
Stable Power Delivery Efficiency in Misaligned Wireless Power Transfer Systems Using Trifid Antennas

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Abstract

Stable power delivery efficiency is difficult in wireless power transfer systems without using power control. Misalignment between power transmitter and receivers makes this difficult since power is delivered axially. This paper reports on a new method for providing stable wireless power delivery efficiency in misaligned systems. By employing trifid antennas arranged in a cube stability is obtained at wide angles and all over the cubical structure.

Keywords: stable wireless power delivery, trifid antennas, misalignment.

1 Introduction

Typical wireless power transfer systems are only useful within a short distance from the power transmitter due to power efficiency degradation [1, 2]. Undoubtedly, a receiver coil that moves away from the transmitter could not maintain a strong magnetic induction with it. The transmitter and receiver also need to be aligned to make a strong impact on power transfer

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efficiency [3, 4]. These variations in distance and alignment are important considerations, which need to be improved upon for mobile devices to maintain high wireless power efficiency. This is required in mobile devices including RFID tags and medical implantable devices. Several techniques have been used to extend the magnetic induction for point-to-point wireless transmission systems. A common technique for increasing the efficiency of power received by the mobile devices is to add relay coils between transceivers [5, 6]. Several attempts have been made to improve the previous communication by using multiple transceivers and relays [7]. However, mobility of the receiver is unpredictable. This is especially with misalignment and inefficient supply of sufficient power for applications such as endoscopic capsules. Single-input multiple-output (SIMO) technique has been introduced for increasing the efficiency of near field communication systems based on inductive coils [8, 9]. In particular [9] suggests the use of a hexagonal transmitter equipped with a primary coil structure that supports six secondary loops to form a hexagonal frame and created from the same inductor. This obtains a multi-dimensional directionality of the resulting magnetic field. This kind of transmission is based on the magnetic field obtained by secondary loops along the hexagonal edges given by the transmitter [9]. This approach has been developed to improve the influence of using multiple receivers on each side of the transmitter. As a result [10], network of multi-dimensional transmitters can be created. The network able to grow and extends which leads the team in [10] to split the frequency. Similarly, in [11] the splitting frequency is optimized, making the complexity of the network more simple by reusing the frequencies of each part along the hexagonal. Furthermore, since the frequency reuse technique is involved, influence of crosstalk on the transmit power is decreased. Therefore, the misalignment of inductive coils can impact constructively or destructively depending on the position and the type of the supplied transmitter.

2 Literature Review

This section provides a brief background on conventional coil misalignments in inductive systems. Three types of misalignment are apparent. First angular elevation misalignment usually occurs in point-to-point of inductive systems and provides strongly coupled communication systems. In this case, one point of the system may rotate in the elevation plane from 0° to 90° from vertical to horizontal plane or in reverse way, while the other point stays fixed as shown in Figure 1.

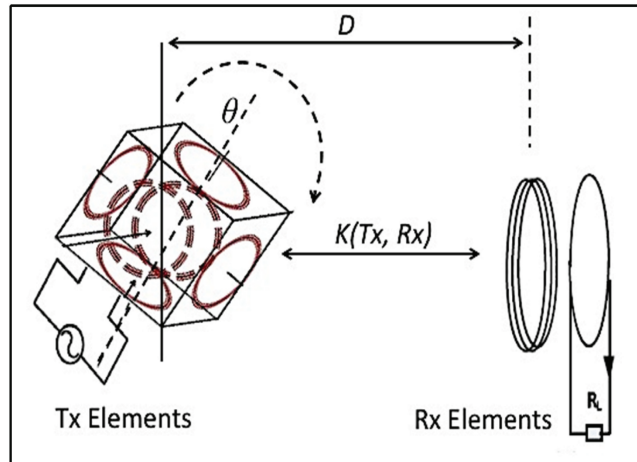


Figure 1 Cubical Wireless Power Transceiver

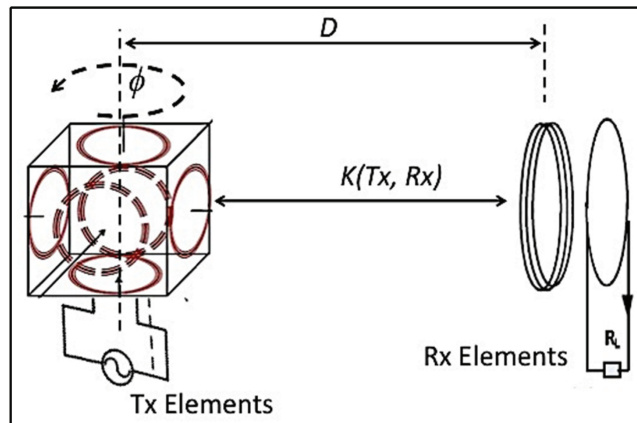


Figure 2 Azimuthal Misalignment in Cubical Wireless Power Transfer Systems

Second azimuth misalignment may also occur. In this case, one point of the system rotates on its axis from 0° to 360° through the azimuth, while the other is fixed as can be seen in Figure 2.

Third rotational misalignment may also take place. In this case, the rotation is of one point around the other fixed point from 0° to 360° as shown in Figure 3.

A coil misalignment model has been demonstrated in [12] for efficient wireless power transmission with the test of angular misalignment. They

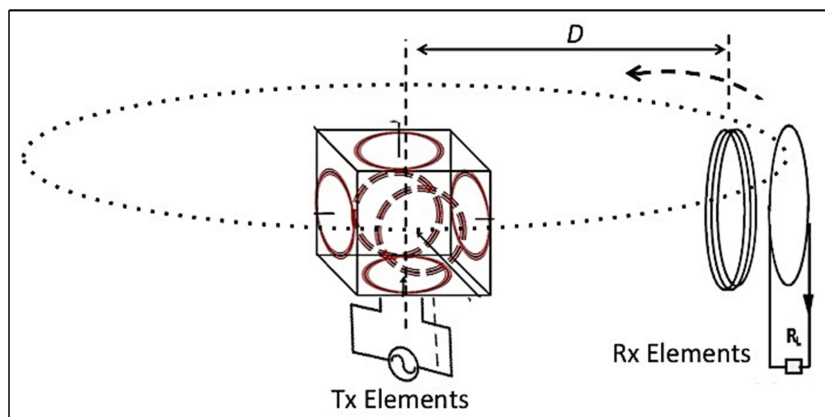


Figure 3 Rotation Misalignment in Cubical Wireless Power Transfer Systems

asserted that about 10dB attenuation can occur as a worst-case power reception. In [13] they improved efficiency by about 5dB when power is received as a worst case. Based on this an adaptive design for efficiency maintenance has been suggested. In [14] it was demonstrated that embedded solenoid-coupling coil can improve misalignment between transceivers in wireless power transfer systems. Their design can cover a range of about 90° with misalignment. This achievement improves the transfer efficiency over the conventional coils. Some researchers [15, 16], proposed a multidimensional coil design to address efficiency and misalignment problems. In [15] a transmitter of hexagonal coil structure produces a multidirectional magnetic field to deliver the power wirelessly from different positions as a circle. This technique therefore uses misaligned coils to advantage. In [16] a receiver of orthogonal coils has been employed to capture the magnetic field from different positions when misalignment occurs. In [17] a multidimensional antenna, which the authors termed a ‘triffid antenna’ due to the shape of its magnetic field pattern, is designed and tested. The influence of the cube antenna as a transmitter and the produced magnetic field was also studied. For the design evaluation, authors have sketches of the magnetic field pattern of the transmitter and the result shows another type of pattern called a triffid power pattern. More details and experiments are discussed in [17]. The cube coil is created from a conical inductor but segmented to support many directive power transfer. Each two coils sharing a common axis which are developed as Helmholtz coils design. The cube produces uniform magnetic field along its common axis. In the cubical design proposed in [17], multiple

pairs of Helmholtz coils are employed to design a ‘trifid’ power transfer pattern. Each side of the cube have a conical coil of small radius positioned at the center of the cube. In this way, the other end of the conical coil which have the larger radius point along the major axis of the cube surface as seen in Figure 4. The conical coil has been designed and studied in a previous work in [1, 2].

This paper focuses on the proposed solution of the cube antenna and its result to enhance misalignment effect of magnetic field patterns. This is despite when some of the papers above resolved that most misalignment types, rotational misalignment influences still obstruct the critical solution of misalignments. This paper will demonstrate a solution of this type of misalignments by involving the trifid antenna. A practical comparison is made for convenience to confirm the proposal.

Thus, this paper compares a “misalignment insensitive system 3D and 3-loop structure” in [18] with the multidimensional cube system to obtain a better performance in many aspects. It should be noted that the 3-loop misalignment structure has been compared in [18] with the typical strongly coupled magnetic resonance. The 3-loop misalignment system shows better performance than the typical strongly coupled magnetic resonance in particular with angular and lateral misalignment. The efficiencies are 10% higher than typical strongly coupled magnetic resonance.

In this paper, a brief explanation of trifid coil structure and a new method of reducing misalignments are presented. The rest of the paper is organized as follows: Section 2 is introduction, Section 3 presents the design theory and Section 4 gives experimental results. Finally, in Section 5 the paper conclusion is presented.

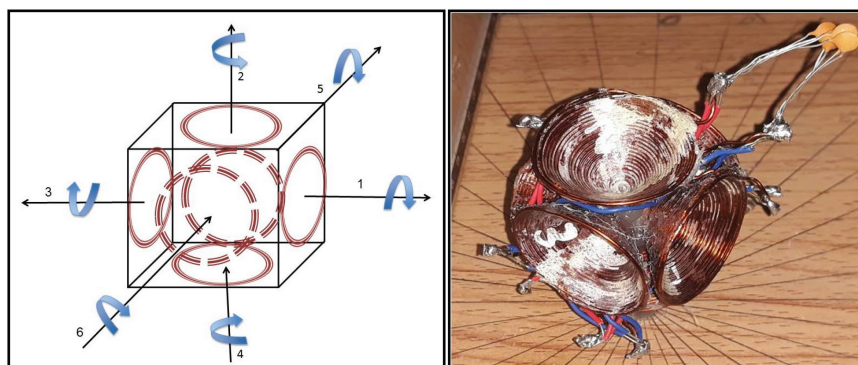


Figure 4 The cube coils structure

3 Design Theory

The known scenario of strongly coupled magnetic resonant (SCMR) system requires that transceivers face each other and have the same axis in order to achieve higher wireless power efficiency. Two scenarios of angular and rotational misalignments can occur when one of the transceivers is rotating. In 2-loop and 3-loop structure cases, all of the above misalignments have been improved [18] upon. Angular misalignment is the only case that can be achieved using strongly coupled magnetic resonant coils, when one element of the transceivers is fixed and the other is rotating. Figure 5 shows the relation between efficiency and angle misalignment from 0° to 90° achieved in [18]. In general, as the angle of rotation is increased, the efficiency decreases.

In 2- loop structure cases, misalignment types that can occur includes rotational misalignment. The efficiency significantly drops when rotational misalignment occurs. In [18] they improved the efficiency by developing the 3- loop structure system. It is efficient in all directions as shown in the result of Figures 5 to 9 [18].

These figures show that maximum stable efficiency is around 70%. This occurs close to 90° .

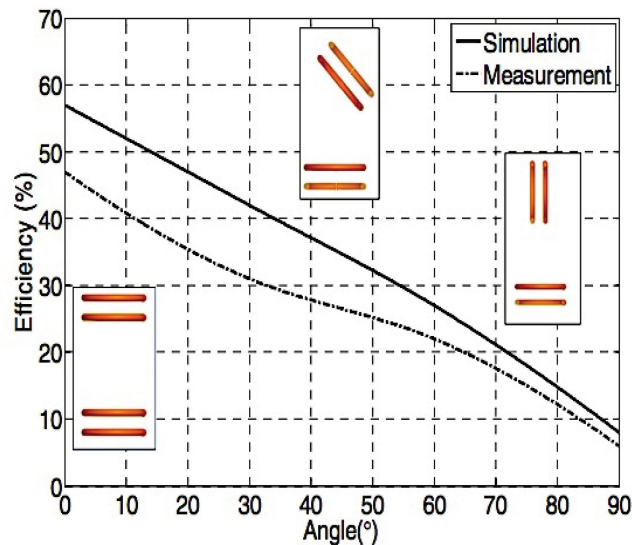


Figure 5 “SCMR with loops and angular elevation misalignment angles, 0° to 90° ” [18].

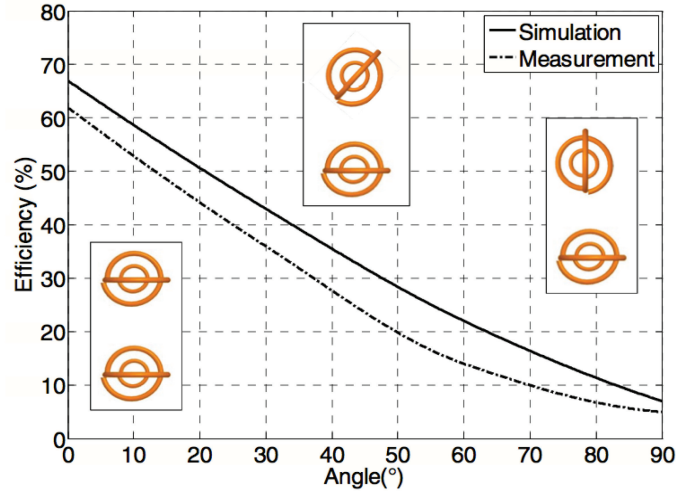


Figure 6 “SCMR with loops with angular elevation misalignment angles, $\theta = 0^\circ$ to 90° ” [18].

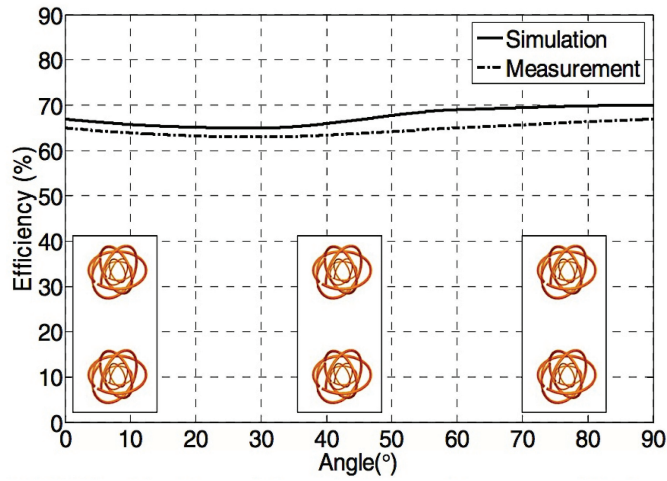


Figure 7 SCMR with orthogonal (connected) loops, the source and load are embedded in the TX and RX devices with angular elevation misalignment ($\theta = 0^\circ$ to 90°). [18]

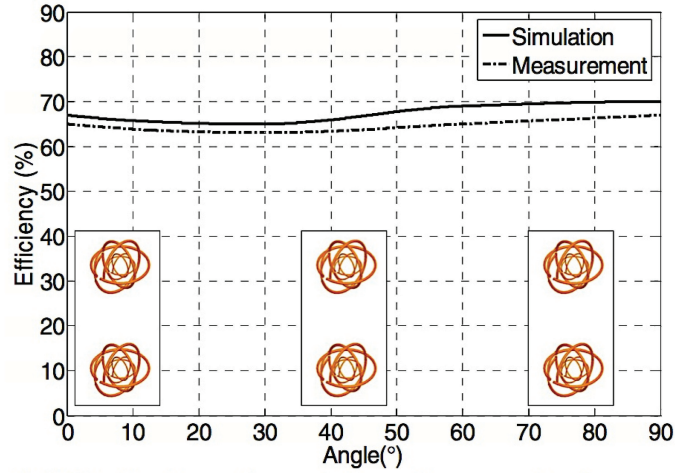


Figure 8 SCMR with orthogonal (connected) loops, the source and load are embedded in the TX and RX devices with angular azimuth misalignment ($\varphi = 0^\circ$ to 90°) [18].

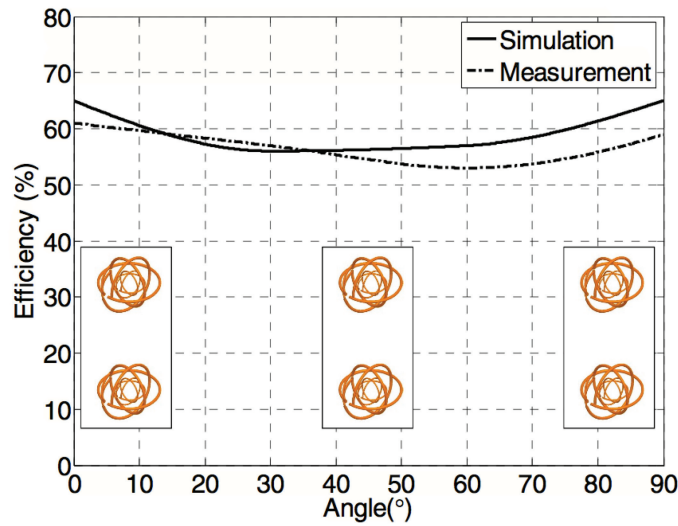


Figure 9 SCMR with orthogonal (connected) loops, the source and load are embedded in the TX and RX devices with angular misalignment ($\theta = 0^\circ$ to 90°). [18]

4 Results

The team in [18] designed this type of structure for wireless power transfers via SCMR to enhance its performance. Their setup involves the 3-loop structure in both Tx and Rx which needs to be embedded in mobile applications. In contrast, the trifid antenna has been studied and tested by using a conventional circular coil as a Rx to receive the power transferred from the trifid antenna which acts as Tx. It improves the power transfer efficiencies over the misalignment range of 0° – 90° degrees with angular and lateral misalignment. The design of trifid antennas is given in [17] by the authors. Figure 10 shows the relation between efficiency and angle misalignment from 0° to 90° that has been achieved from the trifid antenna. The power delivery efficiency is stable at various angles for the power received level. This achievement and improvement is a lot better than SCMR system and in some cases is better than the 3-loop structure. These cases include the type of Rx that can be used which must be of the same type with the Tx in 3-loop design. As a significant improvement, in the trifid antenna, any type of coils can be used to receive the power wirelessly from the trifid antenna. It should be noted that the use of conventional circular coil as an Rx is to show the efficiency of the power transfer. However, other types of coils can achieve

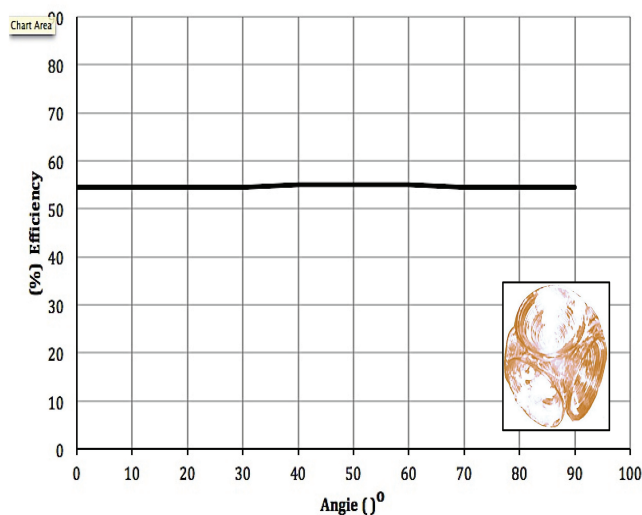


Figure 10 The source of trifid antenna TX is embedded with load of conventional circular RX with angular misalignment

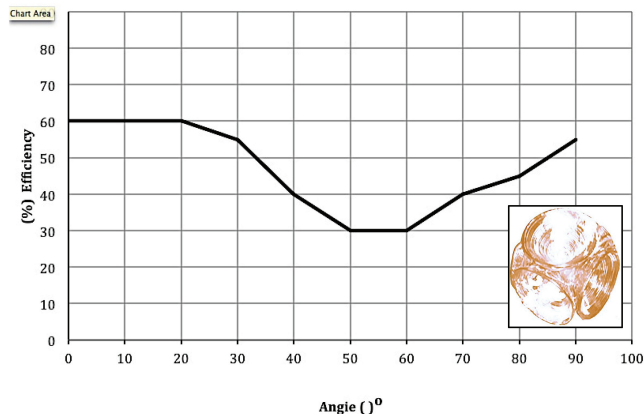


Figure 11 The source of triffid antenna TX is embedded with load of conventional circular RX with edges misalignment

better received power efficiency. In our experiments the receivers are the triffid antenna. Therefore, our design offers the flexibility of embedding any types of receive antennas for wireless power transfer applications. Figure 11 shows the relation between efficiency and angle misalignment from 0° to 90° of the triffid antenna edges. The result showed that as the Rx moves around the triffid antenna edges, angular misalignment can have effects on the wireless power transfer efficiency. The efficiency increases, then drops and then the efficiency goes back to its level as the Rx moves around the triffid antenna (typically the major drops occur from 30° to 70°). To compare with the 3-loop system design, the specification of the geometrical parameters of the triffid antenna are shown in Table 1.

The dimensions of the triffid antenna are smaller than those of the compared systems by about 50%. This gives another feature to the cube design, as it is smaller and efficient.

Table 1 The geometrical parameters of all coils

Number of turns	Wire thickness (mm)	Large radius (cm)	Small radius (cm)	Obtuse angle (degree)
25	0.85	3.6	0.7	45

5 Conclusions

This paper has presented a method for providing stable wireless power transfer. A triffid antenna is embedded in a cubical design to provide stable power

into wide angles of up to 100 degrees. By using three of these structures in a cube, stable power is delivered to nearly 360 degrees. This is a significant extension of the power delivery efficiency of conventional wireless power transfer systems which deliver unstable wireless power transfer efficiency axially.

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Biographies



Nagi F. Ali Mohamed received the Engineer degree in Electrical and Electronics Engineering from University of Garyounis, Benghazi, Libya, in 2006, and the Masters degree of Telecommunication and Network Engineering from La Trobe University, Melbourne, Australia. His research and teaching interests are in telecommunications and its theory, signal processing, networking, Internet of things and antennas design with current emphasis on wireless power transfer systems.

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Mohamed has received a Best Masters Project at the Hooper Memorial Student Project Presentation, from the department of Electronic Engineering, La Trobe University in 2012. The first place of the competition for Creativity and Innovation Award for Excellence Student Project Sponsored by The Higher Institute of Engineering Technology Zliten, Libya in 2016.



Johnson Ihieh Agbinya is Professor of telecommunications, electronic sensors and data analytics at Melbourne Institute of Technology. He is currently Head of School of Information Technology and Engineering, Course Coordinator of the Master of Engineering and Coordinator of the Internship Program. He obtained a PhD in Electronic Engineering from La Trobe University, MSc (Research) from the University of Strathclyde, Scotland and BSc in Electronics/Electrical Engineering from University of Ife, Nigeria. Before joining MIT, he was Associate Professor at La Trobe University and Senior Lecturer at the University of Technology Sydney.

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He is on the editorial board of Remote Sensing journal (MDPI), editor of Software Networking (River Publishers). Consulting Editor in telecommunications for River Publishers, Denmark, editor Pan African Journal of Informatics and African Journal of ICT. He has published ten textbooks in telecommunications, data analytics, sensor networking and computing and more than three hundred and fifty peer-reviewed articles in international journals and conference proceedings.

Professor Agbinya is Fellow of African Scientific Institute (ASI), pioneer of two international conferences (IB2COM and PACT). He has reviewed research grant applications for the Portuguese Science Foundation and a current research grant reviewer and researcher rating expert in ICT for the South African Research Fund. He is also reviewer for a number of IEEE journals in telecommunications, industrial electronics, power electronics,

Progress in Electromagnetics Research (PIER) and for Elsevier, Hindawi and IET journals.

He is a student focused teacher with an aim in establishing practical technical education and foundations to enrich learning experience in students. His current research interests are in data analytics, computational intelligence, short-range communications, Internet of things (machine-to-machine communications), bio-informatics, inductive sensors, biometric systems and wireless energy transfer. He has supervised a significant number of PhD students to completion, MSc Research students and over 300 BSc honours students within the last twelve years.

