockets in the yoke wheels as the DT system, but with six concentric layers of chambers. Each endcap RPC system consists of three layers mounted on the faces of the yoke disks. Each RPC chamber contains two gas gaps of 2mm thickness, between which are sandwiched readout strips that measure the z coordinate. The gaps work in saturated avalanche mode. The relative positions of the different elements of the muon system and their relation to reference elements mounted on the silicon strip tracker are monitored

by a sophisticated alignment system. A system of beam radiation monitors installed along the beam line gives online feedback about the beam structure and about radiation conditions within the experimental cavern. The main components are radio frequency(RF) pick ups located 175m from the interaction point, segmented scintillator rings mounted on both faces of the HF calorimeters, and diamond sensors installed very close to the beam pipe at distances of 1.8m and 14.4m. Signals from the diamond beam condition monitors are used to protect the tracking detectors from potentially dangerous beam backgrounds. In severe pathological conditions, they are capable of triggering an abort of the LHC beams.

Only two trigger levels are employed in CMS. The Level 1 trigger is implemented using custom hardware processors and is designed to reduce the event rate to at most 100kHz during LHC operation using coarse information from the calorimeters, muon detectors, and beam monitoring system. It operates with negligible dead time and synchronously with the LHC bunch crossing frequency of 40MHz. The High Level Trigger (HLT) is implemented across a large cluster of the order of a thousand commercial computers, referred to as the event filter farm, and provides further rate reduction to $O(100)$ Hz using filtering software applied to the full granularity data acquired from all detectors. Complete events for the HLT are assembled from the fragments sent from each detector front-end module through a complex of switched networks and “builder units” also residing in the event filter farm. The event filter farm is 43” [5]

To concern of this training, the building wireless charging station, the CMS cavern subjected to study is the electromagnetic compatibility to RF and induction energy harvesting equipment. Modern high -energy physics detectors EMC is important part in the requirement of designing the detector. Reason of concern about EMC is the potential risk of interactions between subsystems, which comes from cable routing, grounding design and mechanical layout of sub-detector. along with the individual subdetectors there exist additional systems intended to provide cooling, ventilation, power, lighting, safety and industrial controls and monitoring: services that are not part of the detector design process and which are often added late in the construction phases of an experiment. These systems can have as much EMC impact on overall detector performance as subdetector systems do. The most common known contributors to the frequency of the cavern are: 1- Power Converters running at 50Hz. 2- Cooling and Ventilation Systems, as discovered in power distribution network upstream from the CMS detector, that 50KW load being pulsed on and off at approximately 0.5Hz with 503- Lighting Systems, during cosmic ray running, CMS muon RPC detectors bursts last several minutes with trigger rate of 1 Khz, nominal rate 200 Hz, which is traced to mercury-vapor projector lights that had become unstable in the ambient magnetic field. 4- Variable-frequency drives (VFDs) for

pump motors, electrical heaters.[6]

5- The frequency rate of collisions at 40MHz, as LHC provides proton-proton and heavy-ion collisions at high interaction rates. For protons the beam crossing interval is 25 ns.[7]

6 Constraints

1-The batteries of the Robot CMS Robot Inspection Batteries Study: Inspection Robot, is set on 4 wheels driving vehicle, with sensors and wireless controlling mechanism to work and drive in the cavern on operation of the magnetic field and beaming.

for the robot to work, it uses 3 different batteries (collection) for different applications, first one is for the microcontroller, which takes up to from 3.7 to 24V and one Raspberry pi connected with 2 cameras input from 5 to 6V and Wifi which takes up to 3.3V. The second one is for driving the motor circuit, gives up to 25A, input 25Vmax, and 14.4V as max motor (Titan brushed 550 14.4V 21T) input. Third is for 3 Servos, input of 5 to 6V.

The batteries powering the robot, should have a way for recharging (stationary or portable), the coming research design will study a design comparison between both to find the optimum solution. Since there is a use of batteries, different types must be studied and compared for best choice comprehending the idea of controlled charging, implemented by controlling charging board.

The types of batteries were to study are: NiMH, NiCad, SLA, LiFePO4 K2 and Li-on Batteries. In comparison, NiMH don't have memory issues common with NiCad, SLA batteries are sealed lead acid with lower potentials of electrolyte and gasses, however, can't be used due to their reaction with magnetic field since they contain iron molecules. This keeps Li-ion batteries and NiMH as best option, Li-ion are know to have better efficiency than LiFePO4, however, based on experience, environmental and weight to size power ratio, NiMH gave a better results as fire risk probability and efficiency.

Comparison established is shown below: NiMH High Enegry Density for NiMH:

- they have a positive avg. of 2200mAh, bigger than avg. of Li-ion batteries of 1500mAh, which are standard numbers in 1.2V NiMH and 3.7V Li-ions.
- negative side of the NiMH is the high self discharge rate, as they lose large percentage of their charge every month, with number around 5/100 on first week and 50/100 over first month, since the effect of high magnetic field on batteries is usually to high speed discharge rate, this negative effect has to be

solved has to be included in cost and inspection time measurements.

Compatibility: -Positive point about using NiMH batteries, that they come in packs to power different devices with sizes of such AAA or AA, compared to Li-ion that come in specific sizes of cells depending on manufacturer or model of devices. -Negative point, is there unreliability for low load devices, such as clocks, for that they quickly self discharge, hence alkaline, Li-ion or lithium batteries are better. Safety Risks: -As NiMH have less active materials compared

to Li-ion batteries, NiMH can pop if they are overcharged too much or short circuited, however, they are still better than Li-ion which can potentially blow up for no reason. - Also NiMH have the ability to recover from reverser polarization as self-discharge (as long of not long period, hence it will be damaged). -Compared to Li-ion batteries, each AA cell only gives 1.2v whilst Li-ion gives 3.7v. Based on the capacity NiMH have 10-12 hours of standard charge time which is longer than of Li-ion of 1-3 hours. - Under high temperature NiMH voltage output will drop, whilst Li-ion will tolerate these temperatures.[8]

2-Location Consideration:

Coils use induction to harvest energy and transfer it to the secondary coils, the coils are sensitive to the presence of magnetic field in the cavern, the existence of high magnetic field attracts the coils and move to the orientation of magnetic field lines, hence, comprehends dangerous and a possible destruction of the electronics in the cavern.

A solution to the problem discussed above, the station will be place in a Faraday Cage, Faraday cage is placed inside the cavern where the effect of CMS collision and magnetic field is reduced to minimum, pictures below show the faraday cage.

7 Preparation to Enter the CMS underground

Courses Taken to enter CMS cavern are: Computer Security, Safety at CERN, Road Traffic-Bike Riding, Radiation Protection-Supervised Area, CERN-Beam Facilities. Several Lectures, and open lab Experiments. Visiting point 5 to allocate the wireless station base/ or finding alternative portable solution.

8 Design

8.1 First Attempt Try

First Try Attempts: Several attempts were made to build a small wireless charging station using different techniques, first is the inductive, as shown in the

picture:

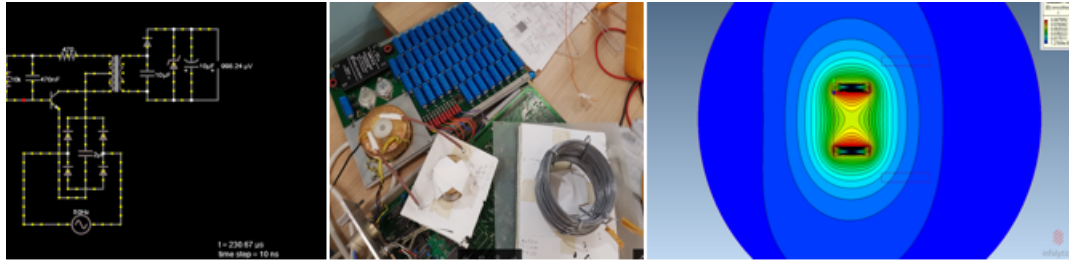


Figure 3: Induction Harvesting Magnet

the secondary was Wireless induction:



Figure 4: Wireless Energy Transfer

HDTV Antenna



Figure 5: HDTV Antenna

small directional antenna

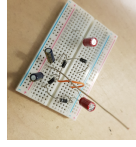


Figure 6: Small Antenna

8.2 Design Standards

Inductive harvesting in this research relies on two main standards Qi, A4WP and WPC compliant wireless charging techniques.

Qi referring to a model that supports inband communication, data(voltage and current) transmitted on the same frequency band of the wireless charging. Usage of Qi-communication and control protocol enable the charger to meet demands of charging device. This communication starts with a ping identifying charger and charging device near-field existence.

On the other hand, A4WP aims to facilities the charging station with spatial freedom and ability to charge more than one changing device at a time, it obtained via magnetic resonance coupling to achieve a spatial freedom. A4WP allows maximum separation and distance between charging and device charged, however, usually adopted and used for (BLE) with supports only low energy transfer for bluetooth systems. The power transmitter unit (PTU) and power receiving unit (PRU) in A4WP do have feedback signaling frequency bands different than Qi-compliant standards, such that A4WP wireless power is generated at 6.78MHz ISM (Industrial Scientific Medical frequency band, while on the other hand Qi operates at band of 2.4GHz ISM.

WPC complaine of this project with Qi, for wireless power consortium requires an alliance of a different frequency than (LC) loosely-coupled wireless transfer for A4WP. As the later is has frequency band different than Qi-WPC of 2.4GHz.

hence, this project aims to having a new approach for finding a resonance frequency band that matches the ranges accessible by Qi and A4WP, optimizing the possibility of maximum customer or battery on robot demand and maximum efficient spatial freedom for positioning the batteries.

Some characteristics of these two standards:

Qi main characteristics:

- 1- Coupled via magnetic field.
- 2- Magnetic field concentrated in a small area between transmitter and receiver coils.
- 3- Single transmitter supply energy to one receiver.

- 4- Coils form a wire wound on ferrite or traces printed on circuit board.
- 5- Frequency ranges from 100-205KHz usually.
- 6- Power classes up to 2.5KW.

A4WP characteristics:

- 1- Working on large distances up to 50mm, without a preference positioning.
- 2- One transmitter supply energy to more than one receiver at a time.
- 3- Planned for low classes of power transfer up to 22W.
- 4- Frequency ranges from 6.78 MHz(ISM band) for charging, data 2.4 GHz(LP Bluetooth).

8.3 Induction Designing Constraints

In order to implement a work with resonance coupling and frequency, some environmental and health procedures should be practiced, examples for major tests are:

1- Radiated Power: evaluates the output power at the desired operating frequency for Antenna or coil configuration.

2- Radiated Spurious Emissions and Harmonics: measuring the field strength of harmonics on test site compared to the applicable limits.

3- AC Line-Conducted Emissions: to quantify the unintended emissions at the AC power input of the charger for purposes of testing.

4- Frequency Stability: applications requiring coupling of frequency, need stability checks.

5- Human RF Exposure: as RF exposure is related to tissue heating due to RF energy absorption.

6- FCC Inquiry: RF exposure evaluations.

7- Methods of demonstrating RF exposure Compliance: (Testing, Modeling and calculation methods).

8- Measurement: use of standard emissions measurement techniques to show exemption from RF exposure compliance to be compared with limits for exposure.

9- SAR Testing: which uses dielectric solution of salt, sugar to fill human body phantom for determining amount of power radiated by a transmitter in mW/g of tissue.

The most important test to be conducted for the approach of this research is ISM bands standards, as they harmonics of ISM bands will fall into high frequency ISM bands where possible, this standard was approved using rules of: United States (FCC): US Code of Federal Regulations (CFR) 47 Part 18. Canada (Industry Canada): Interference Causing Equipment Standard ICES-001. European Union (Various Regulators): CENELEC EN 55011, Group 2 limits. IEEE CB Scheme (International): Cisp 11, Group 2 limits.

following from the table ISM bands bellow:

8.4 Induction Designing Approach

Approach adopted for this project is to finding a frequency band, circuit and geometry modeling which optimizes the highest efficiency, matching between Qi and A4WP standards using ISM table as a base frequency guide to ensure compliance with approved regulation of RF and frequency coupling in countries and electrical departments agreements. This optimization will eventually lead to reach highest electrical demands with abilities of free spatial movement when bigger distances applied between transmitter and receiver for flat spiral loops only.

8.5 Induction Designing

Designing an Inductive harvesting device based on availability and distribution of currents afterwards for different battery charging controlling boards, induction of L11=10uh and L22=24uh, where chosen. The best coupling frequency circuit leaded to a resonance about 50k to 100Khz, which implies a coupling circuit at primary wireless charging side of about C11=0.39mh, C22=0.1666mh to C11=9.9uh C22=4.166uh, based on a thorough study on circuits, for best K mutual inductance coefficient, k is chosen to be between 0.35 to 0.75, hence a trade off between the Q-factor and k was made, for this bandwidth. The formula bellow shows the results

$BW = f_c/Q$ Where f_c = resonant frequency Q = quality factor = $R/(w_0*L) = w_0CR = R*\sqrt{C/L}$ BW = upper – lower And the Q factor formula is

$$Q = 2\pi \frac{\text{maximum energy stored during a cycle}}{\text{average energy dissipated per cycle}}$$

Also, important formulas to reach K factor: Solving for mutual inductance:
 $M^2 = L_2 L_1 L_s$ (1) for $L_s = L_1 (M^2 / L_2)$ The definition of transformer coupling factor k is $k = M / \sqrt{L_1 L_2}$ or $k^2 = M^2 / (L_1 L_2)$ (2) Substitute equation (1) into equation (2) : $k^2 = L_2 L_1 L_s / L_1 L_2 = L_1 L_s / L_1 = 1 (L_s / L_1)$ or $k = \sqrt{L_s / L_1}$ (3)

L_1 is the inductance measured across L_1 with winding 2 open and L_s is the same measurement with winding 2 shorted. K is determined by inserting these inductance values into equation (3).

when $K=0$, the two circuits are separated, by w_1 and w_2 ,

$$\omega_1 = \frac{1}{\sqrt{C_1 L_1}} \quad \text{and} \quad \omega_2 = \frac{1}{\sqrt{C_2 L_2}}.$$

$$\omega_{\text{sys}} = \pm \frac{1}{\sqrt{2}} \sqrt{\frac{\omega_1^2 + \omega_2^2 \pm \sqrt{(\omega_1^2 + \omega_2^2)^2 - 4\omega_1^2 \omega_2^2 (1 - k^2)}}{1 - k^2}},$$

and when $w_1=w_2=w_0$, $w_{\text{sys}} = w_0 / \sqrt{1+k}$

for 50k, $w_0=100\,000 \cdot \pi$, and for 100k, $w_0=200\,000 \cdot \pi$. At best assumption of $K=0.25$, the $W_{\text{sys}}=280992.58$. The designing of the coupling inductance is assumed to take a ratio 3:2 BASED on the choice of coils current rate.

For the above requirement, initial draft simulation for turn rate 120:80 using simplorer

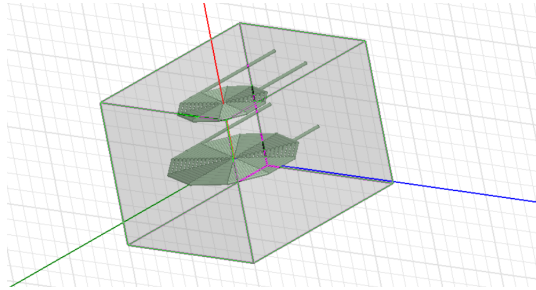


Figure 7: Coil Simulation in Maxwell Simplorer

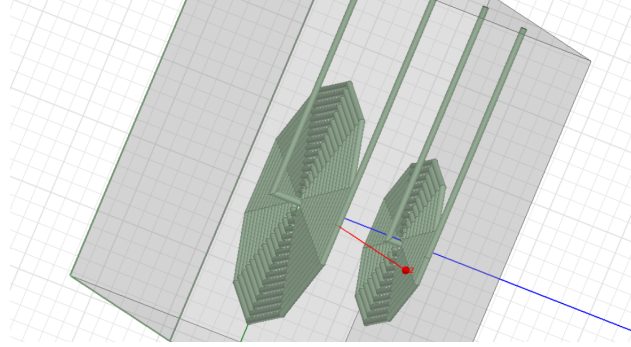


Figure 8: Coil Simulation in Maxwell Simplorer

The simulation based on a distance of 4mm between the coils, resulted in a k faction coefficient of 0.6.

Based on previous calculations $BW = 50k$, $w_0 = 100\,000 \cdot \pi$, this implies that $Q\text{-factor} = 2 \cdot \pi = 6.28$ which is fairly low, hence the construction of circuit for maximum efficiency is built upon the relation the below rules: $Q = \omega L / R$, series resonating circuit $R / \omega L$, parallel resonating circuit

The rules implies that a second inductance in series would increase the Quality factor, with a Resistance in parallel. So, on the secondary side were exists 10uH coils, additional inductance of 36uH is included in series, and a resistance of 10k Ohm in parallel.

The rectification of the circuit is made by diode full rectifier and a capacitance ladder is added to increase the level. <http://publications.lib.chalmers.se/records/fulltext/220840/220840.pdf>. Another way to calculate the Q factor is $Q = \omega L^2 / R$, R is the resistance of the wires.

Following the above calculations, designing of the wireless charging station is made by using a step down transformer from the mains of 220/120V, then is fully rectified by diodes (full bridge), the output DC Voltage is changed to AC for a specific frequency of 50KHz using mosfets, the logic signal of the mosfet is produced by LM324 which is powered by positive 5 V from an adapter the configuration is shown below, for producing 50kHz, $f = 1/RC$, $R = 10K\Omega$,

$C=0.01\mu\text{h}$. On the square wave generation side.

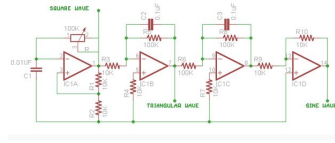


Figure 9: LM324

The LM324 is inverse powered by -5V from inverting the polarity of the voltage using LTM8025. The Circuit is shown below for buck uModule Regulator:

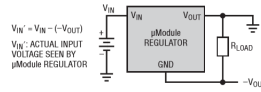


Figure 10: LTM8025

The output AC voltage from the mosfets is inserted into the resonance TX circuit of induction coils and a series capacitor values are mentioned above. On the secondary side, the RX coils is in series with inductance and parallel with capacitance 2, then full bridge rectifier is inserted with parallel protective resistance of 10Kohm and 0.01uh

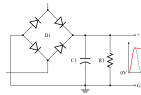


Figure 11: Rectifier

the output voltage can be rectified using Capacitance Diode Ladder as shown below, where voltage is directly proportional by number of ladders:

Second phase advancement is by using half phase rectifier IC or full phase rectifier IC, both have similar configurations with differences in calculating R_T and C_T for the specified switching needed.

Example is shown below:

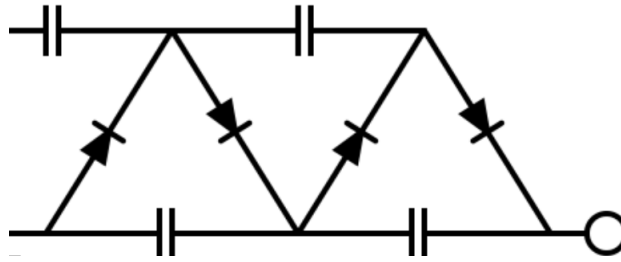


Figure 12: Doubler

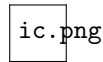


Figure 13: Half Phase Rectifier IC

9 Conclusion

For the above research, several circuits can be built, yet needs to be tested. Using rectifier circuit can be an easy handle for some specified frequencies, if frequencies are higher for coil coupling circuits, then different methodologies can be used. The location of the base station is set after visiting CMS building.

Thanks to supervisors: Dr.Amr Radi- Martin Gastal

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