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DEVELOPMENT OF AN EFFICIENT WIRELESS POWER TRANSFER AND CHARGING SYSTEM (500MHZ – 900MHZ)

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ABSTRACT

Strong coupled magnetic resonance Wireless Power Transfer (WPT) proposed by researchers at Qi IEEE conf. in 2007 attracted the world's attention by virtue of its mid-range, non- radioactive, and high-efficiency power transfer. In this article, current developments and research progress in the technology of WPT are presented. Advantage of WPT are analysed by comparing it with other WPT technologies and different analytic principles of WPT are elaborated in depth and further compared. The important research areas, including system architectural analysis, frequency splitting phenomena, impedance matching, and optimization designs are classified and elaborated. Finally, current research directions and development trends of WPT are discussed and the simulation results are presented as convincing evidences that the proposed model meets the design specifications and it is capable of providing efficient wireless power transfer to portable charging devices.

1. INTRODUCTION

Due to globalization, power transfer efficiency is an important objective in designing Wireless Power Transfer (WPT) system [1]. WPT or wireless power transmission is the process of transmission of electrical power source to the consuming device without the use of solid wires or conductors [2], this is a generic term that refers to the number of different forms of power transmission technologies that use time varying electromagnetic fields [3]. Wireless transmission is very useful to power electrical devices in cases where interconnecting wires are inconvenient, hazardous, or completely not possible. In wireless power transfer process, a transmitter device is connected to a power source such as mains power line, transmits power using electromagnetic field across all the intervening space to one or more receiver devices, where it is converted back to electrical power for utilization. This is similar to how Wi-Fi and Bluetooth became globally standardized. By implementing this work, users can forget about the use of different chargers anymore for a different portable electrical devices in the feature and be able to use wireless means to aid their charging efficiently.

The theory and the idea of WPT and charging system started long time ago by Nicola Tesla who began demonstrating wireless broadcasting and power transmission in early 1900s. He was able to power lights to the ground at his Colorado Springs experimental station remotely [4]. Michael Faraday formulated the law of electromagnetic induction whereby it is now possible to transfer energy from one environment to another using electromagnetic waves. All these contributed to the enhancement of efficient wireless charging. At present, wireless charging has already been developed for low-power devices such as mobile phones and wireless powered access cards. Such charging systems can power up to 5W. In the year 2000, Professor Shu Yuen Hui from the City University of Hong Kong invented a planar wireless charging pad that was able to charge several electronic loads simultaneously. Also, in the year 2007, MIT researchers demonstrated an efficient wireless power transmission based on a strong coupled magnetic resonance that successfully powered a 60W light bulb with 40% efficiency remotely at 2 meters [4]. In the subsequent year, Intel successfully lighted an electric bulb with 70% efficiency at 1 meter distance.

Generally, wireless charging is a multidisciplinary field that includes power electronic circuits, coils, and a control circuitry. Comparing wireless charging topology to wired topology, it has lower efficiency due to added losses on coupling and power conversion units. These increase resistive heating losses and cause overheating on the battery which in turn reduces its life time. Thus, this work addresses the efficiency issue which is the main concern on wireless charging technology using the most advanced solutions to achieve the coupling efficiency of 85% and the overall system efficiency of up to 75% [5].

So many other research work has been conducted to extend the possibility and the efficiency of wireless charging to 2-way and 4-way radios but the limitations are that must of these radios required only 7.5V battery for their operation and the efficiency of the wireless charging is considerably low compared to the traditional wired charging. This work basically is to make improvement on the efficiency of the RF WPT and charging system already on ground and to extend the charging voltage up to 8.5 V and 12V and the transmitter to emit a low-power radio wave at a frequency of 500-900 MHz.

2. Types of RF Wireless Power Transfer

Radio Charging: This charges low-power electronic devices within a distance of 10 meters from the transmitter and sends out low-power radio wave to the receiver which converts the signal to energy. This could activate advanced Radio Frequency Identification (RFID) chips through a considerable enhanced induction.

Inductive Charging: It is the most important method of transferring energy wirelessly through an inductive coupling. Basically, it is used for near field power transmission. The power transmission takes place between two conductive materials through mutual inductance. The typical example of an inductive coupling transmission is a transformer.

Resonance Charging: This applies the concept of resonance whereby both the transmitter and the receiver coils are turned to the same electromagnetic frequency. At resonance, the receiver coil can pick up the signal when energy at resonant frequency is applied.
An inductive charging method is the technique used in implementing this work for it is the commonly used method for electronic devices. This eases the use for both the consumers and the developers. Wireless Power Consortium (WPC) has established Qi as the global standard for wireless power system with the output power of up to 5W to create interoperability between the transmitter and the receiver [6]. Under WPC standard, the type of inductive coupling and communication protocol are always defined.

Wireless charging system consists of basically two distinguishable devices shown in Figure 1:

a) **Wireless power transmitter coil section:** The wireless transmitter section converts the DC power from an oscillator to a high frequency AC power signal. This high frequency alternating current which is linked with the wireless transmitting power creates an alternating magnetic field in the coil due to induction to transmit energy.

b) **Wireless power receiver section:** In this section, the receiver coils receive the energy as induced alternating voltage (due to induction) in its coil and the rectifier in the wireless power receiver converts the AC voltage to a DC voltage. Finally, the rectified DC voltage is feed to the load through the voltage controller section. That means that the main function of a wireless receiver section is to charge low-power devices through inductive coupling.

3. Design Flow and Optimization

Generally, the design process for an inductor coil is very complicated as the physical and electrical parameters which affect the performance of the coil are interrelated whereby any change in one of the parameters has an effect on another. Thus, a design flow for the coils is developed to model the inductor coils based on the design of solenoid shaped coil and Printed Spiral Coil (PSC), where the performance is compared between the two designs. The ultimate goal of this design flow is to optimize the power transfer efficiency between two coils while meeting the design specifications and constraints as per the application system requirements. The design flow for the inductor coil is described step by step as shown hereunder first by explaining the parameters together with the good shape and size of the coil used.

In WPT charging, coil is formed by winding a conducting wire to a certain configuration. This tends to concentrate the magnetic field by the coil, hence, improving the induced voltage collected. This also improves the inductive coupling between coils. The Printed Circuit Board (PCB) gives an easier concept in designing a PSC because it is manufactured using PCB process which is termed as a standard process for manufacturing PSCs. This is also integrated in the receiver circuit which reduces the size of the receiver. The coil area and the number of layers are limited by PCB, where higher self-inductance is very difficult to be achieved. Accurate inductance has to be calculated as it cannot be modified once the PCB is fabricated [8]. Commonly used structures for wireless charging are, printed spiral coil, Helical coil, and planar spiral coil, and as shown in the Figure. 2.

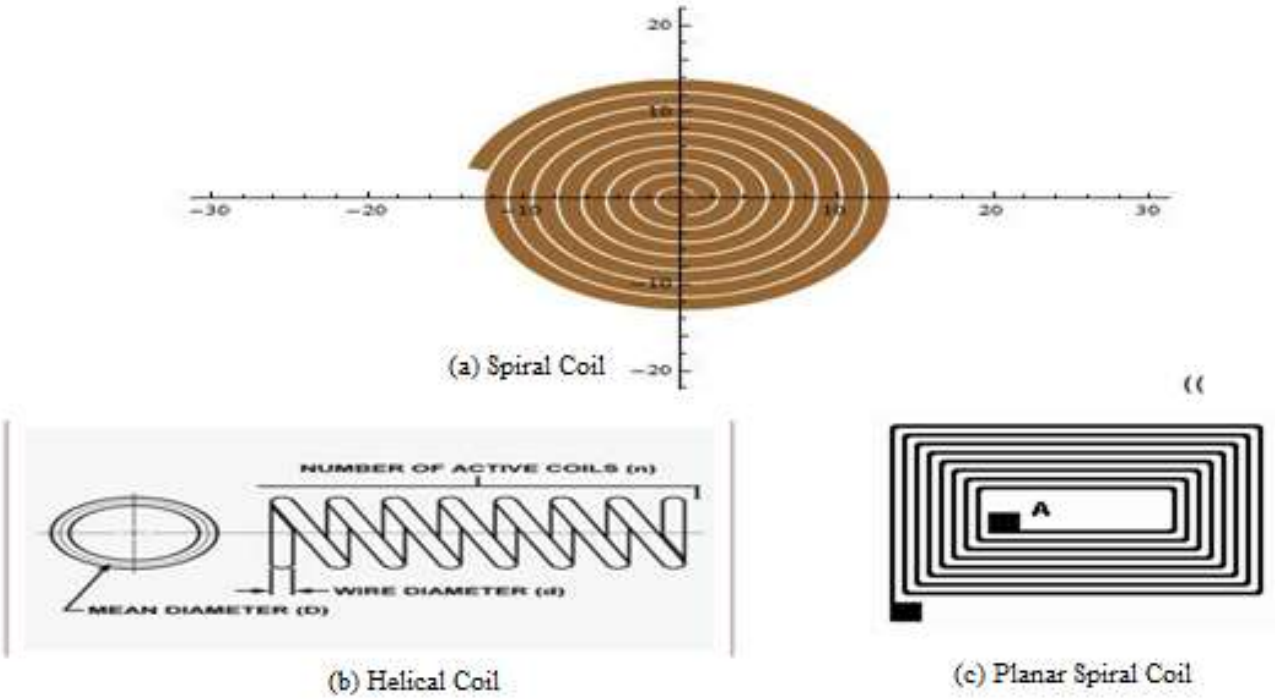


Figure 2: Different Types of Winding Structures on WCC

The structure of a helical coil is similar to an inductor and it can easily be constructed and compared to a planar coil. This gives a better magnetic field with longer wavelength but this does not have an advantage to short range charging [9]. Helical coil occupies more space to obtain a desired inductance compare to a planar coil. Helical coil produces a horizontal magnetic flux as shown in Figure 2. Both the coils are required to be positioned perpendicular to each other in order to allow the capturing of the magnetic flux which is not suitable for a slim design of portable devices.

Planar coils generate vertical flux, where both charging coils can be positioned in parallel position to each other. Hence, it is more suitable for implementation in wireless charging application [10]. The inductance and the design of the coil can be easily modified with a planar spiral coil configuration. Planar Spiral Coil PCB is commonly made up of Litz wire which tends to increase the impedance of a conductor caused by eddy current effects. For this article, planar spiral coil is the targeted coil design to be implemented as it tends to give higher efficiency with Litz wire and is suitable for slim design at higher frequency.

The shape of the coil also affects the magnetic properties as such the choice of better shape of coil leads to an efficient power transfer between the transmitter and the receiver coils. Hence, the typical coil shapes available include: circular, square, and rectangular structures [11]. Segmented shape which splits the rectangular area into two parallel connected coils is also considered. The shape of the coil also affects the coupling factor (k) as in Figure 3. In all the four shapes of the coil, circular shape gives the highest coupling factor [12], but the coil with the higher area has the higher coupling factor. For the purpose of this design, circular coil is used based on its advantage as discussed and shown in Figure 3.

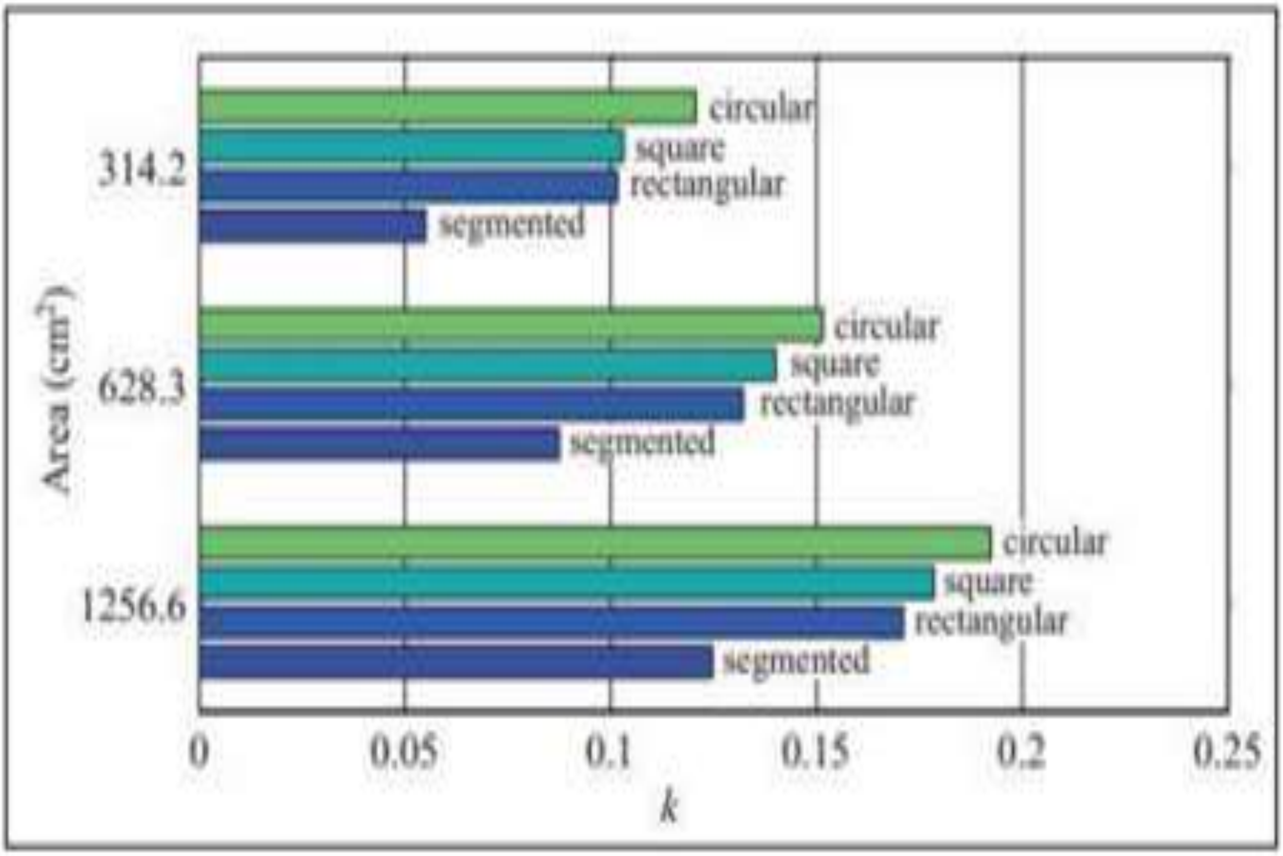


Figure 3: Areas against Coupling Factors for Different Coil Shapes

Computer Simulation Technology (CST) Microwave Studio was used to carry out the design process. It has the ability to simulate 3D electromagnetic coil at high frequency using frequency domain solver and provides full circuit simulation tools and present results in 3D electromagnetic form. The CST software also has many features such as parameter sweep, mesh properties, and mini-match to match the two-port of transmitter and receiver coils. It also provides other features for optimisation and model construction to enhance efficient wireless communications within the circuit.

Table 1: Environment Setting in CST Microwave Studio

Frequency level	High Frequency
Setup Solver	Frequency Domain Solver
Mesh Type	Tetrahedral
Frequency Range	650 MHz -750 MHz
Surrounding Space Diameter	300 mm

Basically, 3D model type of inductive coils are constructed for transmitter and receiver sections of WPT in CST Microwave Studio using **FEM** behavioural approach for the 3D and circuit combination study. The settings in Table 1 are maintained in the simulation environment for the coil's model. As in Table 1, for WPT and charging, the commonly used applications on CST microwave studio are frequency domain solver with tetrahedral meshing. The air domain for model surrounding is represented by normal background material which is 300 mm apart for this work.

Listed in Table 1, are the design specifications for transmitter and receiver modeled coils shown in Figure 4. To reduce the complexity of the coil design and simulations in CST microwave studio, a single core copper wire is used for the modeling of coils instead of the proposed Litz wire in literature. All the parameters of transmitter section are kept constant during modeling with modification on the outer radius of the receiver coil section and changing the distance between coils. Other parameters are kept constant to meet the design specifications and to enhance energy transfer within the coils. This gives a better coupling performance within the coils with the separation Gap of 50 mm.

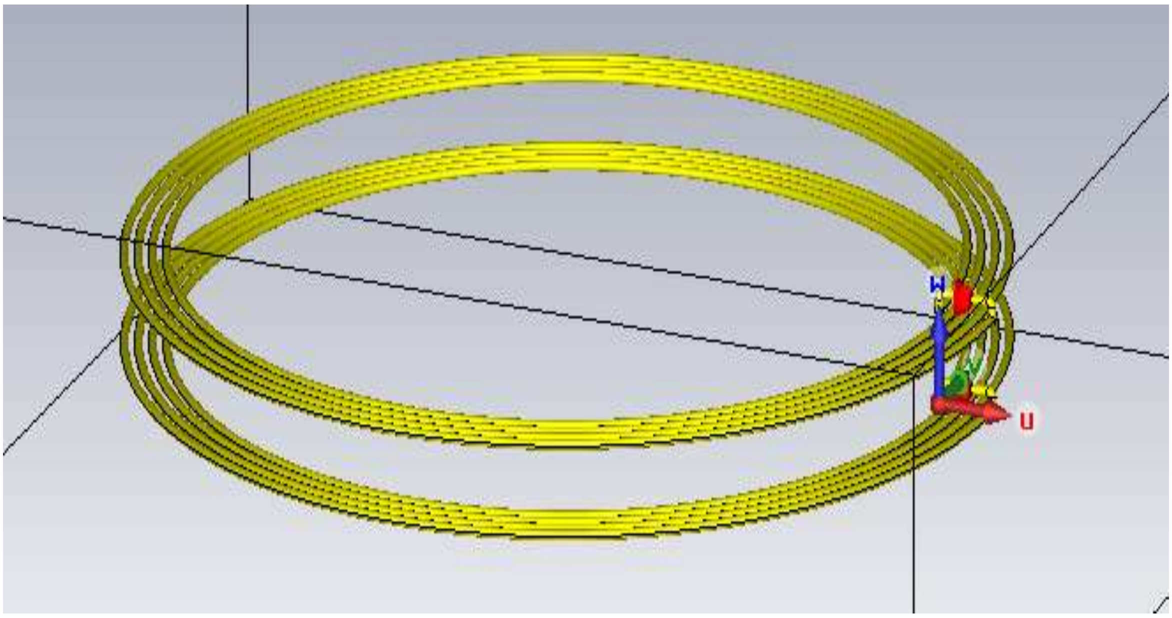


Figure 4: 3D View of Inductor Coils Modeling in CST Microwave Studio

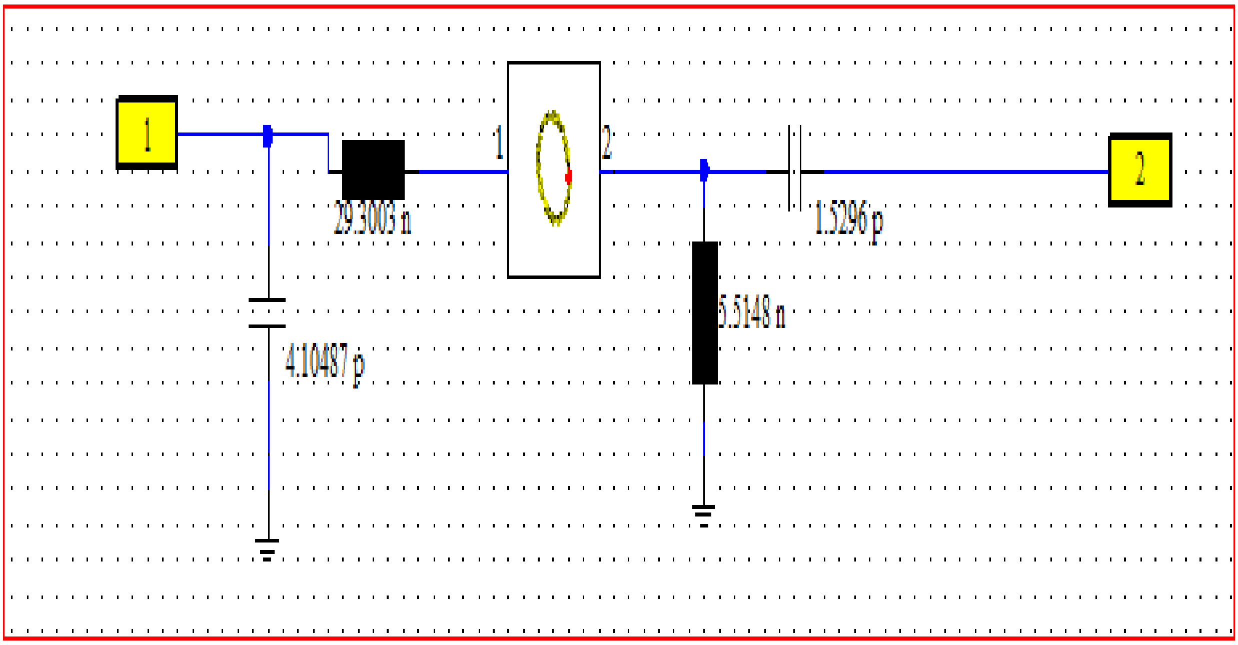


Figure 5: Resonant Matching Circuit Diagram for Inductor Coil Mode

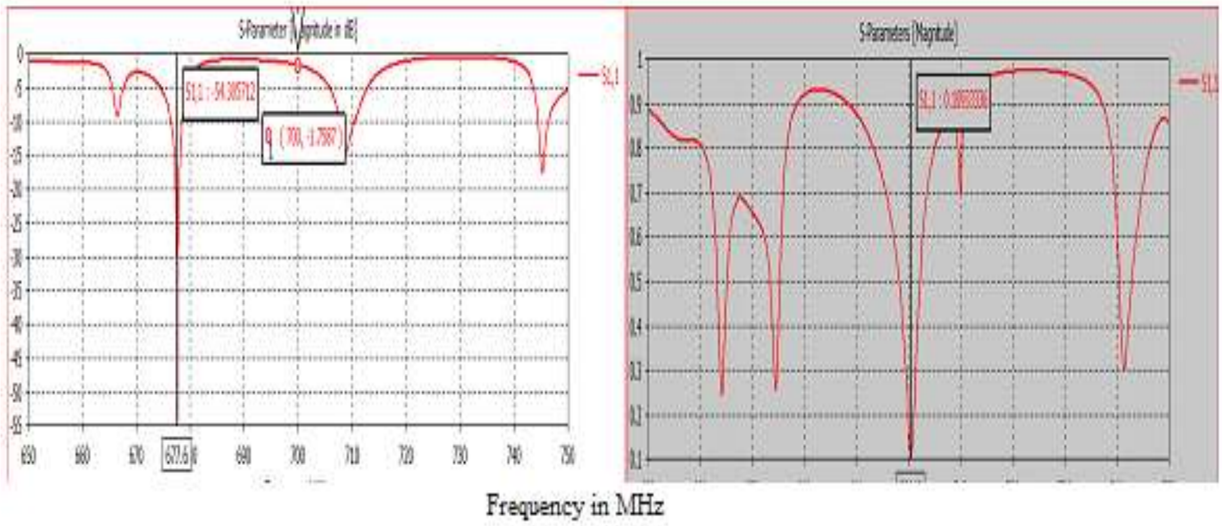
For the receiver coil, the capacitor in the inductive loop of one coil model is simultaneously altered until the surface coil is tuned to 700 MHz called the resonance frequency. At the resonance frequency, the magnitude of S_{11} is at minimum. The voltage and current through the inductive loop should be close to the maximum. Once the coil has been tuned, the tuning capacitors, and inductors are noted. The basic reason for this is to allow the implanted coil to be tuned to 700 MHz while still being inductively coupled to the surface coil, which is to avoid frequency splitting during the energy transfer. Shown in Figure 5 is the designed matching circuit for this work that resonate the frequency at 700 MHz alongside the component value of resonant circuit matching presented in Table 2.

Table 2: Components Value of Resonant Circuit Matching

Components		**Value**
Transmitter Capacitor	**C1**	4.104 pF
Receiver Capacitor	**C2**	1.529. pF
Transmitter Inductor	**L1**	29.300 nH
Receiver Inductor	**L2**	45.51 nH

4. Results from Resonant Circuit Design on CST

Initially, simulation is carried out for the weak inductively coupled transmitter and receiver coils in CST for coupling performance study. The S-parameters results are obtained for power transmission analysis in coils as shown in Figure 6(a). In S-parameters, S_{21} represents the transmitted power from transmitter coil to receiver coil while the S_{11} and S_{22} represent the reflected power in between the two coils.



(a) With Matching (b) Without Matching

Figure 6: S-Parameter S_{11} With and Without Matching

At operating frequency of 700 MHz, the power transmission efficiency obtained for the coils' model is 0.321 % with S_{21} of -24.935 dB. Therefore, wireless power transfer in the coils' model is impossible with almost no coupling between the coils. After matching the resonant circuit the resulting resonant efficiency is enhanced as shown in Figure 7.

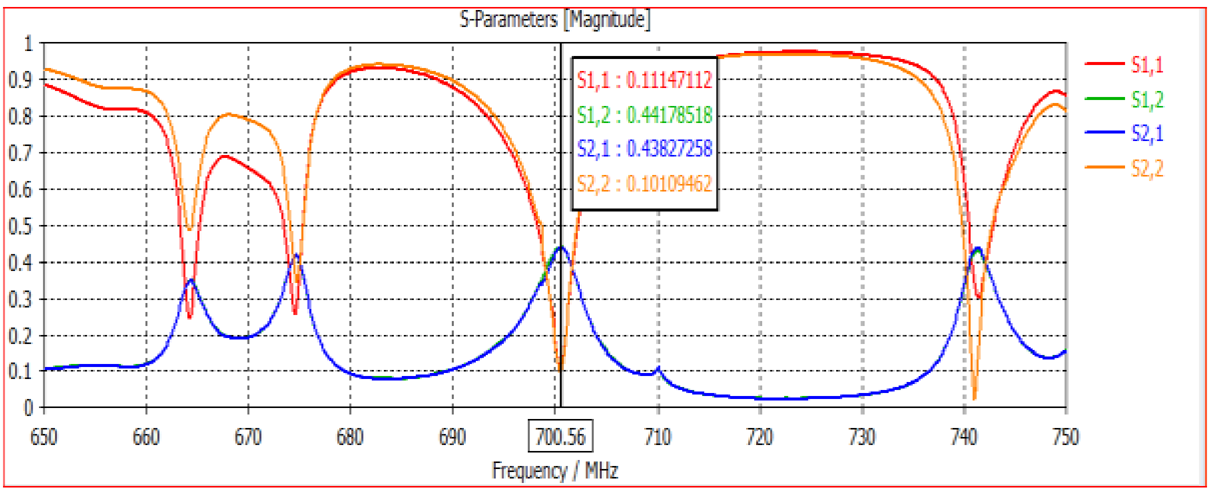


Figure 7: Combined S-Parameter Results after Matching

Figure 7, the coils' model is matched at resonant frequency of 700 MHz with maximum amount of power transfer and minimum amount of power reflection. This gives the maximum power transmission efficiency between coils of 93.1 % for the inductor coils with separation gap of 50 mm at operating frequency of 700 MHz.

5. Conclusions

In conclusion, the proposed coils' model meets the design specifications. It is capable of providing efficient wireless power transfer to portable charging devices through resonant inductive coupling method with maximum power transmission efficiency of 93%. Furthermore, it passes the coils performance evaluation test that is subjected to different external factors in real situation. The additional adjusting freedoms existing in CST systems architectural design are beneficial for optimizing system transfer characteristics. The global optimization design and regulations methods by considering multi-effects factors are also valuable for its engineering applications.

In real practice, a certain rated power is required but this MHz resonant frequency may bring a great challenge to some portable electronics components, for example the circuit rectifier, MOSFET driver, and so on. Fortunately, with the rapid development of semiconductor and material industry, this will overcome these challenges. Generally, wireless power transfer actually belongs to a marginal discipline between physics and electronics as such it needs the efforts from different research fields for an effective compromise. The simulations of high frequency range wireless power transfer need a super speed for its simulations process in order to obtain high efficiency and high quality factor.

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