Maximizing Efficiency of WPT System Using Amplifier

by

Rafid Sadad Ibna Haque (160021129)
Abrer Mohsin Samin (160021141)
Nazmus Sakib Rudro (160021164)

A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

Department of Electrical and Electronic Engineering

Islamic University of Technology (IUT)

Gazipur, Bangladesh

March 2021

Maximizing Efficiency of WPT System Using Amplifier

Approved by:

Md. Thesun Al-Amin

Supervisor and Assistant Professor

Department of Electrical and Electronic Engineering

Islamic University of Technology (IUT)

Boardbazar, Gazipur-1704.

Contents

List of Figures

Acknowledgments

This note of acknowledgment is the final touch on our thesis after a time of rigorous learning and growth. We'd like to thank those who have mentored, helped, and assisted us through this time.

Firstly, we are very humble to our Creator for cherishing us with the chance to study in this institution under such glorious teachers. We would also like to thank our parents and guardians for providing us the chance to study at IUT and helping us in all aspects of life.

We would like to express our special gratitude to our mentor and supervisor **Md. Thesun Al-Amin** for guiding us throughout the whole research and assisting us in every aspect. We are truly blessed and thankful that we had the opportunity to do our bachelor thesis with you and work under your supervision. Thank you for your constant guidance, motivation, patience and help.

We would also like to thank all the faculties of the Electrical and Electronic Engineering (EEE) Department for their co-operative and helpful attitude towards us during the entire process.

Abrer Mohsin Samin

Nazmus Sakib Rudro

Rafid Sadad Ibna Haque

Abstract

The use of the wireless network has been increasing day by day. Wireless Power Transfer System is one of the most important sectors of wireless networking. In this paper, we have developed a circuit relating to Wireless Power Transfer System. Conventionally the circuit was constructed using Op-amp which leads to more complexity and less efficiency. In our circuit, we have used an amplifier to make the circuit more simple and more efficient. We have designed the circuit using Proteus software. Where we compared the output from the conventional circuit with our designed circuit. The result shows quite an improvement in terms of efficiency. So, the main thing for the operation of the WPT system is to have a high-frequency sine power for the coils to produce the altering flux. So, in our model, we made this high-frequency power by using high-power amplifiers. Amplifiers, as we know, can produce a high power version of their input signal and its input current is very low so we can generate the signal from a very low power controller like Arduino mini and feed that to the Amplifier. Besides amplifier's output is very close to the sine wave with very little distortion. Also as amplifiers are generally used to amplify audio signals they are very responsive to frequency change.

Chapter-1

Introduction

1.1 Introduction:

We can no longer imagine our days without electricity. There has always been a need for energy since the dawn of humanity. Electricity improves, brightens, and cleans our lives. Before electricity can be delivered to our homes and businesses, it must first be generated at a power plant and then transmitted over high-voltage power lines. The transfer of power from a power distribution system to various load centers is achieved by electric power transmission systems.

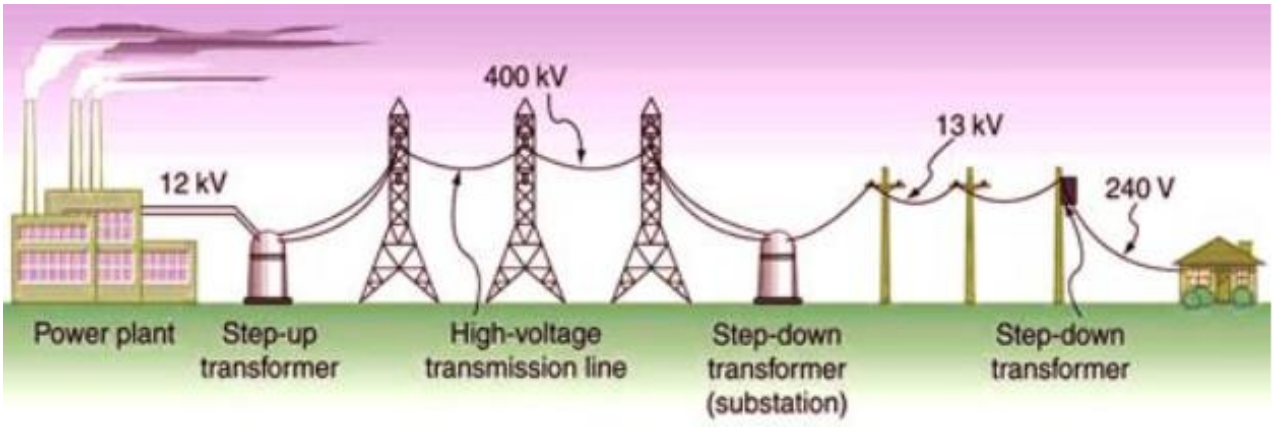


Fig 1.1:Electrical Power System Components

Generally, distributing electricity from a generating facility, such as a power station or a power plant, is a risky situation. A transmission network is a set of interconnected lines that allow the flow of electrical energy[1]. These lines make up an electrical power transmission system or

power grid as it is more widely known. Although the specifications vary from country to country, any perfectly rated device can operate within the confines of a given electrical system.

The complication in this case, however, is wire or cable. Short-circuiting, burning cables, plugging in or out, twisting, and other issues. Wireless power transmission is a more reliable, new, and required technology than the traditional transmission system.

1.2 Introduction to Wireless Power Transfer:

A wireless power transfer device is one in which electrical energy is transferred without the use of physical wires. It is a device that requires electricity to be supplied through an air gap rather than through wires. WPT will charge mobile phones and laptops, drones, motorcycles, and even transportation equipment. WPT transports energy between transmitters and receivers by using fields produced by charged particles. Converting energy into a shape that can pass through the air bridges the air gap. Energy may be efficiently transmitted by an electric field, a magnetic field, or electromagnetic waves such as radio waves, microwaves, or even light, depending on the strength and distance.

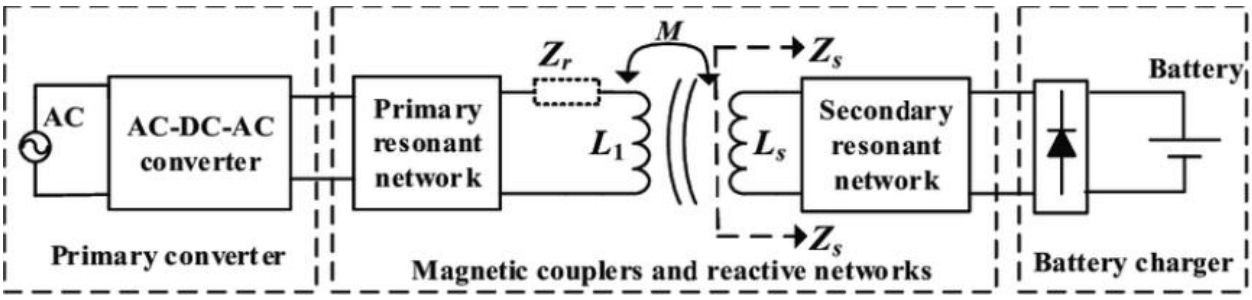


Fig 1.2:Typical Structure of Wireless Power Transfer System

In a WPT system, we get more efficiency in the near field than in the far-field. Because in the near field the magnetic field, as well as the flux cutting, is more than the far-field[2].

1.3 The invention of WPT:

The concept of transferring power without wires was introduced in the late 1890s. The name, Nikola Tesla is mostly famous in the case of wireless power transfer. Nikola Tesla successfully lighted electric bulbs wirelessly at his Colorado Springs Lab. In his experiment, he used electrodynamics induction which is also known as resonant inductive coupling. While he was doing his experiments in the lab, he invented an electrical resonating transformer in the year 1891. That transformer was also known as the Tesla Coil or Tesla's Coil. Nikola Tesla was hopeful that his transformer would deliver power without the connection of wires. At Pikes Peak, North America the weather was a bit rough. Lightning storms were common there. Tesla observed the natural lightning and analyzed how it acted. He also examined how the lightning traveled to the ground. He found that just after the lightning the air remains charged for some moments. Then he experimented with his transformer and observed how the charges were reflected. He found an extra-ordinary result even with a small tesla coil. Though he was not only testing with the small one also built one of the largest coils ever built. The fascinating matter is, the discharges from the large coil in Colorado Spring Lab could be seen from a long distance[3].

1.4 Motivation:

After Nikola Tesla had introduced the concept of wireless power transfer and experimented with related technology patents in 1902. Since then, many scientists have researched it. Some of them were able to gain some achievements in induction power transmission at close range. In our case, the main purpose of our analysis was to achieve a brighter output and thus contributing to the transmission of wireless power transfer. To

keep pace with modern technologies, the concept of wireless power transfer is needed to be brought to light which was another reason behind choosing this concept. In modern times, no one wants to use the wire or cord in case of charging any device, and there comes the necessity of WPT. According to the IMF, Bangladesh's economy is the second-fastest-growing major economy of 2016[4]. With the advanced growth of the economy, the standards of living are getting higher day by day. In that case, the uses of smart devices are getting very popular nowadays. Smart devices have various features but the transmission of power into them wirelessly is one of the spectacular features in recent times. People are much fond of using devices that do not require the connection through wires or cords. It has been mentioned earlier that, to get rid of the annoying wires, WPT is the perfect solution.

1.5 Contribution of this project:

Here in our paper, we're trying to improve the efficiency of the WPT system by using amplifiers. Mainly we get the idea from a paper in which they discussed the WPT system by using MOSFET and also they used an H-bridge circuit to implement the result[5]. Here in our project, we've used Amplifier despite using MOSFET and we also don't use H-bridge, so our circuit becomes simpler. Though we could not able to show in hardware because of the pandemic situation it is possible to implement very easily and also we can maximize the power by using an amplifier we've shown this through software.

1.6 Research Objective:

Previously, those who have worked researched on WPT have faced many challenges. The limitations that the researchers and engineers are recharging batteries, the continuation of supplied power, dealing with moving points, optimizing the sensors, and so forth. Though these challenges still exist, day by day the limitations and problems are getting minimized because of the continuous research going on WPT. The purpose of our research was to contribute to minimizing the limitations of the transmission of power wirelessly.

1.7 Advantage of the WPT system:

The advantages of wireless power transfer are too many to be described. Some of them are mentioned below:

- WPT is a safe, waterproof, and long-lasting method of power transmission.
- We no longer have to use inconvenient wire connections thanks to WPT.
- Wireless infrastructure enables a network to access areas where a network cable would be ineffective.
- The expense of distribution and transmission decreases, as does the cost of electrical energy for the user.
- Short circuits and cable faults can never cause power outages in the power transmission system, and power theft will be impossible.

- The loss of transmission in Wireless Power Transmission is marginal. As a consequence, this approach has much better quality than wired transmission.

- Wireless power makes for a highly expandable power set, which is one of the main advantages.

- WPT expands the usable life of a system.

1.8 Overview of this project:

We wanted to increase the efficiency of the WPT system by using the amplifier. And we've seen that using an amplifier gives us more efficiency than using MOSFET. We used Arduino for the power supply and we get the output by using an amplifier.

1.9 Summary of the following chapters:

The 1st chapter describes the basics of wireless power transfer (WPT), the historical background of the invention of WPT, and the reason behind choosing this topic for our thesis. It also gives a clear idea about our contribution to this project and the purpose of our project. Moreover, the advantages and disadvantages of wireless power are being described here.

The 2nd chapter explains the basic concepts of wireless power transfer. For example Ampere's law, Faraday's law of induction, Lenz's law. It also describes the two main types of WPT and they

are i) Far-field and ii) near field WPT. The basic differences between wired and wireless power transfer are mentioned here properly.

The 3rd chapter is titled “Existing improvements on Wireless Power Transfer”. Here the three techniques of power transmission are described; which are i) inductive coupling, ii) mix-inductive coupling, and iii) microwave.

The 4th chapter is titled “Wireless power transfer using Amplifier”. Here the implementation of the amplifier for creating the High-frequency side is described and ideas about how the amplifier works are explained.

The 5th chapter is titled “Project Implementation”. Here traditional circuit and our modified circuit have been described.

The 6th chapter is titled “Results”. Here the comparison between the outputs of the traditional circuit and the modified amplifier used circuit has been shown.

Chapter-2

Wireless Power transfer

2.1 Basic Concept of Wireless Power Transfer:

Wireless power transfer is the process where electric energy is transmitted from a power source to an electrical load without any wire connection. Wireless power transfer is based on the magnetic resonance and near field coupling of two-loop resonators was reported by Nicola tesla a century ago. Power is wirelessly transferred when a magnetic field is transferred over a short distance. The magnetic field is created using inductive coupling between coils of wire or electric fields using capacitive coupling between electrodes. The concept of inductive coupling and magnetic field comes from the following principles.

2.2 Ampere's Law:

According to Ampere's law, when current is passed through a closed loop of conductor or coil, a magnetic field is created around it. The magnetic field created by the current is proportional to the size of that current with a constant of proportionality equal to the permeability of free space.

2.3 Faraday's law of induction:

It states that the instantaneous electromotive force (emf) or voltage induced in a circuit due to changing magnetic field is directly proportional to the change of that magnetic field.

2.4 Lenz's law:

It states that the induced emf generates current that sets up a new magnetic field which acts to oppose the existing magnetic field. In wireless power transfer systems, these principles are adopted. In general, a WPT system consists of a transmitter connected to a power source and a receiver that receives the power and delivers it to the load. On the transmitter side, there is a primary coil and on the receiver side, there is a secondary coil. When the power is connected to the primary coil a current passed through it and a magnetic field is formed around it. When the secondary coil is brought close to the primary coil a voltage induces in the secondary coil which generates a current that causes another magnetic field around the secondary coil. The current produced in the secondary coil is used by any load without any physical connection.

2.5 Types of Wireless Power Transfer:

There are 2 types of Wireless Power Transfer:

- *Radiative:* Mainly it is used for far-field.
- *Non-radiative:* Mainly it is used for near field.

2.6 Difference between Wired and Wireless Power Transfer:

The word "wired" refers to any physical link made up of cables. Copper wire, twisted pair, or fiber optic cables, for example, are used. The transmission of power through cables is known as wired power transfer. Wireless, on the other hand, is a term that refers to a medium made up of electromagnetic waves. An antenna or sensor is used in all wireless devices. Wireless power transfer is a method of transmitting energy from one physical device to another without any physical connection. The main difference between wireless and wired connection is the physical

medium between two devices. For example, the cables can be damaged and require repair or replacement. The cost for the replacement or repair can be high. When compared with cables, wireless are easy to install, and no need to worry about the damage of cables. Using wire, we can transfer power from one device to another. Wireless power transfer allows users to quickly transfer power from one computer to another. Because of the presence of wires, there is a risk of power failure or loss in a wired link due to a short circuit. In a wired network, managing the interconnecting wires between devices can be difficult at times. Wireless systems, on the other hand, are relatively low-maintenance and if maintenance becomes necessary, they are easy to maintain.

Chapter-3

Existing Improvements of Wireless Power Transfer:

3.1 Qi Technology:

Small inductors are used to transmit power over higher frequencies, and a charging distance of only a few centimeters is possible. As a result, portable devices must be placed very precisely on the dock in order to avoid a lack of a large magnetic field. Qi components can use multiple resonator arrays to create a larger charging area due to its limited charging area. Individual coils switched on, on the other hand, do not mitigate the problem and even waste a lot of power. Users must align their devices precisely with the magnetic fields in order to maintain a strong enough connection. Due to the operating frequency heating conductive materials, the wireless charger can get warm while charging and heat the back of a device. A limited communication protocol is also included in the Qi standard to limit the amount of power consumed by multiple coils. The receiving device can tell the charger how much power it needs and when it is fully charged using this method[6]. The charger can also change the power output to suit any receiving device and go into standby mode once the device is fully charged or if no device is connected. Even though wireless charging is not as effective as traditional charging, the Qi standard will soon be able to be used in wireless charging[7].

3.2 Alliance for Wireless Power (A4WP) Technology:

A4WP is a next-generation wireless power transfer protocol that allows for efficient power transfer to electronic devices. This is based on resonators that transmit and receive reference power without the use of interconnecting wires. This technology allows a single transmitter to charge several devices with different power requirements at the same time. Since this technology

makes use of a larger electromagnetic field rather than small inductor coils, devices can be charged without having to line up perfectly with the coil. Even though A4WP has yet to be published on the market **{**the presence of this technology allows electronic devices to be charged in any place. A further advantage of A4WP is allowing chargers to be embedded in the objects where the magnetic fields can still emit the energy from the objects.

3.3 PMA Technology:

Power Matters Alliance (PMA) is also another new technology. This is the organization that has been collaborating with a group of research group leaders to build a better power model for battery-equipped devices using wireless charging technology in a national, not-for-profit industry[8]. Since its inception, PMA has evolved at a rapid rate. More than 100 participants from a variety of industries, including telecommunications, consumer electronics, automobile, retail, furniture, surfaces, and others, have recently begun to collaborate with this emerging technology standard. PMA's growth and success can be credited to the members ’ hard work and commitment, as well as a creative approach to making wireless charging commonplace in the areas where customers need it most[5].

List of recent technologies[7]**:**

No	Recent Technologies		
	Qi Standard	**PMA**	**A4WP Standard**
1.	Magnetic induction charging	Induction charging	Magnetic resonance charging
2.	Lack of large magnetic field	Enough magnetic field	Huge magnetic field
3.	Charging distance a few centimeters at most	Less than 10 cm	Much larger charging distance
4.	Not easy to charge more than one devices at a time	One device at a time	The design allows charging more than one device from a single transmitter
5.	Heat the back of the devices	Heat the devices	Don't heat the devices
6.	Uses a small precise inductor coil	Small coil	Much larger coil
7.	Need to line up perfectly within the coil	Line up with the coil	No need to line up

3.4 Significance of the research:

In the present time, wireless networks have become more popular than wired networks. So for this reason we can see that wired objects are not as available as the previous ones. For using the wireless networks or else our work become less hazardous. By using wired objects we have to face some troubles with wires but using wireless networks these troubles can be minimized. The **efficiency of the WPT system** decreasing rapidly with increasing air-gap. Many circuit topologies have been employed to enhance the **efficiency** of the **WPT system.** For using the WPT system in the electrical car we can see the increase in mobility. Such as electrical cars, tesla cars, etc. The mobility of these cars is much higher than the regular used car because of using the WPT system. But WPT system is still now underdeveloped. So we are trying to improve as much as possible by simplifying as well as trying to increase the efficiency.

Chapter 4

Wireless Power Transfer Using Amplifiers

4.1 Introduction:

The Wireless Power Transfer system's main weak point is that it needs a high-frequency oscillating current to minimize the leakage inductance so that power can be transferred from the primary to the secondary coil. This production of the high-frequency current takes up some of the efficiency from the WPT system and lowers the overall efficiency of the system. Because there will be always some loss associated with the power being transferred from the primary to the secondary coil due to the leakage inductance if we can improve the production side of the high-frequency power needed for the wireless transfer it will be a great step to increase the efficiency of the WPT system. So for this, we improved this section of the WPT system by using Amplifiers instead of the general way of using MOSFET setups to create the high-frequency power.

4.2 Working principle of an Op-Amp:

Op-amp is made of a multistage amplifier which means there are several amplifiers interconnected in a complex way. Its internal circuit consists of many transistors, FETs, and Resistances. An **Op-Amp** can be used in different ways like for amplification, addition, subtraction, integration, etc. Op-Amps has differential inputs and a single output. An Op-Amp circuit can be used for different purposes. Some of the notable ones are as follows:

1. As a Voltage Follower:

This is the most basic use of an Op-Amp circuit that is being uses used as a voltage buffer. In this circuit, the output voltage is equal to the input voltage but the main reason for this type of circuit is its very high impedance input and very low impedance output which is important for interfacing logic levels between two components. The circuit of a voltage follower circuit is as follows:

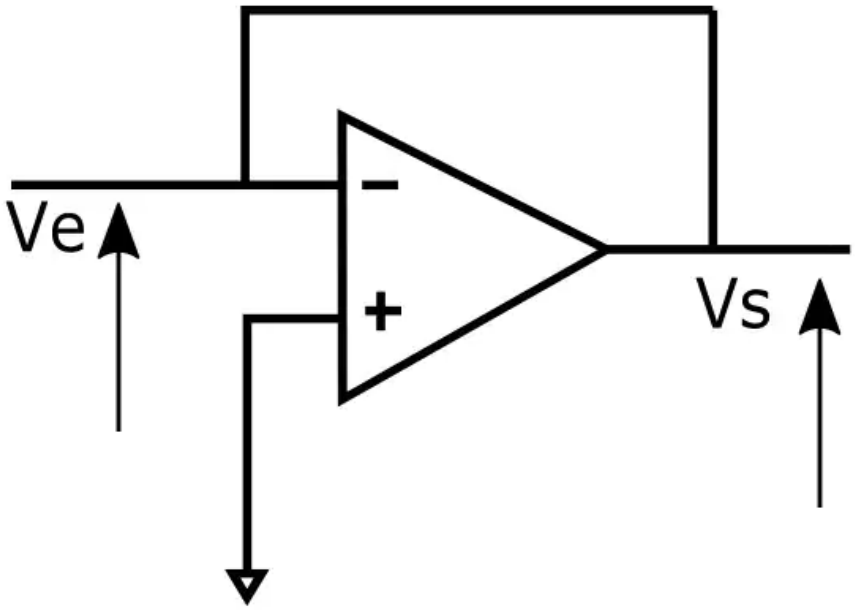


Fig 4.1: Voltage follower Circuit

Here, Ve is equal to Vs.

2. As an Inverting Op-Amp:

In this circuit, the output of the Op-Amp is fed back to the negative terminal of the input of the Op-Amp and the positive input terminal is connected to the ground. The input signal is also applied to the inverting pin through a resistance. Due to this the output signal comes out as complementary to the input signal. The circuit of an inverting Op-amp is as follows:

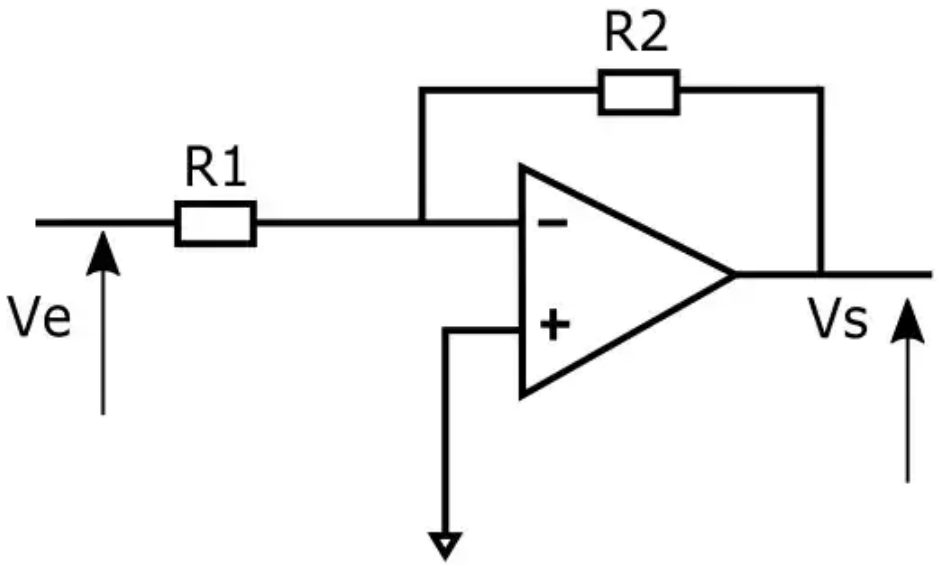


Fig 4.2: Inverting Op-Amp

Here Ve and Vs are complementary to each other

3. Non-inverting Op-Amp:

In this circuit configuration, the input signal is connected to the positive input terminal and the feedback and the negative terminals are connected to the ground. A diagram of this circuit is as follows:

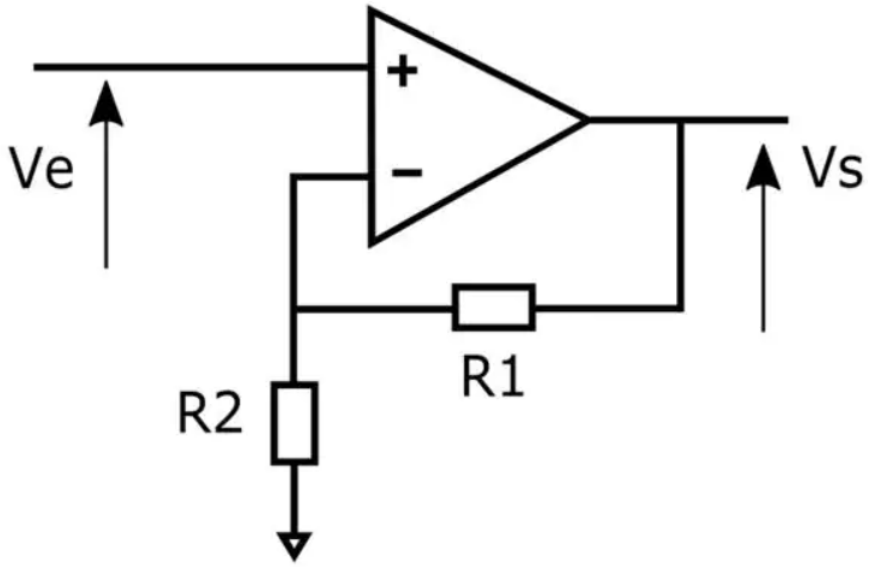
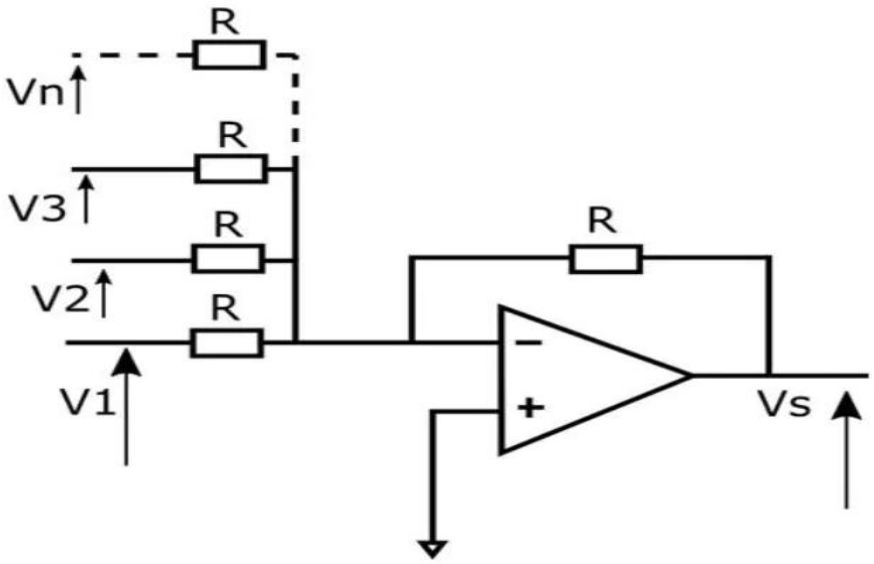


Fig 4.3: Non-inverting Op-Amp

4. Summing Op-Amp:

Summing can be done both in the Inverting and Non-Inverting ways. The diagrams are as follows:



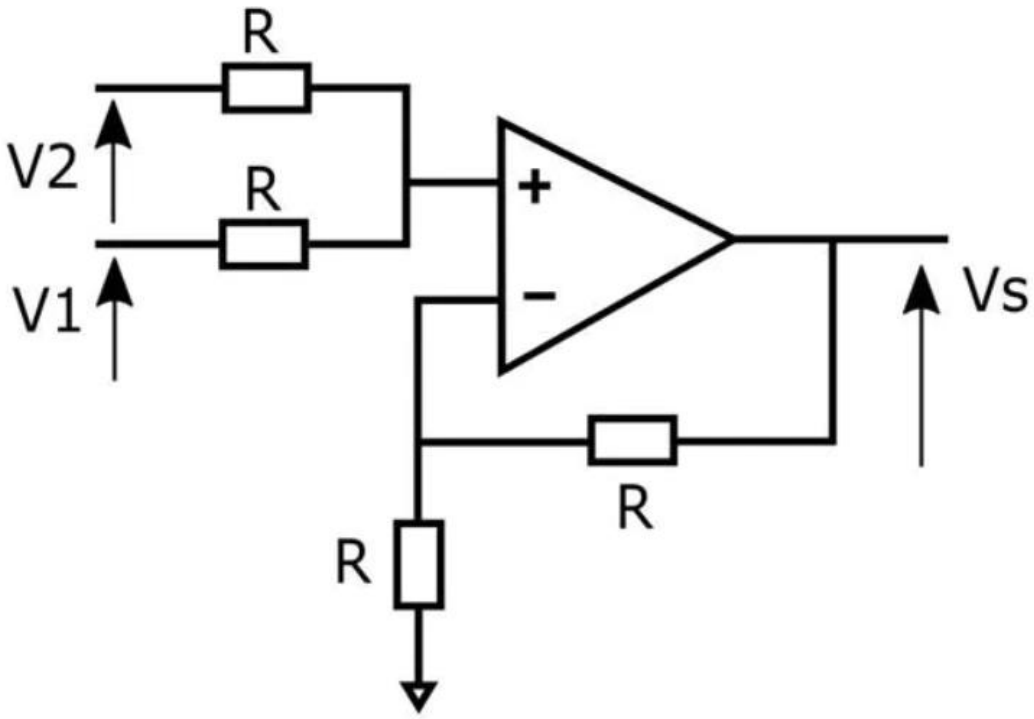


Fig 4.4: Summing Amplifier

Amplifiers can be used in many other ways as well like a Differential Amplifier, Integrator, Differentiator, Converting current to voltage, etc.

But here the main circuit that is important for our wireless power system is the non-inverting Op-Amp because this can amplify the input signal onto its positive terminal and thus we can get an amplified signal of our high-frequency input signal.

4.3 Advantages of using Op-Amp:

Op-amps are theoretically very efficient and they are easy to connect. The traditional way to make the high-frequency signal for the WPT system consists of the H-Bridge connection of the MOSFETs which is very energy inefficient and also very complex in the connection. On the other hand, amplifier circuits are very easy to make and implement they have only 3 major connections and a power input connection. Also, the input impedance is very high so a very

low power signal can be used, and does the microcontroller that will be producing the high-frequency signal can be very small and of very low power. In H-bridge also there need to be MOSFET drivers which also makes the circuit very complex and also consumes some power. That's why amplifiers are a better choice.

Chapter 5

Project Implementation

5.1 Traditional System:

In the traditional system, the AC power from the grid is first converted to DC power using needed which also consumes power. The connection is a little complex too as the MOSFETs are to be connected in H-Bridge configuration and act like an Inverter. Besides this, there are MOSFET controllers which have a complex connection as well and also need power connections. Low power microcontroller boards can't drive the MOSFETs alone as they might fry the board. Inverter Circuits are also of low efficiency and power is lost due to a higher rate of switching. An H Bridge inverter will also not create a pure sine wave, but rather a modified square wave. That is to say, a square wave with some off time between the positive and negative transitions. These off-times are needed so that the MOSFETs are not shorted. Id this off-times are minimizes by tuning their switching times the MOSFETs will flow current among themselves and will be shorted. And due to these off-times, there is power loss too as well as the waves will not be pure sine waves. A diagram of this type of circuit and output is as follows a rectifier circuit then the DC power is taken and with the help of MOSFETs and switching techniques the DC is converted to a high-frequency AC power[2]. For this MOSFET controllers and controlling devices are:

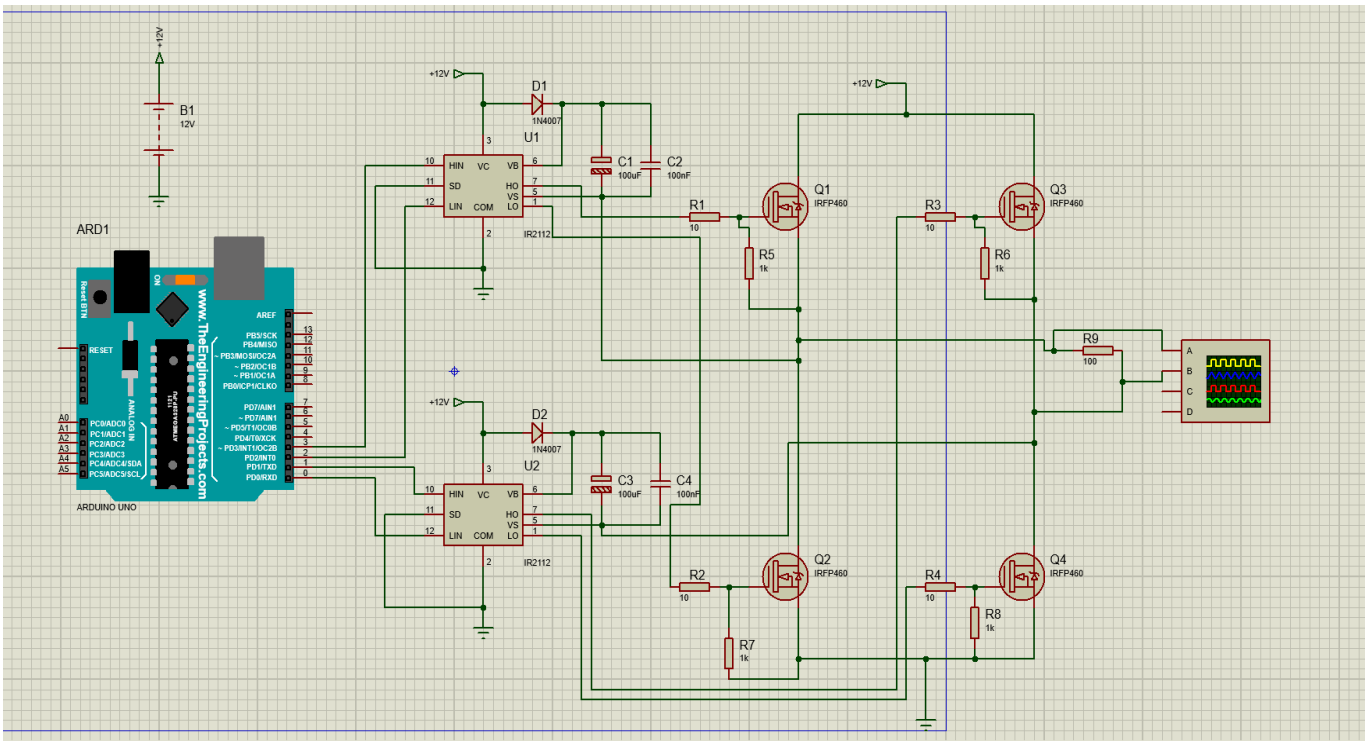


Fig 5.1: High-Frequency Power Circuit using MOSFETs.

5.2 Modification:

So, the main thing for the operation of the WPT system is to have a high-frequency sine power for the coils to produce the altering flux. This high frequency is tuned to the resonance frequency of the capacitor and the inductor to minimize the leakage inductance so that maximum power transfer can occur. So, in our model, we made this high-frequency power by using high-power amplifiers. Amplifiers, as we know, can produce a high power that is higher magnitude for both voltage and current of their input signal and its input current is very low so we can generate the signal from a very low power controller like Arduino mini and feed that to the Amplifier. Besides amplifier's output is very close to the sine wave with very little distortion. Also as amplifiers are generally used to amplify audio signals which's why they are very responsive to frequency change. The frequency depends on the resonance frequency between the capacitor and the inductor. Say the distance or the medium between the two coil changes for any reason the present resonance frequency will also change so by using a feedback option we can give the data to the microcontroller which will change the input signal to the amplifier. So if we need to change

the frequency due to the efficiency purpose of our signal as the KQ factors may change depending on the environment then the amplifier can take care of it more efficiently than a simple H-bridge inverter system. A circuit diagram is as follows,

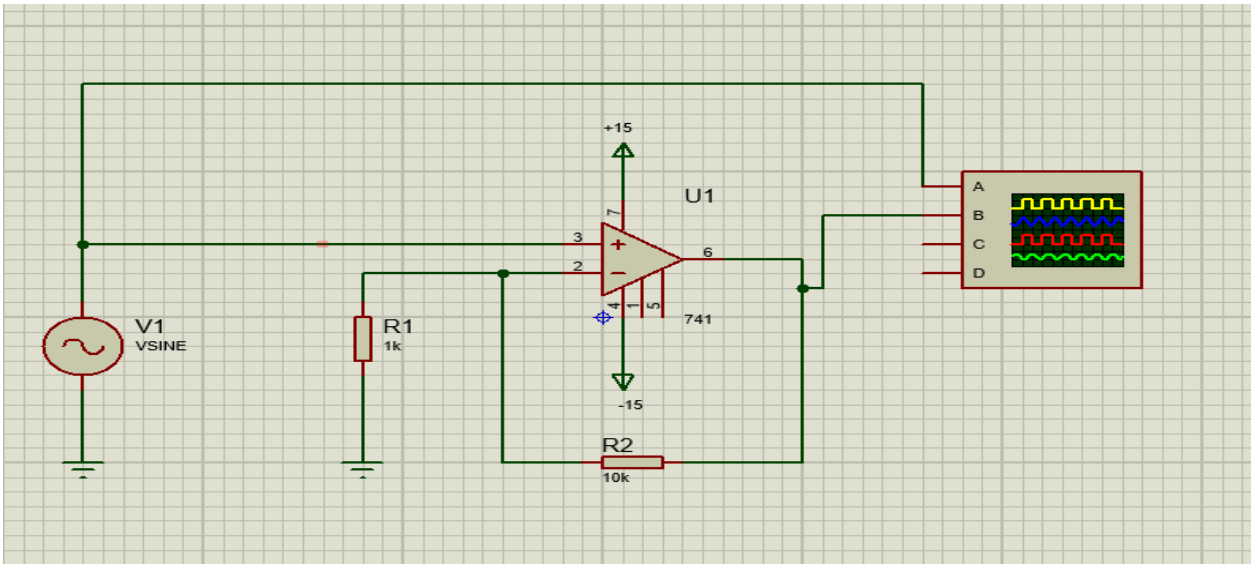


Fig 5.2: High-Frequency Power Circuit using Amplifier.

In the receiving end, there is also a coil to receive the power transmitted to it and a capacitor connected in parallel to keep the leakage flux in check. After receiving this high-frequency power there will be a rectifier circuit that will convert the Ac power to DC and can be used for either running the load or charging batteries. The receiving end is kept as simple and lightweight as possible because they will be in mobile units. The receiving end only contains a coil a parallelly connected capacitor and a rectifier circuit to convert the high-frequency power to dc for either charging or driving the load.

Chapter 6

Results

6.1 Traditional Circuit Output:

In traditional circuits, high-frequency making is done by MOSFETs or other semiconductor devices which switch the DC power very quickly to make the High-frequency signal. This type of Circuit has been shown in the Implementation Chapter. The output of that Circuit is as follows:

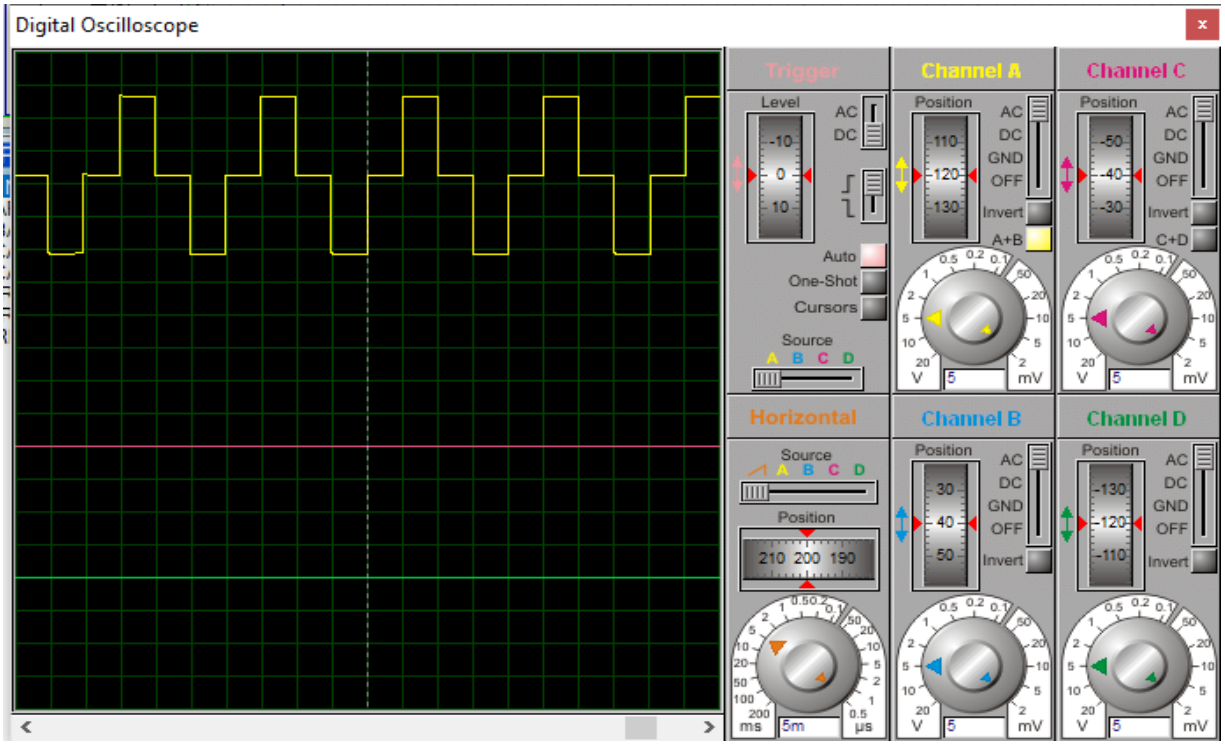


Fig 6.1: Output of MOSFET H-Bridge Circuit.

6.2 Modified Circuit Output:

In our circuit, as shown in Chapter 5 uses an amplifier to make this high-Frequency Signal. The out of this Circuit is as follows:

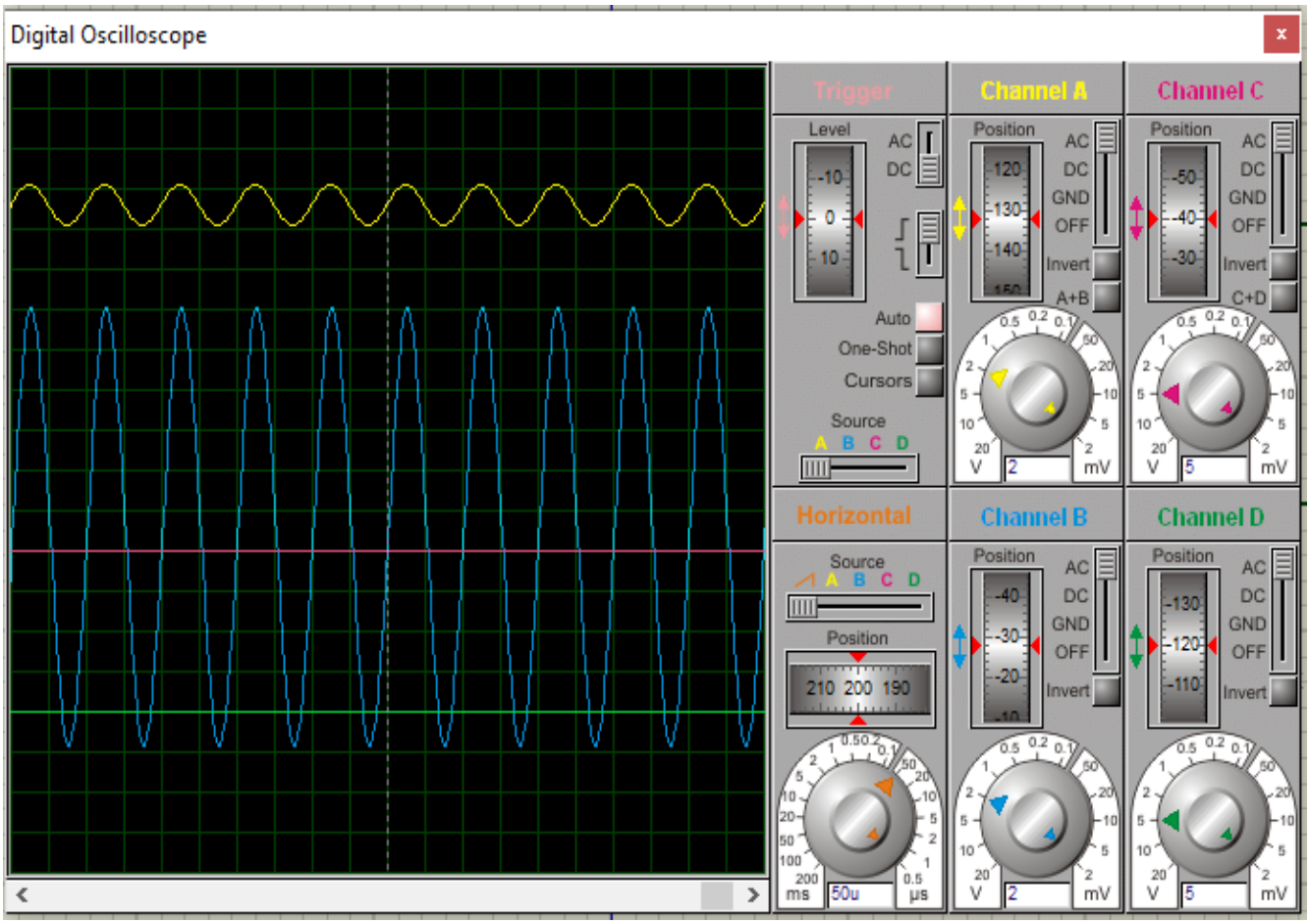


Fig 6.2: Output of Amplifier Circuit.

- So here we can see to produce the same type of high-frequency power output from the amplifiers came out as pure sine signal and with no off-times as well as theoretically amplifiers are more efficient.
- D-class amplifiers nowadays support a wide range of frequencies as they are used mainly for audio amplification and also have greater power outputs. Besides this, they reach very close to their input wave shapes. Wireless power transfer greatly depends on the resonance frequency and the alignment of the coils.
- The Efficiency can be maximized if we can go very close to the resonance frequency of the circuit. So before we saw, if we increase the frequency of the power to the coil quality

increases as thus the power transfer efficiency. So as amplifiers are more responsive to frequency change if needed according to need they can cope up with the issue too.

- Besides this using amplifiers, the circuit becomes more simple as well as easy to understand. In the MOSFET circuit, MOSFET drivers are also needed which also need some power to run and do efficiency decreases a little bit whereas for amplifiers no controllers are needed and input of the amplifier can be directly taken from the microcontroller.

Chapter 7

Conclusion

The importance of the WPT system is increasing day by day as more and more our life is getting dependent on electricity. WPT system is a hassle-free system and also a very safer system than wired connections and can be concealed too. In many dangerous environments like aquatic environments wired connection is quite a hassle to use and also risky in those places, WPT is a great help. It can also be Automized to work without human interaction then the proper benefit of this technology can be understood. But the problem with the WPT system is the efficiency. Due to limitations of the coil, capacitor, and inductor designs, this sector is getting saturated and increasing efficiency is getting tougher. Besides the circuit design is also very complex. That's why we worked on the high-frequency generation side which is considered a great loss in the WPT system. Although the Efficiency increase is minor it greatly simplifies the circuit design as fewer parts are needed.

REFERENCES

[1] "(PDF) Introduction to Wireless Power Transmission." https://www.researchgate.net/publication/265565291_Introduction_to_Wireless_Power_Transmission (accessed Mar. 18, 2021).

[2] "Wireless power transmission, opening up a world of possibilities - Emrod Energy." https://emrod.energy/wireless-power-transmission/ (accessed Mar. 18, 2021).

[3] "Wireless Power Transfer—An Overview | IEEE Journals & Magazine | IEEE Xplore." https://ieeexplore.ieee.org/document/8357386?denied= (accessed Mar. 18, 2021).

[4] "Wireless Power Transmission Circuit and Its Working." https://www.elprocus.com/wireless-power-transfer-circuit-and-working/ (accessed Mar. 18, 2021).

[5] K. Lee and S. H. Chae, "Power Transfer Efficiency Analysis of Intermediate-Resonator for Wireless Power Transfer," *IEEE Trans. Power Electron.*, vol. 33, no. 3, pp. 2484–2493, Mar. 2018, doi: 10.1109/TPEL.2017.2698638.

[6] "Energous Corporation Joins Power Matters Alliance – Energous." https://energous.com/blog/energous-corporation-joins-power-matters-alliance/ (accessed Mar. 19, 2021).

[7] W. Zhong and S. Y. R. Hui, "Maximum Energy Efficiency Operation of Series-Series Resonant Wireless Power Transfer Systems Using On-Off Keying Modulation," *IEEE Trans. Power Electron.*, vol. 33, no. 4, pp. 3595–3603, Apr. 2018, doi: 10.1109/TPEL.2017.2709341.

[8] "PMA - Power Matters Alliance - Wireless Charging Standards." https://wirelesschargingstandard.weebly.com/guides/pma-power-matters-alliance (accessed Mar. 19, 2021).