# Three-dimensional Wireless Power Transfer Method to Realize Efficient Charging of IoT Devices

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**Many users desire to charge their Internet of Things (IoT) devices such as mobile or wearable devices wirelessly. Wireless power transfer technology using resonant magnetic coupling makes it possible to charge a receiver that is distant from the transmitter. However, the receiver can take various orientations over that distance, and this causes problems, such as an extreme decrease in power transfer efficiency in certain cases. To solve this problem, we developed a method to control the direction of the magnetic field corresponding to the various orientations of the receiver, so that efficient power transfer can be achieved. To control the magnetic field direction, we selected the current path using multiple transmitter coils. As an example of the developed system, we made a transmitter in a table shape with a receiver in a smartphone. With this system, we demonstrated that a smartphone in use can be charged wirelessly by placing it above or on the table, and proved the validity of the three-dimensional (3D) wireless power transfer system. In this article, we explain the 3D wireless power transfer system that we developed. We also introduce various efforts we have made for domestic and international standardization or institutionalization to popularize wireless power transfer systems.**

## 1. Introduction

Recently, mobile devices such as smartphones or tablet PCs have been becoming popular rapidly, and many users are charging their mobile devices frequently. And with the diffusion of the Internet of Things (IoT), the problem of ensuring charged batteries for wearable devices will become greater. At present, many users are charging their devices with wires (charging cables), but connecting cables causes inconvenience to users. To eliminate this inconvenience, wireless power transfer technology without using cables is being developed and incorporated into the design of some mobile devices. However, the present wireless technology is often based on magnetic induction. Because magnetic induction leads to limited efficiency over short distances, the receiver devices are placed on, and cannot be removed from, the transmitter plane, even though cable connections are unnecessary.

Resonant magnetic coupling, a next-generation wireless power transfer method, was proposed by Massachusetts Institute of Technology (MIT) in 2007 and it demonstrated a wireless power transfer over 2 m using a transmitter and receiver coil that were 60 cm in diameter.[1] After this demonstration, research on wireless power transfer using resonant magnetic coupling became active, not only being applied to the IoT devices but also to electric vehicles or medical devices.[2] The resonant magnetic coupling method places the transmitter and receiver coil in a near-field region, using a series resonance mode with inductance of a coil and capacitance of a capacitor. It achieves highly efficient power transfer by resonance using a magnetic field. As a result, it is possible to extend the receiver some distance from the transmitter coil and achieve high transfer efficiency.

We, Fujitsu Laboratories, are researching ways to apply this magnetic resonance to various devices.[3)–5)] Especially, to achieve power transfer for a device in use, we think technology to deal with various orientations or angles will be necessary.[6), 7)]

In this paper, we will introduce the development of a wireless power transfer system to charge a smartphone, which is representative of a mobile device, while it is being used. And we explain the possibilities of the system and our future activity.

## 2. Types of wireless power transfer method

There are two types of wireless power transfer method using magnetic resonance: two-dimensional (2D) wireless power transfer and three-dimensional (3D) wireless power transfer. In the case of 2D wireless power transfer, the receiver device is placed on the transmitter without flexibility in the vertical direction (z-axis), but with flexible positioning on the surface of the transmitter (xy-plane). To achieve 2D wireless power transfer, we have designed the transmitter coil to be larger than the receiver coil using magnetic resonance. This makes it possible to extend the distance between the coils, and achieve a wide flexibility of positions in the x-axis and y-axis in wireless power transfer. Furthermore, we can place multiple receivers in the charging area, which will enable simultaneous charging of multiple devices.

The present standard for 2D wireless power transfer is being developed under an alliance between companies, the AirFuel Alliance,[8] and the possibility of a 2D wireless power transfer system has appeared. Details about the effort for standardization will be described in section 6. With this charging, the merits to the user are that there is no need to connect a cable, and no need to set the receiver in a certain position. It is only necessary to place the receiver on the transmitter and this is relatively flexible in terms of positioning. However, receivers need to be in touch with the transmitter and set in parallel; users cannot take a smartphone in their hand and use it during wireless charge.

On the other hand, in the case of 3D wireless power transfer, the receiver can be flexibly placed not only in the horizontal direction (x-axis, y-axis), but also in the vertical direction (z-axis). In this case, the receiver can be set distant from the transmitter, and users can take a smartphone in hand and use it during wireless charge. Therefore, the 3D wireless power transfer system is much more desirable for users, and is expected to be achieved.

In the case of 3D wireless power transfer, however, trying to extend the chargeable distance led to new problems. Namely, the variety of orientations the receiver device can adopt. In the case of 2D wireless power transfer, the receiver device can always be set flat on the transmitter. For example, if they are smartphones, they will be set on the transmitter as shown in **Figure 1(a)**. As a result, the transmitter and receiver coils which are mounted in the device will be assured to be nearly parallel. However, when the receiver device can be set far from the transmitter, there is no restriction in orientation, and the receiver coil may be parallel to the magnetic flux made by the transmitter [**Figure 1(b)**]. In this case, the interlinkage magnetic fluxes are almost zero, and the transfer efficiency decreases seriously and causes the problem that wireless power transfer cannot be done. This orientation-related problem was a big barrier in achieving 3D wireless power transfer.

## 3. Combination of multiple transmitter coils

We proposed a method to solve the above problem by placing multiple transmitter coils, selecting the current path, and controlling the direction of the

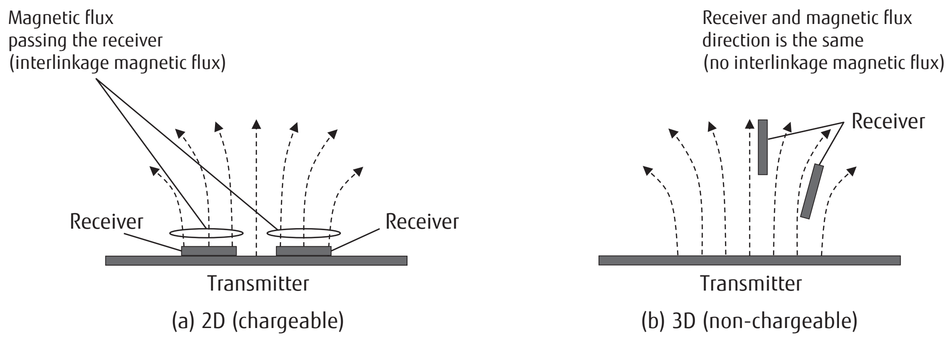


**Figure 1**
**Difference between 2D and 3D wireless charging.**

synthetic magnetic field. In particular, we introduced a selector between the transmitter coil and the power source shown in **Figure 2**, and made it possible to select the connection path among the transmitter coils and the power source.

For example, we assume the case with two transmitter coils, 1 and 2, arranged orthogonally. In this case, there are two current paths, connecting transmitter coil 1 or 2 to the power source independently, and two other current paths, connecting transmitter coil 1 and 2 with in phase and reverse phase, which makes for four different current paths. The directions of the magnetic field at the center position made by four current paths differ in steps of 45°, and we can make a suitable magnetic field to charge the receiver in a way that corresponds to its orientation, by selecting a suitable current path. In a similar way, in the case of three transmitter coils, 1, 2, and 3, all arranged orthogonally, there are three independent paths, six paths using two coils, and four paths using three coils, which will make for 13 different paths and thus 13 different magnetic fields. With this method, we can select the most suitable magnetic field direction for wireless power transfer, and much more importantly, we can avoid the situation in which wireless power transfer cannot be done.

In this article, we considered a 3D wireless power transfer system[7] that can charge a smartphone in use above a table, as an example of the proposed method. Considering the orientation of the smartphone in use, we arranged two transmitter coils orthogonally and introduced a selector to select two current paths (Figure 2).

## 4. Experimental evaluation

We used the magnetic and circuit linked simulator[8] that we developed to design the transmitter and receiver coils. As table-size transmitter coils, we arranged two coils for 1 turn with dimensions of 500 mm × 1,000 mm. And as a receiver coil arranged at the back side of the smartphone, we set a coil with three turns and dimensions of 60 mm × 130 mm. As the target transfer efficiency among the wireless part (power transfer between transmitter and receiver coil), we assumed 35% to receive 18 W of power when transferring 50 W.

We made the coils according to the simulated design and placed the transmitter coil under the table and in the partition, and placed the receiver coil at the back of the smartphone. With these coils, we evaluated the transfer efficiency above the table. For representative orientations of the smartphone, we assumed a flat orientation at 0° [**Figure 2(a)**], and a tilted orientation at 45° [**Figure 2(b)**]. With these two orientation conditions, we moved the position of the receiver in the xz-plane as shown in **Figure 3**, and evaluated the transfer efficiency at each position. At each position, we evaluated the system with two transfer conditions: using only the downside coil as "downside transfer," and using two orthogonal coils as "L-shaped transfer." And we defined "selected transfer" as selecting the higher transfer efficiency path at each position. The transfer efficiency at each position for two orientation conditions as a contour map is shown in **Figure 4**. The region that is over the target transfer efficiency of 35% is shown with hatching.

According to the Figure 4 results, at 0° orientation,

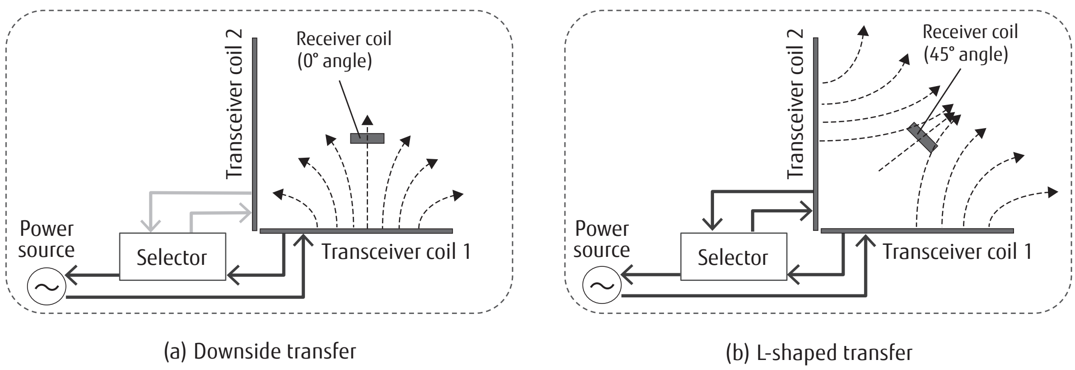


**Figure 2**
**Arrangement of transceiver coils and current path.**

downside transfer is preferable, and at 45° orientation, L-shaped transfer is preferable. On the other hand, at 0° with L-shaped transfer, the region over the target transfer efficiency is narrow, and at 45° with downside transfer, the region over the target transfer efficiency is also narrow. These results are caused by the fact that the variation in the interlinkage magnetic flux becomes higher when the receiver is placed vertically to the magnetic flux made by the transmitter coils, which will lead to higher transfer efficiency. They show that limiting the magnetic flux direction to one direction may cause a serious decrease in transfer efficiency when a device has a certain orientation. Conversely, they also show that if we can select from two different magnetic fluxes, we can achieve the transfer efficiency shown as the "selected transfer." That is to say, we can achieve a high transfer efficiency in a wide region in either orientation. We will explain the selecting method in the next section.

We also evaluated the transfer efficiency in a transverse direction (y direction), and confirmed that the chargeable region is about 800 mm and covers almost all regions above the table.

As a consequence, we showed that by using a system with two transmitter coils and selecting the current path we can achieve wireless power transfer for receivers in various orientations.

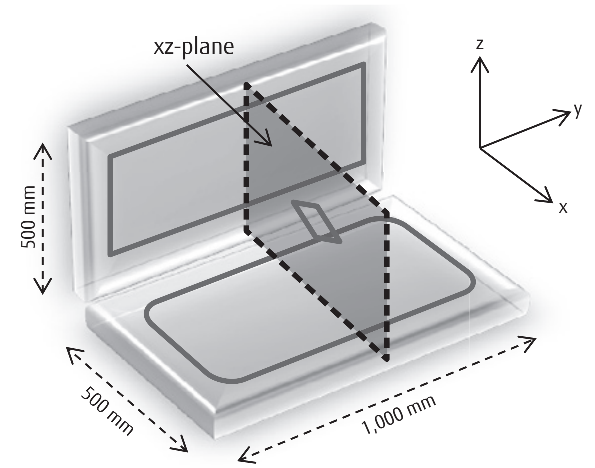


**Figure 3**
**Method of evaluating transfer efficiency.**

## 5. Controlling system

We are adopting two controlling methods as follows.

The first one is monitoring the receiving power.

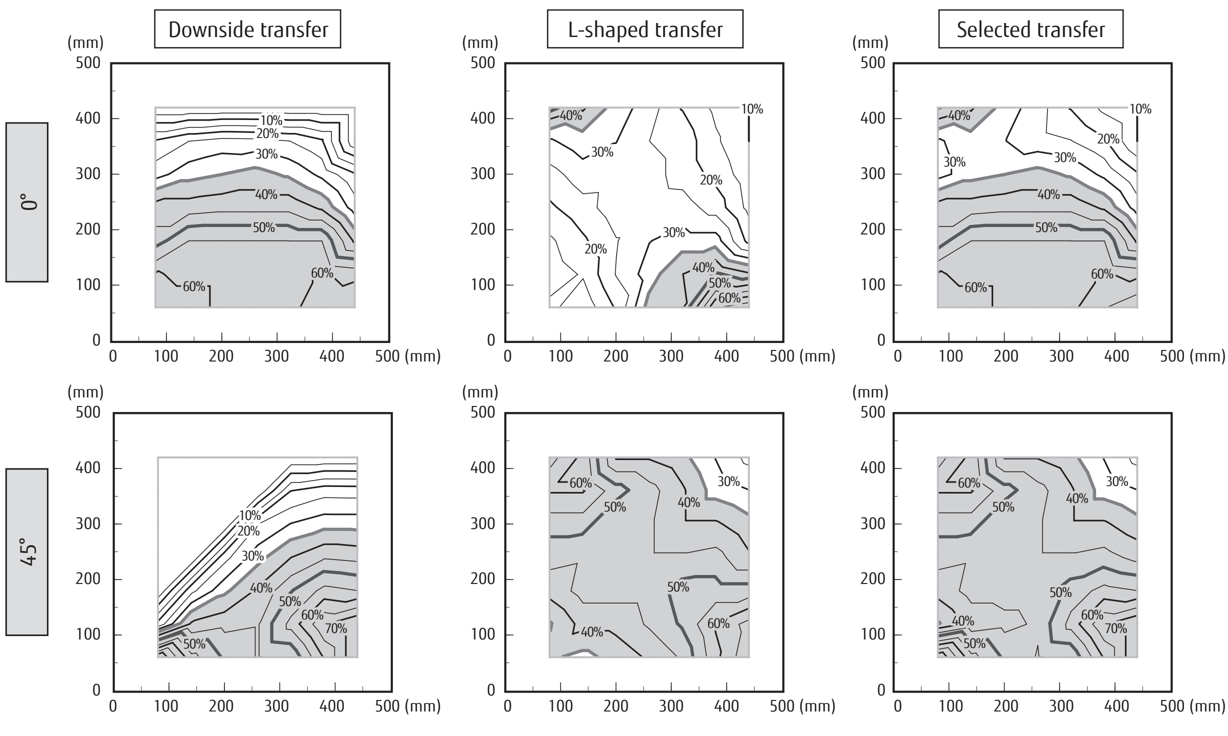


**Figure 4**
**Experimental results of proposed system in xz-plane (vertical axis: z, horizontal axis: x).**

The receiving power is monitored all the time while there is wireless power transfer, and the results are communicated to the transmitter. The transmitter adjusts the transfer power according to the receiving power. For communication, we adopted Bluetooth technology.

The second one is test power transfer done before the ordinal power transfer. In the test transfer, we operate the "downside transfer" and "L-shaped transfer" for a short time, and select the path with the larger receiving power using the monitored power. With this procedure, we can achieve the "selected transfer."

With these controlling methods, constant power can be transferred efficiently regardless of the position or orientation of the receiver, and this system makes it possible to charge smartphones that are in use. One example of applying this system is a service to wirelessly charge users' smartphones in use above the table region in a café (**Figure 5**). Figure 5 shows the transmitter coils hidden behind the dashed line. In Figure 5, a smartphone placed on the holder is charged wirelessly, having a distance from the table top or the partition that is almost equal to a situation where a user is using a smartphone while holding it in their hand. Besides, magnetic resonance technology is a method of transferring power only to certain tuned resonant circuits, so only a limited amount of heat is generated in any surrounding metal (such as spoons), and this point means it is suitable for application on a café table.

## 6. Efforts for standardization

So far, we have explained technological research concerning 3D wireless power transfer at Fujitsu Laboratories. On the other hand, to popularize 3D wireless power transfer, it is necessary to ensure compatibility with other makers' devices. The merit of 3D wireless power transfer is that a device can be charged anywhere, and the technology will be of limited use if a device is chargeable only with a Fujitsu product. To be able to charge other makers' smartphones or to be able to charge a device using other makers' transmitters, it is essential to standardize many technologies of wireless power transfer methods, controlling methods, and authentication.

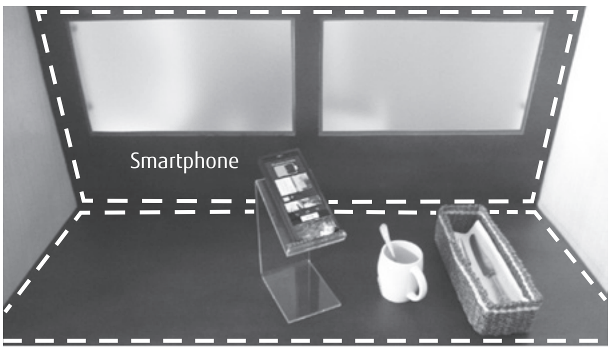


**Figure 5**
**Appearance of proposed system.**

Fujitsu has been working on many cases of technology standardization mainly at the International Electrotechnical Commission (IEC). In the case of wireless power transfer, we are establishing a Task Force composed of related departments to work on standardization. The IEC is an organization for international standardization, and in Technical Area 15 (TA15, Wireless Power Transfer) under technical committee 100 (TC100, Audio, video and multimedia systems and equipment), the members are discussing wireless power transfer. The IEC is composed of members representing each country, and the Japan Electronics and Information Technology Industries Association (JEITA) is the member for Japan. Fujitsu is attending the discussions as a member of JEITA, acting as a project leader in a proposal for standardization (PT62827), and working on international standardization actively.

For standardization in Japan, as a member of the Broadband Wireless Forum (BWF) under the Ministry of Internal Affairs and Communications, we are contributing especially in Sub Group-7 (SG7, a sub group to study wireless power transfer using a magnetic connection for mobile devices) to make standards. As result of the activities there, we have been revising the ministerial ordinance for easing the restrictions on magnetic emissions in 2016, or establishing the standard of the Association of Radio Industries and Businesses (ARIB).

So far we have explained de jure standards which are standards of legal systems or restriction. To put products on the market, de facto standards which are standards made by companies are also important. The AirFuel Alliance is a well-known standards body for magnetic resonance wireless power transfer, and Fujitsu is one of the members. The AirFuel Alliance was established in 2015 through the merger of the Alliance for Wireless Power (A4WP), which was the alliance for magnetic resonance, and the Power Matters Alliance (PMA), which was the alliance mainly for magnetic induction. Now it is working on standardization for several kinds of wireless power transfer. At present, the standard for 2D wireless power transfer has been published, and FUJITSU is planning to contribute to future standards.

Fujitsu is working on standardization activities omnidirectionally by utilizing the Task Force, and planning to continue its work.

## 7. Conclusion

In this article, we explained a 3D wireless power transfer system that can charge a smartphone in use by applying magnetic resonance technology. To charge a smartphone in use, it is necessary to charge the smartphone not only when it is placed on a transmitter, but also while it is a distance from the transmitter, which is the system of 3D wireless power transfer. By allowing the receiver to be at a distance from the transmitter, the receiver can take various orientations and as a result it is difficult to charge it with a single transmitter coil.

We developed and showed a method using multiple transmitter coils and selecting the best current path that can solve this problem. Applying the technologies to a table-size transmitter and a smartphone charging system, we confirmed that we can charge in a region 300 mm above the table with a transfer efficiency of over 35% for receivers in various orientations.

We are planning to study ways to simultaneously charge multiple receivers, and we will work on making standards for the developed technologies.

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