A Study of Dynamic Wireless Charging and Simulink Modelling of Electric Vehicle

Summer Internship Project Report Under the Guidance of Professor Dr. R.K. Saket, IIT BHU

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Abstract

Electrified transportation is continuously playing an important role in reducing greenhouse gas emissions and also an alternative to raising oil prices. Electrified transportation demands that a good type of charging networks line up, during a user-friendly environment, to encourage adoption. Wireless electric vehicle charging systems (WEVCS) is a possible alternative technology to charge electric vehicles (EVs) with no plug-in problems. In this project, I will be focusing on the method of Dynamic Wireless Charging of Electric vehicles. Along with that, also discussed the Simulink Implementation of the Wireless Power Transfer circuitry along with the proper practical situations like Coil detection, Efficient Power Transfer, and Foreign Object Detections. All the circuit parameters are designed according to the SAE Standards.

Introduction

Wireless power transfer (WPT) is one of the emerging technologies where power is transferred from transmitter coil to receiver coil with no additional physical contact. Inductive Power Transfer (IPT) is a type of wireless power transfer technology and is based on Faraday's law of electromagnetic induction [1]. In the IPT system, a high-frequency AC supply of range in KHz is given as an input to the primary side. The secondary side uses a resonant tank to tune the frequency of transmission. Since secondary coil uses resonance phenomenon to be tuned to transmitter frequency, therefore IPT is also known as resonant IPT. By using the resonance phenomenon, the power transferred to receiving coil, and hence, the efficiency is increased. [2]

The transmitter and receiver coil present in the IPT system have poor coupling due to the presence of an air gap, and hence, it's a loosely coupled transformer. Because of this reason, there is leakage flux which ultimately results in increased reactive power input requirement. The increased reactive power requirement has a direct effect in decreasing power transfer capability and not only that, but the rating of devices in converter circuits also increases. This is a serious hindrance to the efficient implementation of IPT technology. But with the advancement of time, researchers have developed compensation circuits so on achieve near-zero input reactive power [3]. In this technique, the capacitor is added to both sides of the IPT circuit to compensate for the leakage flux and hence reduce the reactive power input [2].

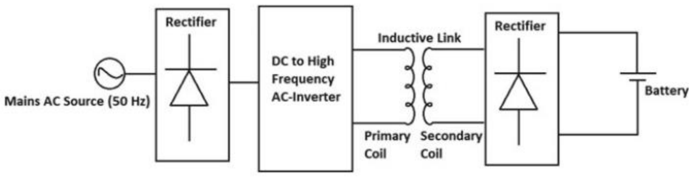


Fig. 1 Block diagram of inductive power transfer system

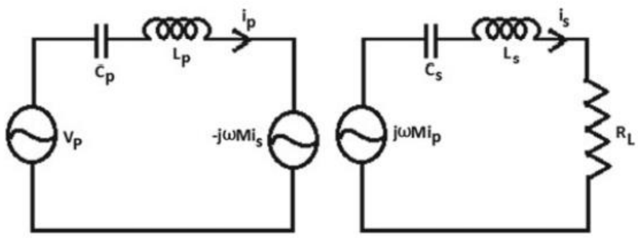
In this project, I will focus on designing the Simulink Model using IPT technology, a wireless charger is 7.7 KW rating wireless charger is designed using SAE standards.

Table 1 Desired Specifications as per SAEJ2954 standards

Power output level	7.7 KW
Output voltage	400 V (Compatible with available lithium-ion battery available)
Resonant frequency	85 kHz
Supply voltage	240 V

Power Converters Designing Parameters

In this section, the formulas for electrical parameters designing used in [4] for SS-IPT topology are revisited and derived using equivalent circuit as shown below.



Deriving the circuit parameters:

a. Calculation of RL and Vs(rms) [4]

$$R_0 = \frac{V_o^2}{P_0} = \frac{400 * 400}{7700} = 20.77\ \Omega$$

$$R_L = \left(\frac{8}{\pi^2}\right) * \frac{V_o^2}{P_o} = \left(\frac{8}{\pi^2}\right) * \frac{400 * 400}{7700} = 16.84\ \Omega$$

$$V_{\text{srms}} = \frac{2\sqrt{2}V_o}{\pi} = 2\sqrt{2} * \frac{400}{\pi} = 360.12\ \text{V}$$

b. For bifurcation free operation considering quality factor Qs = 4, and calculating the value of Ls (Inductance of secondary Side) and M (Mutual Inductance). [4]

$$L_s = Q_s * \frac{R_L}{\omega_0} = 4 * \frac{16.84}{2 * \pi * 85{,}000} = 1.261 \times 10^{-4}\ \text{H}$$

$$I_{\text{srms}} = \frac{V_{\text{srms}}}{R_L} = \frac{360.12}{16.84} = 21.38\ \text{A}$$

$$I_{\text{prms}} = \frac{P_o}{V_{\text{prms}}} = \frac{7700}{240} = 32\ \text{A}$$

$$M = i_{\text{srms}} * \frac{R_L}{i_{\text{prms}} * \omega_o} = 21.38 * \frac{16.84}{32 * 2 * \pi * 85{,}000} = 2.106 \times 10^{-5}\ \text{H}$$

c. The value of critical coupling coefficient Kc: [6-7]

$$k_c = \left(\frac{1}{Q_s}\right) * \sqrt{1 - (1/(4 * Q_s^2)} = (1/4) * \sqrt{1 - (1/(4 * 4^2))} = 0.248$$

d. So, in order to have bifurcation free operation, the condition to be satisfied is k < kc, and for this, the value of coefficient of coupling is taken 0.2. [5]

$$L_p = \frac{M^2}{L_s * k^2} = \frac{2.106 * 10^{-5} * 2.106 * 10^{-5}}{1.261 * 10^{-4} * 0.2 * 0.2} = 8.793 \times 10^{-5}\ \text{H}$$

$$C_p = 1/L_p\omega_0^2 = \frac{1}{8.793 * 10^{-5} * 2 * \pi * 85{,}000 * 2 * \pi * 85{,}000} = 3.98 \times 10^{-8}\ \text{F}$$

$$C_s = 1/L_s\omega_0^2 = \frac{1}{1.261 * 10^{-4} * 2 * \pi * 85{,}000} = 2.78 \times 10^{-8}\ \text{F}$$

Basic Simulink Implementation of SS-IPT Model

A. Designing the Primary Side Circuit Model:

Using the calculated results, first the High Frequency DC (400v) is inverted to AC supply.

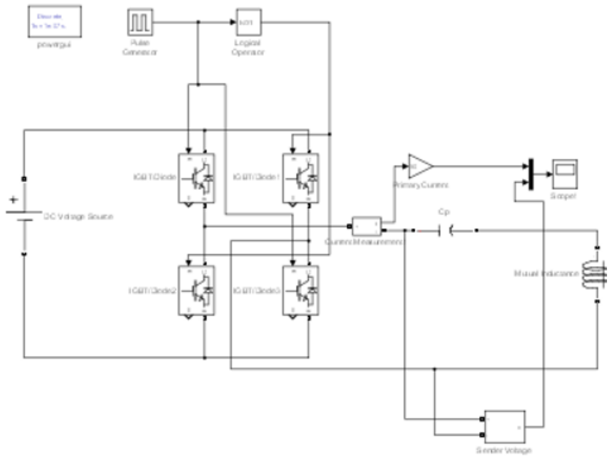


Fig 2: Primary Side Simulink Model (DC-AC inverter)

B. Setting up the Mutual Inductance between the Loops

C. Using Calculated values designing the Secondary Side of the Model:

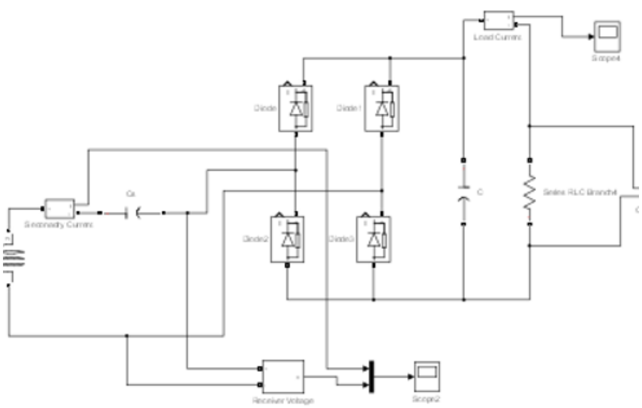
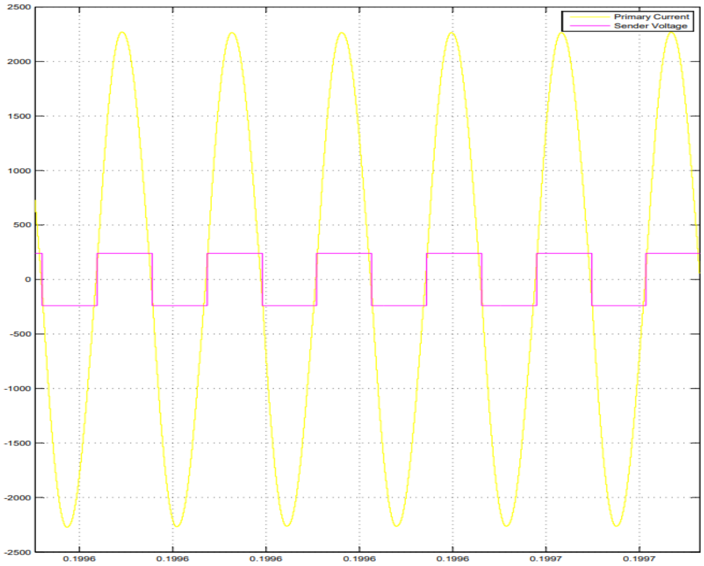


Fig 3: Secondary Side Simulink Model (AC-DC converter)

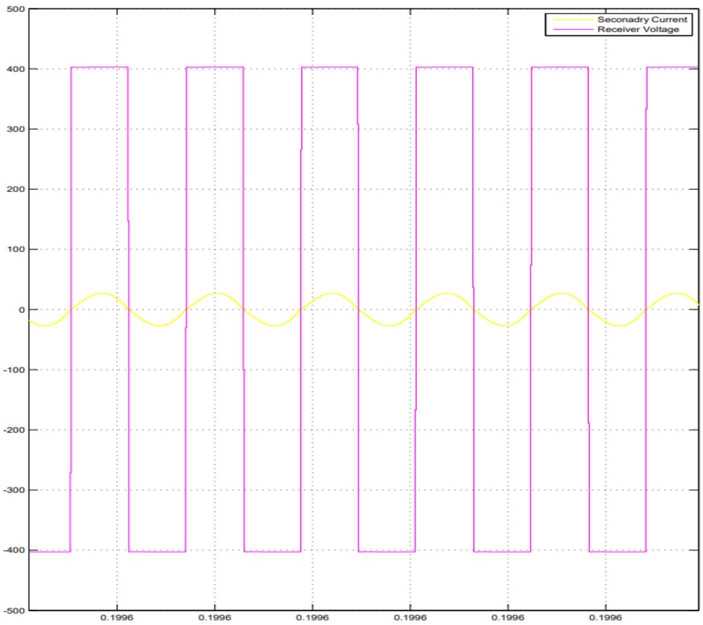
Simulink Implementation Results

The graphs obtained from Simulink platform can easily infer that the theoretical values calculated for output voltage Vo, primary current RMS value Ip(rms), secondary current RMS value Is(rms) match almost.



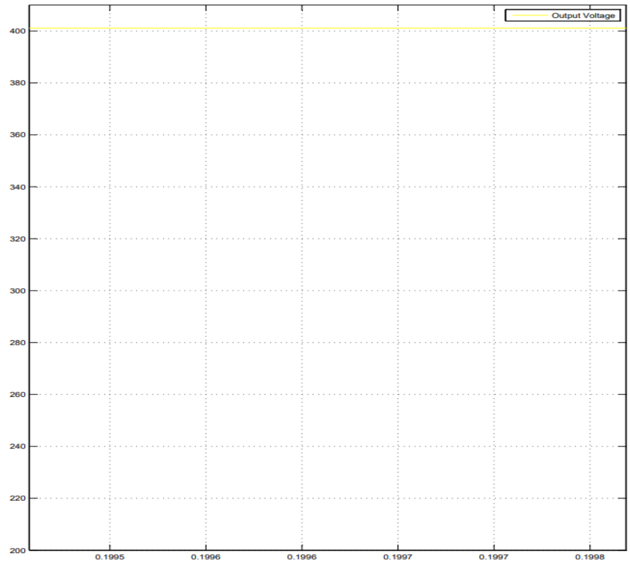
Graph 1: Primary Side (Current and Voltage)

From the coils power gets wirelessly transmitted, which is in the form below.



Graph 2: Secondary Side (Current and Voltage)

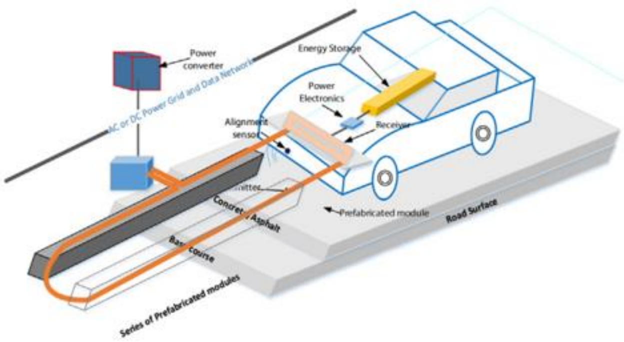
An DC output of 400V is obtained at the Secondary side after rectification.



Graph 3: Output Voltage

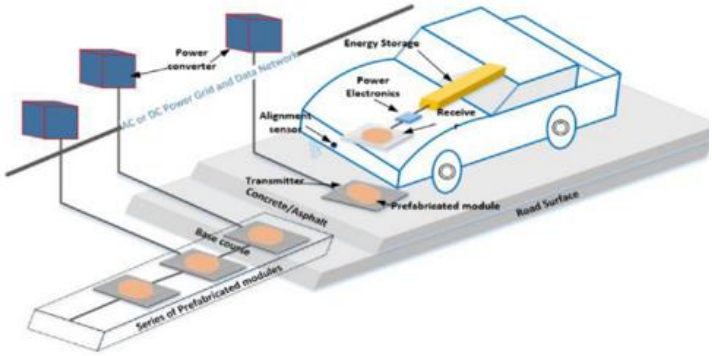
Wireless Dynamic Charging Practical Problems

Although, it is a promising technology, which can reduce the problems associated with range and cost of EVs. It is the only solution for future automation EV. It is also known as a "roadway powered", "on-line" or "in-motion" WEVCS. As shown in Fig. below, the primary coils are embedded into the road concrete at a certain distance with high voltage, high frequency AC source and compensation circuits. Has many



practical problems which need to be addressed for the efficient and safe power transfer.

The power supply segments are mostly divided into centralized and individual power frequency schemes as shown in Fig. In the centralized power supply scheme, a large coil (around 5–10 m) is installed on the road surface, where multiple small charging pads are utilized. In comparison with the segmented scheme, the centralized scheme has higher losses, lower efficiency including high installation, and higher maintenance costs. [6]



With the perfect alignment between the transmitter and receiver coils which can significantly improve the overall power transfer efficiency.

Problems to be Discussed in this Project:

A. Detection of Electric Vehicle to control the Charging.
B. Foreign Object detection between the coils to maintain safe power transfer.

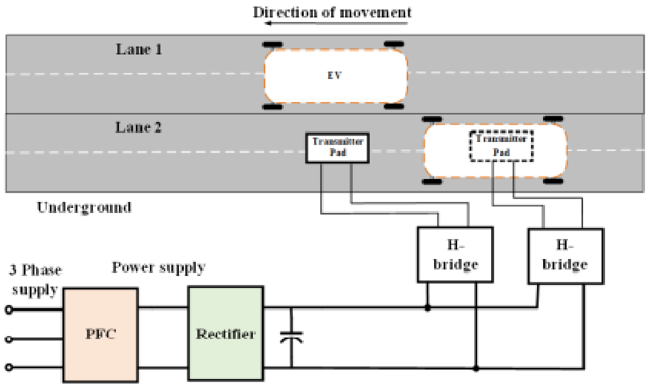
Understanding Coil Placing and its parameters

Till now, what we have understand that the Segmented Coil placing scheme is the best way to dynamically induce Emf in EVs. But this method has its own issue while automatically detection of the Vehicles. To solve this, a coil detection system is proposed. [7]

In the following block diagram, two types of detection scheme are shown. First one is when the EV is coming from the same lane to the transmitting pad. Second one is the case, when the EV is approaching from another lane to the Transmitting pad. The System is capable to distinguish the direction of coming and respond by turning on/off the respective coil placed below the EV, for the smooth and efficient power supply.

The basic principle behind this is the placing of Two Coil Detection system.[7]

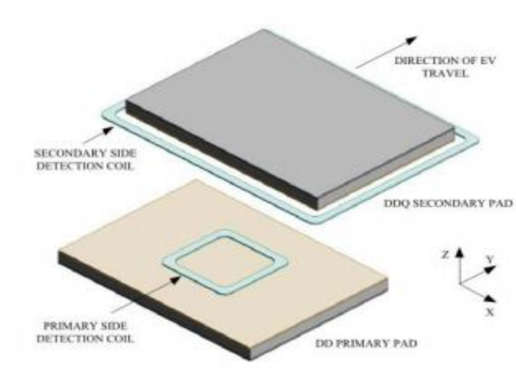
Block Diagram of EV Detection:



Possible ways to detect EV

1. The detection is done by placing of two auxiliary coils in the Transmitting Coil and Receiving Coil of the EV.
2. The basic concept is that, the Secondary Auxiliary coil is energized by high frequency AC signal, which is present in the EV.
3. When the EV is over the Transmitting coil, then the Primary Auxiliary coil gets activated due to the magnetic coupling of the Auxiliary coils, that turn on the respective T.coil to transfer the power to the EV.

Diagram of Detection Coil Placing:

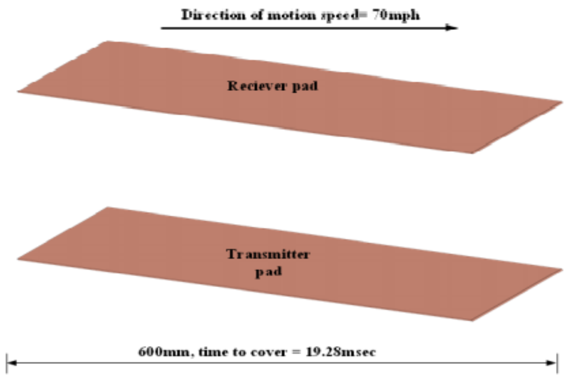


(a)

Charging Pad Parameters:

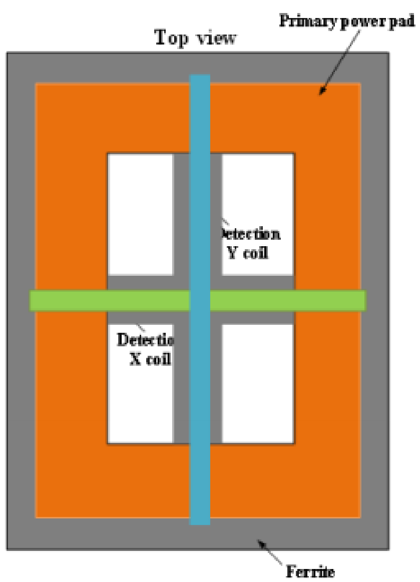
i. One of the major hurdles in implementation of the segmented DWC is detection of EV as it travels on the road and turns on the appropriate pad. [7]

ii. In the case of driving on a highway, speed of the EV can be very high (70mph or 112.654km/h). If the length of the ground pad is 600mm this implies that each ground pad has to be turned on in less than 19.28msec per EV. [7]



Two Coil System

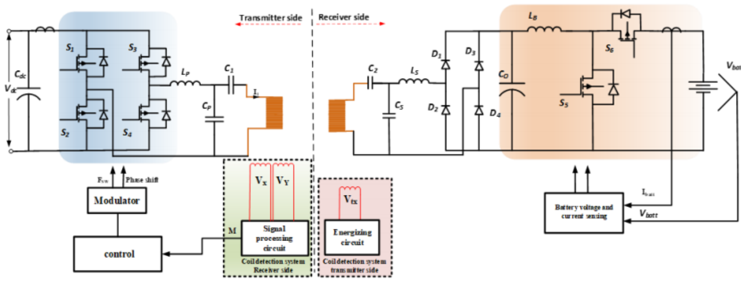
For detecting the vehicles coming from another lane, there is a method known as two Coil detection system. In which two coils are placed in the primary side in such manner that it detects the vehicles in X and Y axis separately and turns ON/OFF transmitting coil. [7]



Power Electronics of the Coil Detection System

This is the proposed power electronics system of the coil detection system. Both the Auxiliary coils are placed in their respective sides of the circuit. And then the Signal processing unit is attached to the output of Primary side Auxiliary coil, to respond to the specific received signal [8]. I will design both the circuit in Simulink with the implementation of Signal Processing unit in Multisim and Control Circuit in Tinkercad using Arduino UNO.

Proposed Circuit Diagram [8]:

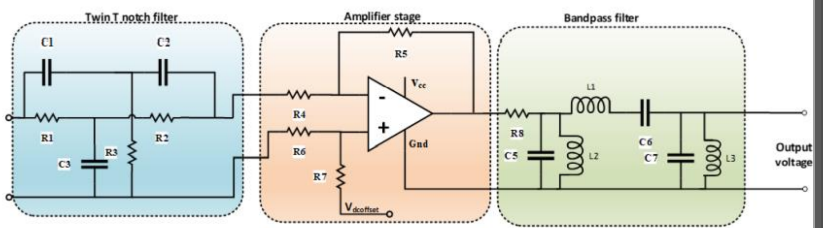


In the above diagram, secondary Ax. Coil is Energized by a separate circuit which has High frequency AC supply of 5V, 1W at 460KHz and the primary Ax. Coil has two parts for X and Y axis detection. After getting magnetically coupled, Emf is induced which is used to control the switching of Charging Circuit [7].

Signal Processing Unit

It is very important to Distinguish between the Signals of Detecting coil Transmitting Coil as it can results in the false triggering of the transmitting circuit. The Analog processing unit is divided into three parts.

Filters :

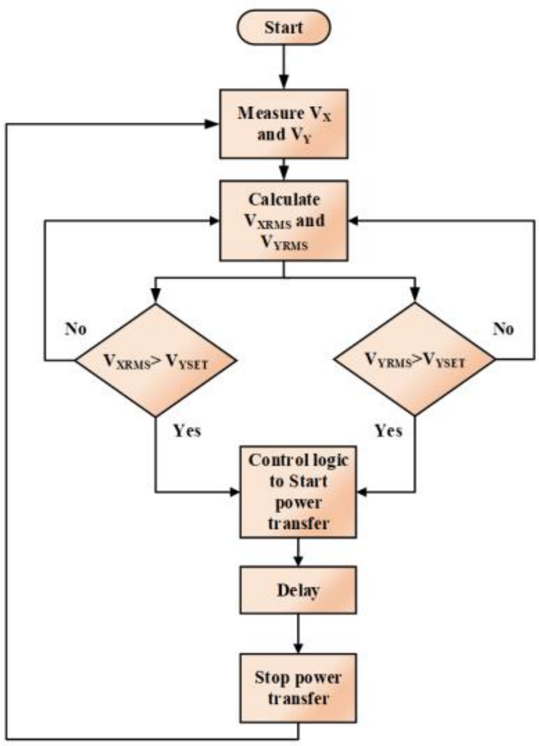


Types of Signal Filters used[7]:

1. Twin T notch filter is designed to remove the fundamental IPT frequency component (81 kHz) present in the Signal. Notch filter is designed to give maximum attenuation at IPT frequency and to pass the 460 kHz coil detection frequency without any attenuation.
2. The second stage is an amplifier stage and the purpose of this stage is to increase the gain and avoid loading effect on the detection coil.
3. Bandpass filter is employed to reduce further IPT frequency component and some additional unwanted frequencies.

Control Unit

After filtering the Input signal in the primary Aux. Coil, the Vx and Vy voltages Rms value is calculated, and used to control the Switching of the DWC circuit.

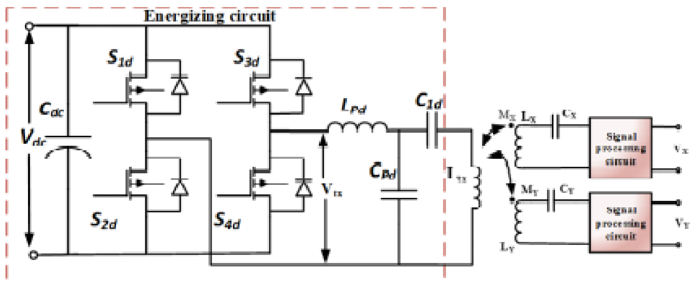


Flow Chart of the Control Logic

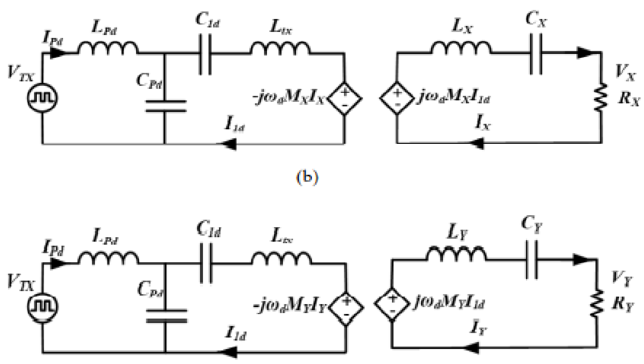
Implementing Circuit Parameters from Derived Experiments

Taking the SAE standards in reference, following circuit parameters are calculated for the coil detection circuit [7]. Which I am using to implement the Simulink Model of Coil Detection system.

Auxiliary coils Equivalent Circuit :



Primary Side



Secondary Side

For the above equivalent circuit, circuit parameters are derived as follows:

Experimental results to simulate the Coil Detection system [8]:

Parameters	Value
Operation frequency(f_c)	460 kHz
Output power (P_o)	1W
Input voltage	5V
Output voltage	2Vpk-pk
Transmitter detection coil (L_{TX})	257.5μH
X-coil (L_X)	127μH
Y-Coil (L_Y)	217.3μH
Distance between coils (d)	200mm

Auxiliary coils Equivalent Circuit Parameters:

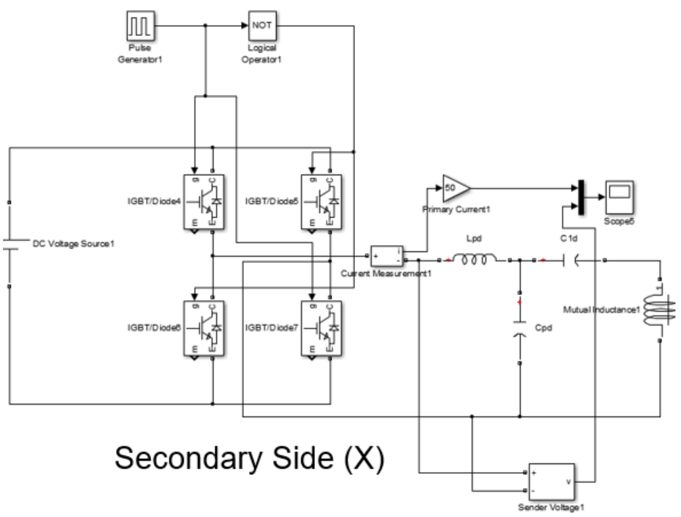
Parameters	Designed value
L_{Pd}	$45\mu H$
C_{1d}	$472pF$
C_{Pd}	$30nF$
C_X	$942pF$
C_Y	$550pF$

Parameters	Value
V_X	.6V
V_Y	0.6V
R_X	1Ω
R_Y	1Ω
I_{1d}	0.02A
ω_d	2.8903e+06 rad/sec

These data are calculated by taking SAE standards. [7]

Simulink Implementation of the Coil Detection System

1. First in the Secondary Side 5v DC is inverted to AC supply. Which then provided to the Secondary Auxiliary coil.



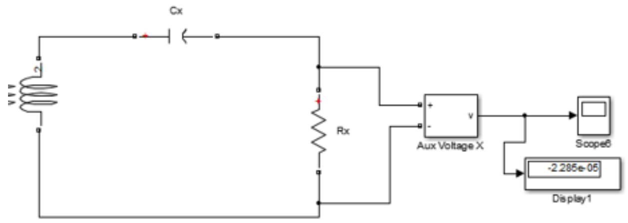
Secondary Side (X)

2. Mutual Inductance is set as derived from the experiment [7].

$$M_X = \frac{V_{XO}}{\omega_d I_{1d}} = 8.6802\mu H$$

$$M_Y = \frac{V_{YO}}{\omega_d I_{1d}} = 6.5051\mu H$$

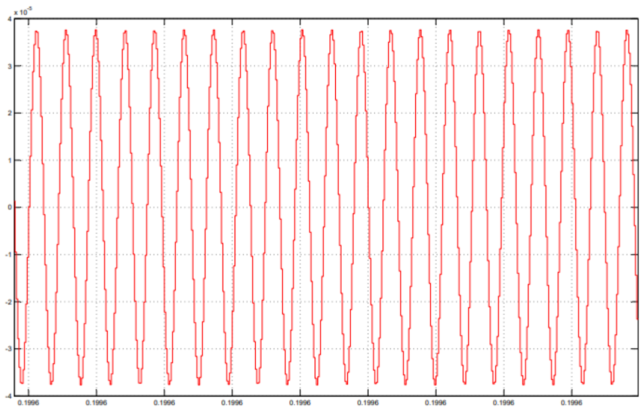
3. In the Primary side, the received power is then measured and if the Voltage is 2vpk-pk. It triggers the Control Circuit and Signal Processing Circuit.



Primary Side (X)

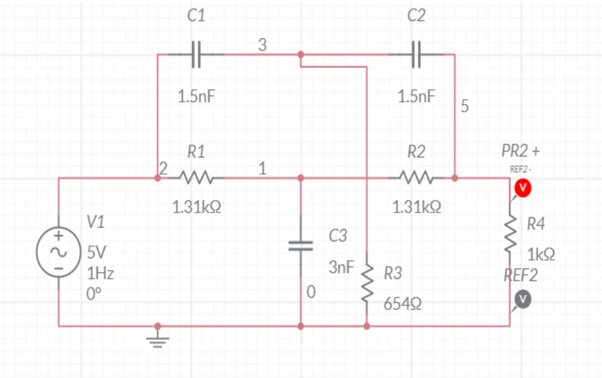
4. This Whole Detection process, simulates the Electric vehicle position above the transmitter coil.

Output voltage waveforms at the primary auxiliary circuit.

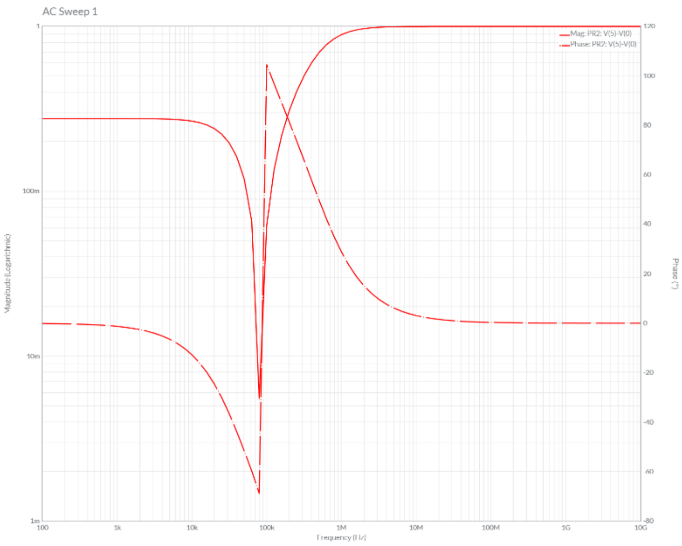


Multisim Simulation of Signal Processing unit

The designed signal processing circuit is simulated in Multisim. The frequency response of the designed notch filter is plotted in Fig below. The designed notch filter gives maximum attenuation at 81kHz and for 460kHz the attenuation. [9-21]

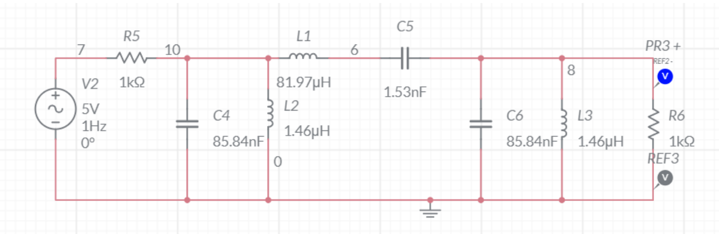


Notch Filter Circuit

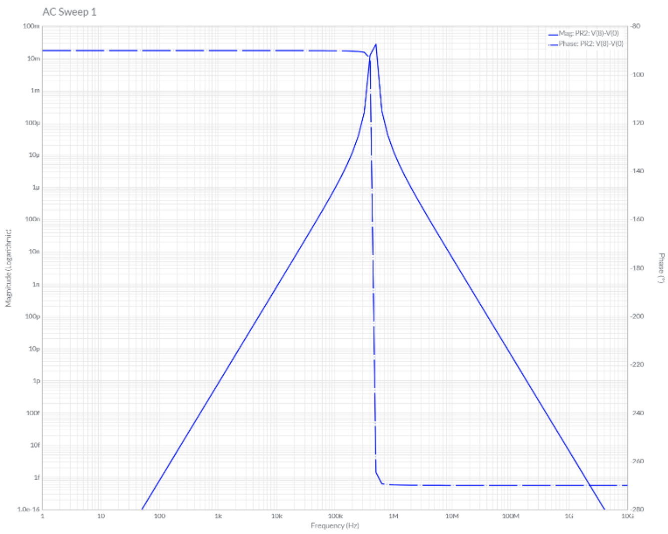


Signal below 81Khz is attenuated

The bandpass filter is designed with centre frequency of 460 kHz to avoid any signal attenuation at the frequency of interest. If these additional frequencies are not removed, they can cause malfunction of the detection circuit. [8]



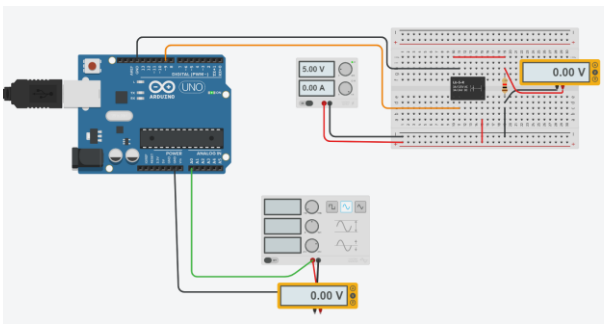
Band Pass Filter Circuit



Centre Frequency is 460khz

Control unit using Arduino

Control unknit is designed to switch the Charging circuit as it detects the Electric Vehicle over the Transmitting coil. It is Designed and Implemented in Tinkercad.



If the Coil is Not detected the Transmitting coil delivers minimal power, reducing power loss and increased safety for pedestrian.

Conclusion

In this report, using IPT topology, a WPT-based charger is designed for Electrical Vehicle Dynamic charging. In designing procedure, SAEJ2954 standards have been followed which meet the latest charging requirements. Another important consideration in designing that has been taken is the additional Coil Detection system for smooth and safe Electric Power Switching between the coils which is most of the IPT charging designs have avoided. The Simulink results match the theoretical calculation which prove that designing methodology is correct.

References

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