Smartphone Wireless charging

Yuxiang Su

Michigan state University, U.S.

suyuxian@msu.edu

Abstract: Smartphones are gradually becoming the most important personal device. In the first quarter of 2013, global smartphone shipments reached 216 million, which is approximately twice as large as in 2011.[1] In the absence of breakthroughs in mobile phone batteries nowadays, mobile phones are unable to run for long periods. For devices to work continuously, the convenience of their charging method is important. Wireless charging is a better solution to get rid of the charging cable and the convenience it brings. One of the main objectives of this paper is to find ways to improve the efficiency of wireless charging by analyzing different designs of wireless charging models, dual coil charging lines, dual charging frequencies, and coupling coefficients as well as the influence of the coil on charging. Based on the review of the different designs, it was found that the dual coil design can improve the charging efficiency in terms of quantity. The dual-charging frequency design improves the versatility of wireless charging. Variations in the number of turns and coupling coefficients of the coils can improve the efficiency of the transmission.

Keywords: Smartphone, Wireless Charging, Circuit Model.

1. Introduction.

Smartphones are an integral part of people's lives in modern society. With the widespread popularization of the 4G network and the gradual maturity of 5G technology, the application scenarios of smartphones are becoming more and more abundant. The thinner and thinner the phone's body, the shorter the battery life of the phone. Improving charging power and providing more convenient charging methods are one of the keys to improving battery life. Although there is a relatively common QI wireless charging technology, its charging power is only 10 watts, which seriously affects the consumer experience. The detachable battery in the early 20th century had a continuous and good battery life experience, but it could not achieve the integrity of the mobile phone and the dustproof and waterproof performance to improve the reliability of the device in complex environments. Wireless charging technology can provide reliable battery life for mobile devices while maintaining the integrity of the mobile phone body.

The basis of wireless charging technology is the conversion of energy between two coils. If the charging cable is not connected, the wireless charging performance of the phone will be affected by, for example, the relative position of the charging coil to the phone, and the number of turns of the coil. From figure 1, the primary coil is connected to the source, which will induce a magnetic field. Under influence of the magnetic field, the secondary coil on the receiver end will induce the voltage which will power the load of the smartphone and start charging.

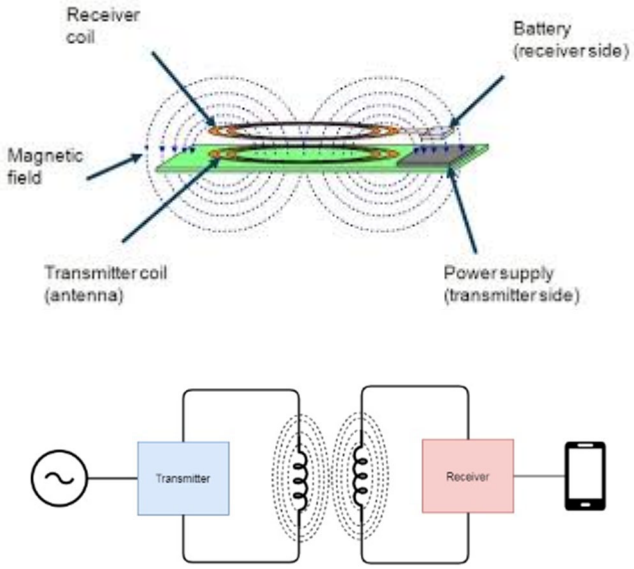


Figure 1. Wireless Power Transfer [2]

In addition to mobile phone charging, wireless charging technology has good prospects in other areas as well.[3] One example of wireless power transmission is the charging of electric vehicles. There are different wireless power transmissions technologies such as inductive coupling, resonant coupling, or MPT. Inductive coupling is already used by many manufacturers such as Hino Motors Ltd. [4] and Showa Aircraft Industry [5]. Resonant coupling for radio transmission is also popular for research into electric vehicle charging. Toyota Motor Corporation and the Toyohashi University of Technology have jointly proposed a new charging method that allows the exchange of vehicle power with road power through a specially modified tire while the vehicle is in motion. [6] The MPT theory of power transmission was proposed by Kyoto University in 2000. Experimenters used microwaves as a means of transmitting electricity to charge the vehicle, for which they obtained an experimental beam efficiency of 76.0%[7] so that the requirements for transmitting power were met.

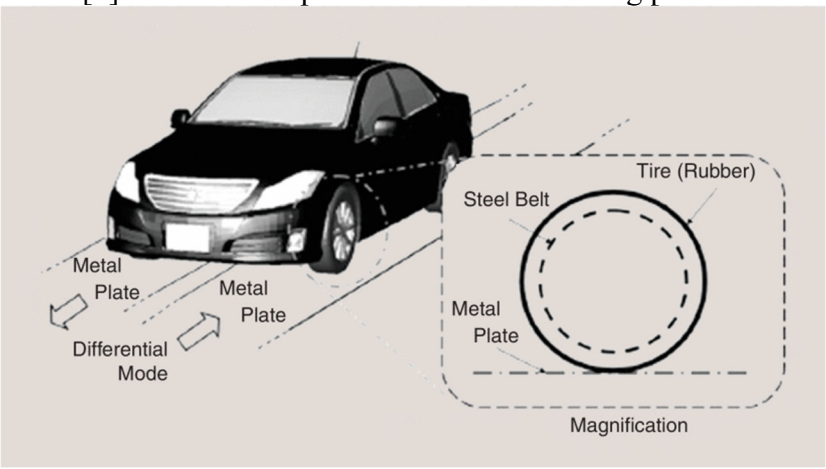


Figure 2. Diagram of the power transfer system proposed by Toyota Central R&C Lab., Inc. and Toyohashi Univ. of Tech., Japan [6]

Wireless power transmission can also be used in different scenarios. One such application of the MPT principle is RF identification (RFID), which operates in the 900 MHz range. Other researchers have proposed the construction of buildings that use microwave technology to transmit electricity. By using non-traditional building materials as waveguides to transmit microwave power, the use of cables can be reduced. [8]

This Review first talks about the wireless charging technology standard for cell phones, the Qi standard, in which magnetic resonance was used [9][10]. At the same time, it introduces the problems

that still exist at this stage of wireless charging both charging powers are not enough to support smartphones for fast power replenishment. And the charging location is relatively fixed is also one of the major obstacles when the current radio. The review goes through three different designs of wireless transmission systems for mobile phones from dual charging coils, dual charging frequencies, and systems with different coupling factors and coil ratios. It is clear from this that wireless power transmission systems, especially for mobile phone charging, still have a lot of room for development, for example in terms of charging power, charging efficiency, etc. By analyzing the principles and experimental data of these designs, a basis for the development of future wireless power transmission technology can be provided.

2.Standard of Wireless charging for smartphone

Qi standard [11] is the trending standard that uses inductive charging theory which delivers the power between the charging base and devices. It is developed by the Wireless Power Consortium (WPC). The charging base and devices both contain several turns of coils, and they will be placed in one line to get the maximin transfer rate. One way to line up two coils is called guided positioning. The manufacturer of the charging base will label a marker on the charging pad. Users must place their devices on that marker to have the power delivered. The second way to get power transferred is called free positioning. The charging base will contain a coil that generates the magnet field at the location of the receiver coils of the device so that users do not place the device accurately.

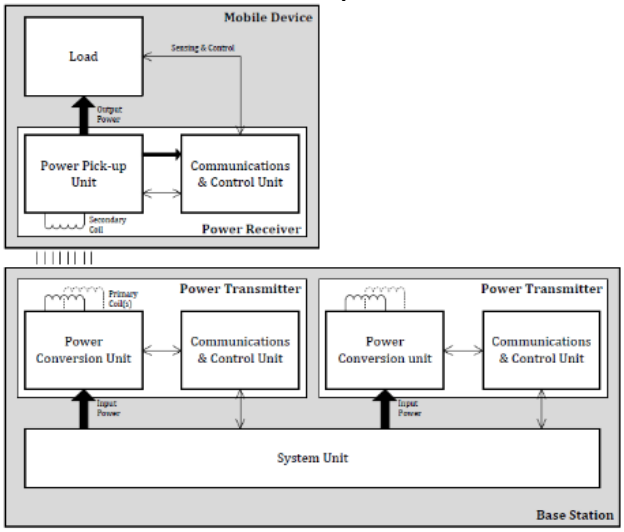


Figure 3. basic wireless charging model [12]

On the 1.2 version of the Qi specification, the number of turns of transmitters has been increased to 20 turns and it is wounded on form with a 40mm outer diameter and 19mm inner diameter. With this change, the transmitter coil could transfer its power up to 45mm away. On the receiver end, it contains a rectangular coil with the size of 44mm × 30mm and is wrapped with 14 turns. With its area increased, the receiver coil will have a higher chance to capture the magnetic flux from the transmitter end.

2.1 Critical Issue of wireless charging

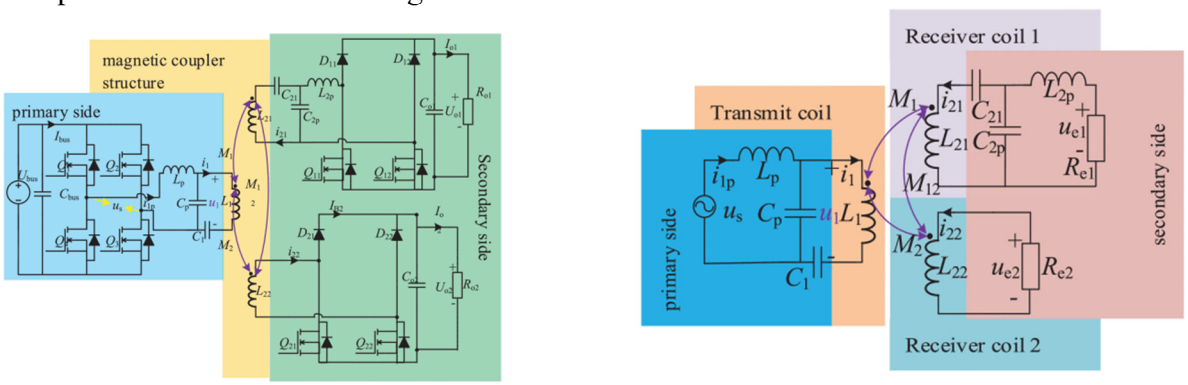
Wireless charging is a promising technology. It can expand from mobile phones to other aspects of development, such as unlimited charging of laptops, wireless charging of electric vehicles, etc. However, due to technical limitations, many problems in the wireless charging of smartphones continue to be solved. This also limits the development of wireless charging in other fields. The first problem to be solved is the problem of charging power. The maximum charging power of the Qi standard is now only 15 watts. Compared with the high power of wired charging, this is a problem that must be improved. This also leads to the second question. Increasing the charging power

necessarily increases the range and strength of the magnetic field. How will this affect people's lives and health? We all know that magnetic fields can rewrite the internal data of nearby hard disks, chips, etc. How to prevent the magnetic field from being too strong to demagnetize the chip and hard disk? Will the electromagnetic field emitted by the magnetic field of wireless charging with increased charging power have an impact on people's health? These are all questions to be argued. Another problem is to solve the problem that the device is randomly placed on the charging board for charging. Now the common charging board is to place the transmitter coil in a fixed place. To power up, the user must place the device in the marked position. Such charging methods have great limitations. Designing a charging pad that can be placed at will and can be charged is also a problem to be solved. At the same time, unified regulations for wireless charging are also the key to promoting development. Now some mobile phone manufacturers have designed and sold high-power wireless charging pads. But those are unified standards, the standards of their respective manufacturers. It greatly limits the common progress of the wireless charging community. A unifying principle is required.

3. Model analysis

3.1 High power Density Dual Receiver Wireless Charging System

The design [11] below, is split into two parts. The (blue) part on the left is called the primary or transmitter side of the wireless charging system. It contains a full-bridge inverter, which generates a square wave AC output voltage on the application of DC input by adjusting the switch turning ON and OFF based on the appropriate switching sequence, and an LCC compensation, which compensates the circuit when there is poor magnetic field induction. On the right end of the circuit (Green part), there are two sets of receiver devices which also contains a full-bridge inverter and LCC compensation to keep the circuit secure. Two resistors are used in the two circuits to represent the smartphone that needs to be charged.



Circuit design [13] Simplified circuit figure [13]

Figure 5. Circuit design and Simplified circuit figure [13]

A simplified figure of the circuit is shown above. The diagram shows that the circuit at receiver 2 has only the coil and the load R2, so to transfer as much power as possible to the consumer R2, the inductance of L22 must be reduced so that R2 receives sufficient power.

To verify the feasibility of the system the author tested the designed circuit in a simulated environment with two receivers A and B set at 12V and 3A and 5V and 3 A respectively.

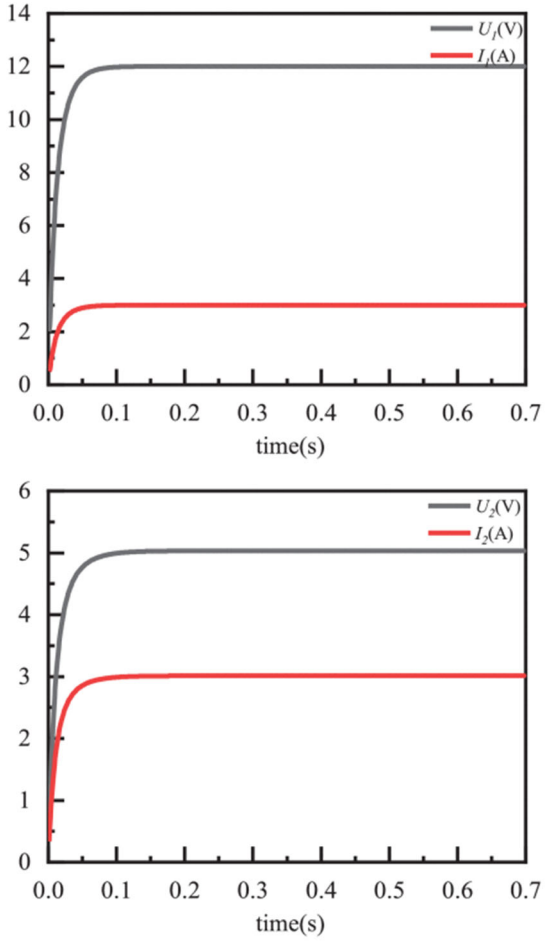


Figure 6. Output current and Output voltage when receivers A and B work at the same time[13]

As we can see from the diagram above, both receivers are working steadily at their respective set targets for voltage and current, so we can say that the system is stable.

The authors also investigate the problem of the receiver that has already started working influencing the receiver that works later when the two receivers start working at different times. The following diagram shows that the later receiver B does not have a significant effect on receiver A, which is already working.

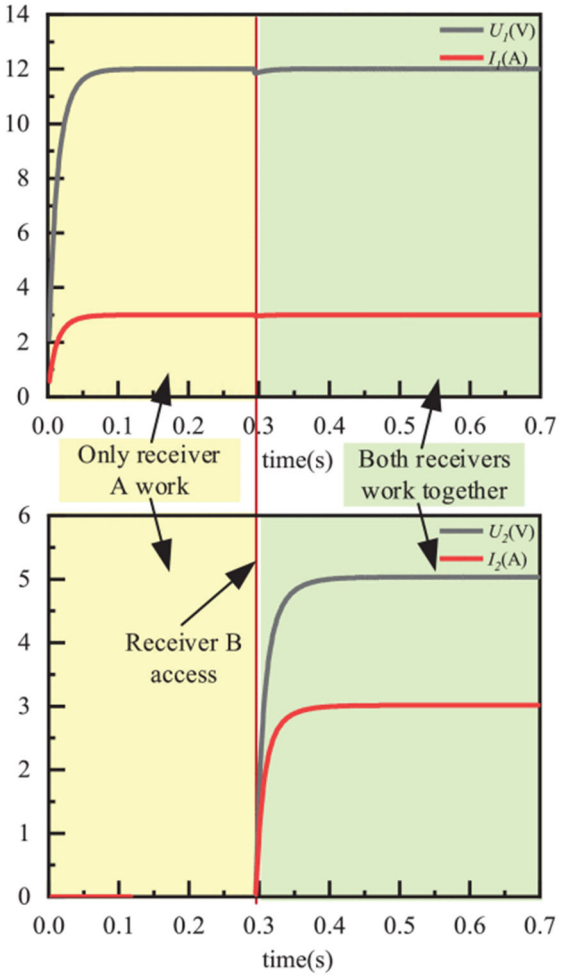


Figure 7. output voltage and current of the receiver A and B [13]

The results of this dual power transmission model show that the authors' circuit design is reliable and that all lines operate within the design objectives, while also meeting good power transmission design objectives. The design using dual receivers solves the problem of charging multiple devices for the purpose of use and increases the charging efficiency at a quantitative level.

3.2 Dual-mode wireless power transfer module for smartphone

Here is another example of a wireless charging design.[12] In this case, the receiver side has two separate lines adapted to different modes of operation. The first mode (the circuit in the red circle) of operation is in the 13.56 MHz NFC mode. First, the circuit detects the impedance at that frequency for the best transmission efficiency. Then the receiver side of the NFC receives the signal and proceeds to the next interaction through the control circuit, for example, to start charging. The second mode(the circuit in the blue circle) works at 6.78MHz. After impedance matching, the transmitted magnetic field is transformed into current through the coil and is controlled by rectifier and voltage, and finally delivered to the charging circuit. At the same time, an additional system is used to detect the charging status. If a full charge is detected, the communication with the charging coil is stopped.

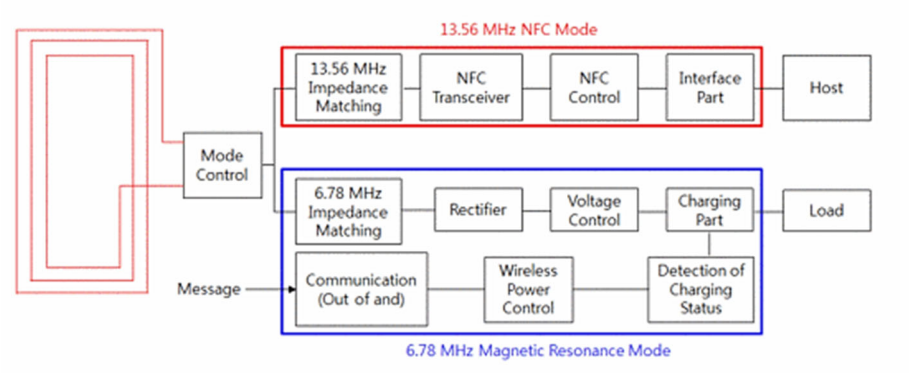
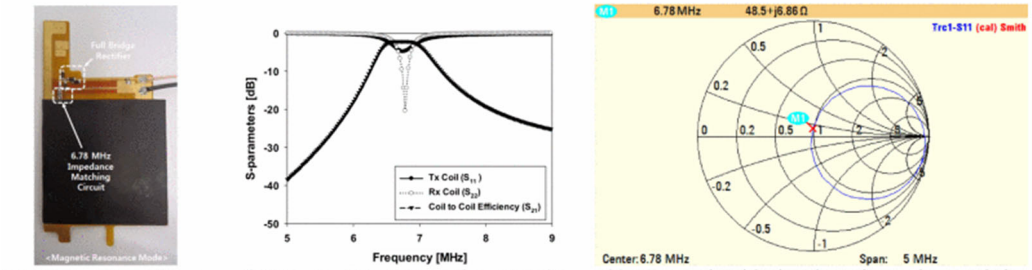


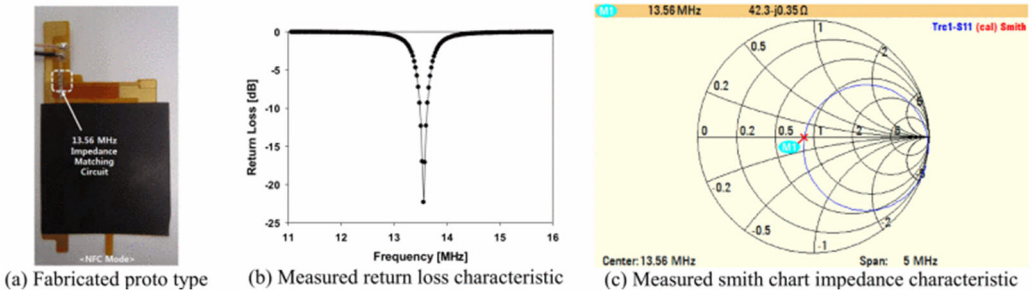
Figure 8. circuit design of dual-mode WPT [14]

To verify the feasibility of the designed circuit, the designer used the Samsung galaxy note 4 as the experimental cell phone, because the size of this dual-mode WPT coil is the same as the size of the cell phone.



(a) Fabricated proto type (b) Measure S-parameter characteristics (c) Measured smith chart impedance characteristic

Figure 9: 6.78MHz operation mode [14]



(a) Fabricated proto type (b) Measured return loss characteristic (c) Measured smith chart impedance characteristic

Figure 10: 13.56 MHz NFC operation mode [14]

The a's in Figs. 9-10 represent prototypes designed by the author. Figure 9(b-c) shows the measured S-parameter characteristic and the smith chart impedance matching characteristic respectively. B of fig.9 shows that the system has a relatively good return loss characteristic at 6.78 MHz. C of fig.9 shows that a 150pF capacitor was connected in parallel and a 43pF capacitor in series to match the most suitable impedance. Figure 10 b shows the return loss characteristic at an operating frequency of 13.56, which is 23 dB. Figure c shows that to match the optimum impedance, the author added a 308pF capacitor in parallel and a 23pF capacitor in series.

From the authors' experimental data, it appears that this design has the advantage of operating in two different modes, 6.78MHz and 13.56MHz. Both frequencies also have low loss characteristics, with 6.78MHz achieving as much as 70% transmission efficiency. However, the actual transmission efficiency is reduced due to the interference of other frequencies in the specific usage scenario.

3.3 WPT circuit for smartphone wireless charging

The third example [15] of a wireless charging system is still based on the basic Faraday electromagnetic induction principle. However, the authors used NI Multisim 14. 2 to design the specific circuit for the specific design of transmitter and receiver side. On the transmitter side, the

authors use a 12 V power supply to power the transmitting magnetic field and an oscillator to transmit a sinusoidal signal. On the receiver side, a coil is used to receive the magnetic field from the transmitter side and convert it into a current through Faraday's principle of electromagnetic induction. A parallel capacitor is used to stabilize the circuit's oscillation. The diode further back is used to protect the circuit from voltage spikes.

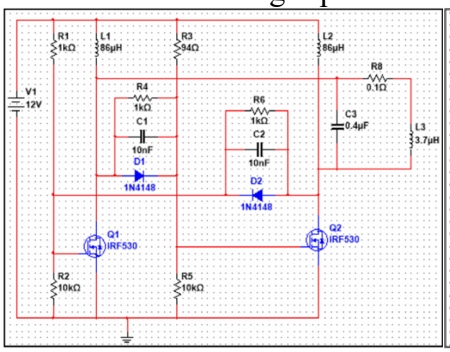


Figure 11. Transmitter side [15]

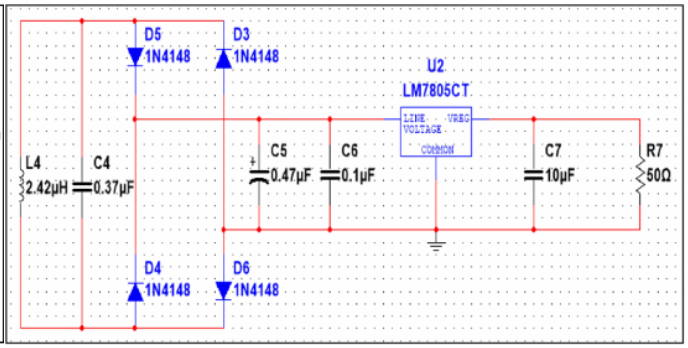


Figure 12. Receiver side [15]

For efficient power transfer, tight coupling is used with k values close to 1. The equation for K is as follows:

$$K = \frac{M}{\sqrt{L_3 L_4}} \quad (1)$$

In equation 1, M stands for mutual inductance, which is related to the diameter of the two coils, the distance between the two coils, and the permeability of the coil material.

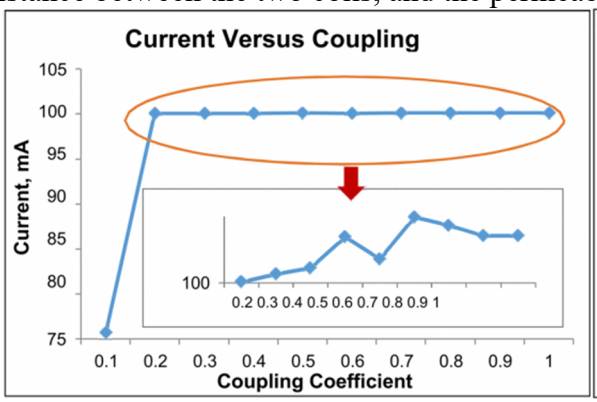


Figure 13. current VS coupling [15]

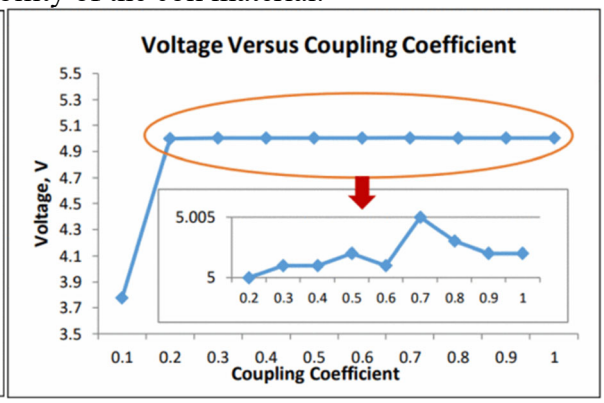


Figure 14. Voltage VS coupling [15]

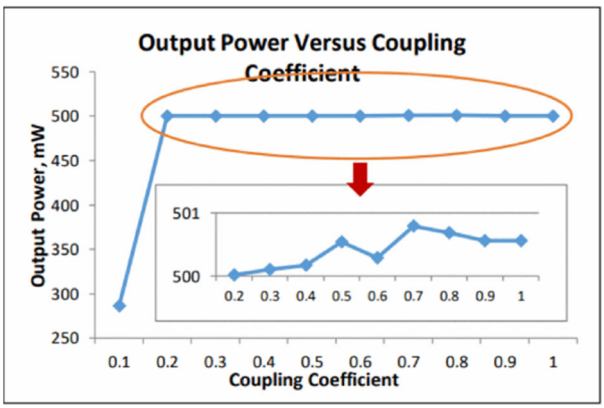


Figure 15: Output power VS coupling [15]

After simulating and analyzing the designed circuit, the authors obtained the relationship between voltage, current, and power versus coupling coefficient as shown above. According to equation 2,

$$P = V * I \tag{2}$$

changes in voltage and current affect changes in output power. The graphs of voltage and current show that after a coupling factor of 0.2, both voltage and current tend to stabilize, fluctuating within a small range so that the output power appears to be consistent with the voltage and current, and after a coupling factor of 0.2, tends to be stabilized.

Turn ratio	Frequency, kHz	Voltage, V	Current, mA	Power, W
1:2	84.3	5.00	100	0.500
1:3	57.4	5.01	100	0.501
1:5	33.7	5.01	100	0.501
1:7	23.1	5.01	100	0.501
2:1	169	5.00	100	2.496
3:1	186	5.00	100	1.501
5:1	179	3.11	62.2	0.193
7:1	149	1.67	35.5	0.059

Figure 16. turn ratio VS power output [15]

In addition, the authors investigated the effect of different coil turn ratios on the efficiency of the circuit in transmitting energy. N1 is the number of coils that turns at the transmitting end and N2 is the number of coils that turns at the receiving end. When N1 > N2, the output power is significantly higher than when N2 > N1. From this, the turn ratio of the coil is also one of the more important factors affecting the transmission of wireless power.

4. Conclusion

The convenience of smartphones drives the need for the convenience of their accessories. Wireless charging is one of them. The review goes through three different designs of wireless transmission systems for mobile phones from dual charging coils, dual charging frequencies, and systems with different coupling factors and coil ratios. It is clear from this that wireless power transmission systems, especially for mobile phone charging, still have a lot of room for development, for example in terms of charging power, charging efficiency, etc. By analyzing the principles and experimental data of these designs, a basis for the development of future wireless power transmission technology can be provided.

The existence of WPT and Qi standards provides a unified path for the development of wireless charging. The Qi standard is now more popular in mobile phones. But his convenience and unified features allow him to be extended to more fields, such as office environments, and kitchen scenes. These are all areas with good application prospects. I believe that wireless charging has a broader prospect in the future.

References

[1] Qiuhong, Z., Qin, Q. and Hongliang, C., 2013. Chinese Smart Phone Market Competition Analysis Based on AHP. 2013 Third International Conference on Instrumentation, Measurement, Computer, Communication and Control,.

[2] "How To Manage Loss Efficiently With Ferrite Tiles In Wireless Power Transfer". 2022. Kemet.Com. https://www.kemet.com/en/us/technical-resources/how-to-manage-loss-efficiently-with-ferrite-tiles-in-wireless-power-transfer.html.

[3] Shinohara, Naoki. 2011. "Power Without Wires". IEEE Microwave Magazine 12 (7): S64-S73. doi:10.1109/mmm.2011.942732.

[4] "HINO TRUCKS". 2022. Hino.Com. https://www.hino.com/hino-trucks.html..

[5] "TOP | Showa Aircraft Industry Co.,Ltd.". 2022. Showa-Aircraft.Co.Jp. http://www.showa-aircraft.co.jp/en/index.html.

[6] M. Hanazawa and T. Ohira, "Power transfer for a running automobile", *Proc. IMWS-IWPT*, pp. 77-80, 2011.

[7] Shinohara, Naoki. 2010. "Beam Efficiency Of Wireless Power Transmission Via Radio Waves From Short Range To Long Range". Journal Of Electromagnetic Engineering And Science 10 (4): 224-230. doi:10.5515/jkiees.2010.10.4.224.

[8] Shinohara, Naoki, Naoki Niwa, Kenji Takagi, Kenniti Hamamoto, Satoshi Ujigawa, Jing-Ping Ao, and Yasuo Ohno. 2014. "Microwave Building As An Application Of Wireless Power Transfer". Wireless Power Transfer 1 (1): 1-9. doi:10.1017/wpt.2014.1.

[9] Kim, Seong-Min, In-Kui Cho, Sang-Won Kim, Jung-Ick Moon, and Ho-Jin Lee. 2020. "A Qi-Compatible Wireless Charging Pocket For Smartphone". 2020 IEEE Wireless Power Transfer Conference (WPTC). doi:10.1109/wptc48563.2020.9295616.

[10] Kurs, André, Aristeidis Karalis, Robert Moffatt, J. D. Joannopoulos, Peter Fisher, and Marin Soljačić. 2007. "Wireless Power Transfer Via Strongly Coupled Magnetic Resonances". Science 317 (5834): 83-86. doi:10.1126/science.1143254.

[11] 2022. Wirelesspowerconsortium.Com. http://www.wirelesspowerconsortium.com/.

[12] "Qi (Standard) - Wikipedia". 2022. En.Wikipedia.Org. https://en.wikipedia.org/wiki/Qi_(standard).

[13] Liu, Hao, Zhenjie Li, and Yuhong Tian. 2021. "High Power Density Dual Receiver Wireless Charging System Using Anti-Misalignment Designed Magnetic Coupler". 2021 IEEE 2Nd China International Youth Conference On Electrical Engineering (CIYCEE). doi:10.1109/ciycee53554.2021.9676920.

[14] Han, Minseok, Ji-Min Kim, and Hoon Sohn. 2015. "Dual-Mode Wireless Power Transfer Module For Smartphone Application". 2015 IEEE International Symposium On Antennas And Propagation &Amp; USNC/URSI National Radio Science Meeting. doi:10.1109/aps.2015.7304441.

[15] Zable, M. A.H., Z I. Khan, N. A. Zakaria, N.E. Abd Rashid, K. K. M. Shariff, and S. A. Enche Ab Rahim. 2020. "Performance Evaluation Of WPT Circuit Suitable For Wireless Charging". 2020 IEEE Symposium On Industrial Electronics &Amp; Applications (ISIEA). doi:10.1109/isiea49364.2020.9188073.