International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 47 No. 1 October 2024, pp. 77-92

Contribution To The Improvement Of The Wireless Power Transmission System Using Magnetic Inductance Systems

H Clerc Randrianjafiniarivo, J. J Zoé Tiganà MANDIMBY, Jalalaina ANDRIANAIVOARIVELO, Zely A. Randriamanantany

Institute for Energy Management – University of Antananarivo, Madagascar

Thermal, Thermodynamics, and Combustion Laboratory

Corresponding author: J. J Zoé Tiganà MANDIMBY; zoetigana@gmail.com

Abstract –This article presents a comprehensive study of the system dedicated to wireless power transmission via magnetic resonance. The primary objective of this article is to address the shortcomings in wireless power transmission through magnetic coupling. It begins with a detailed review of previous research in this field, highlighting current challenges and gaps to be overcome. A thorough analysis of magnetic resonance principles is then presented, emphasizing key aspects related to long-distance power transmission. The proposal of new coil configurations is systematically discussed, accompanied by numerical simulations. In conclusion, this article makes a significant contribution to the understanding and improvement of wireless power transmission systems through magnetic resonance. The results obtained pave the way for future developments towards the realization of intelligent, sustainable, and modern wireless charging stations.

Keywords – Transmission, Magnetic Coupling, Magnetic Resonance, Coil Configurations, Power Transmission Systems.

I. Introduction

The advent of wireless technologies has revolutionized the way we interact with the world around us. In this context, wireless power transmission emerges as a crucial component of our energy future, providing innovative solutions for powering various devices in a practical and efficient manner. This necessity is even more pressing with the transition towards sustainable lifestyles, emphasizing the judicious use of energy resources and the reliance on renewable energy sources.

Our goal is to design efficient antennas for a public wireless charging station powered by renewable energy sources and capable of operating autonomously and intelligently. This project aligns with the current objective of creating environmentally friendly charging infrastructure that meets the growing needs of electric mobility and wireless electronic devices.

The initial literature review highlights recent advances in the field of wireless power transmission, while underscoring technological challenges and research opportunities. We then explore the fundamental principles of magnetic resonance applied to power transmission, thus establishing the theoretical foundation for our approach.

1. Theoretical Review of Wireless Power Transmission Phenomena

In general, there are three methods of wireless power transmission:

- Radiative power transmission through far-field radiation

Far-field energy transmission involves the unidirectional emission of electromagnetic wave radiation using an antenna, typically in the high-frequency range between 1 MHz and 2.5 GHz.

The maximum range of these waves, as well as their shape, depends on both the form and dimensions of the antenna.

The Friis equation describes the power received by an antenna at a certain distance, taking into account the antenna gains and the frequency used. [1]

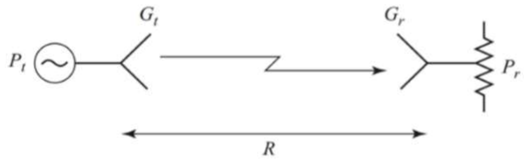

Figure 1: Wireless Power Transmission via Far-Field Radiation [2]

$$P_r = \frac{G_r G_t}{4\pi R^2} \lambda^2 P_t \quad (1)$$

P_r **:** Represents the power transmitted from the transmitter to the receiver with a gain G_r

P_t **:** Represents the power emitted by the transmitter with a gain G_t

λ **:** Wavelength

R **:** Transmission distance

The efficiency of such a transmission is defined by:

$$\eta = \frac{G_r G_t}{4\pi R^2} \lambda^2 (2)$$

This formulation shows that the transmission power undeniably depends on the gain of the transmitting antenna as well as its shape. However, it unfortunately only applies to an ideal transmission path, excluding multipath propagation.

A more extended form of the Friis equation accounts for losses in the antennas, losses due to multipath propagation, and mismatch due to polarization

$$P_r = P_t \,.\, G_r \,.\, G_t \left(\frac{\lambda}{4\pi R}\right)^2 \left(\frac{1}{L_S}\right) (3)$$

L_S is the system loss, which accounts for antenna losses, multipath losses, and polarization mismatches.

$$L_{Transmitting\ antenna} + L_{Multipath\ propagation} + L_{\text{Désadaptation\_polarisation}} = Ls$$

$$\eta_t \,.\, \eta_r \,.\, (1 - S_{11})\,(1 - S_{22})\,|\vec{u}.\vec{v}| (4)$$

η_t **:** Transmitting antenna efficiency

η_r **:** Receiving antenna efficiency

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 47 No. 1 October 2024, pp. 77-92

$\boldsymbol{S_{11}}$, $\boldsymbol{S_{22}}$ **:** Reflection coefficient at the input of both antennas

$\boldsymbol{\alpha}$: Coefficient representing the multipath effects experienced by the emitted wave before reaching the receiving antenna

It is defined by the equation:

$$\boldsymbol{\alpha} = |1 + \sum_{n}^{N} \left(\Gamma_n . \frac{D}{D_n} e^{-j\frac{2\pi}{\lambda}(D_n - D)} \right)|^2 \ (5)$$

Direct application: RF-DC or RFID

The transmitter generally consists of an oscillating circuit generating a high-frequency signal of 2.45 GHz, followed by a signal amplifier, then a power amplifier, and finally a transmitting antenna.

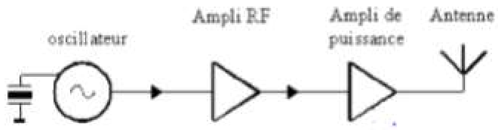

Figure 2 :Schematic diagram of a far-field transmitter

While the receiver consists of a similar antenna, a high-frequency filter, a rectification stage, and finally a low-pass filter.

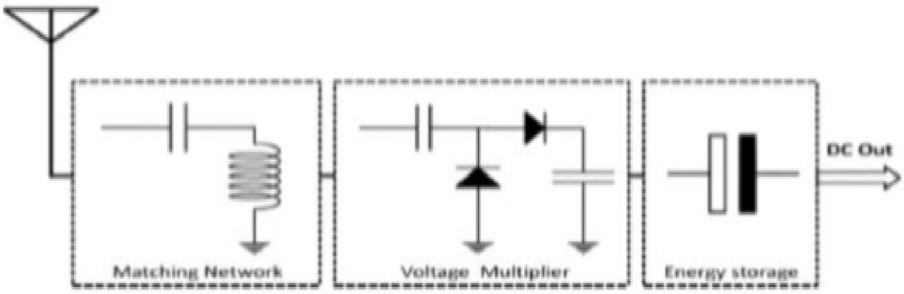

Figure 3 : Schematic diagram of a far-field receiver

For far-field energy transmission, the efficiency is defined by the ratio between P_{DC} and P_{RF}

$$\eta = \frac{P_{DC}}{P_{RF}} \ (6)$$

- Wireless power transmission through magnetic coupling

Wireless power transmission through magnetic coupling is based on the extension of Faraday's theory.

According to Faraday's law, the passage of a magnetic flux through a conductive coil generates a varying electromotive force, in other words, the appearance of a sinusoidal voltage at its terminals and vice versa

Faraday's theory defined by:

$$\varepsilon = \frac{d\emptyset}{dt} \ (7)$$

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 47 No. 1 October 2024, pp. 77-92

$\emptyset$: Magnetic flux

ε : Electromotive force (EMF)

Wireless power transmission through magnetic coupling generally operates in the same way as an electrical transformer.

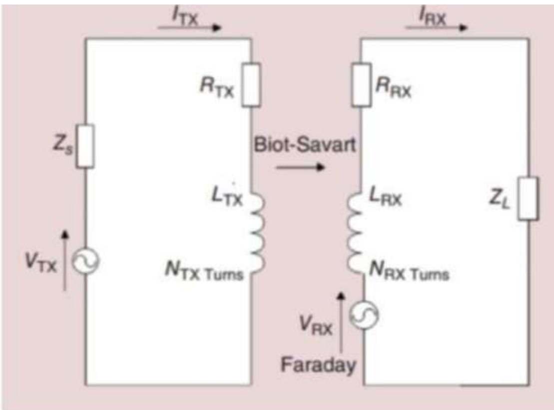

Figure 4 : Diagram of the transmitter and receiver for wireless power transmission through magnetic coupling [3]

R_{TX} : Internal resistance of the coils LTX

R_{RX} : Internal resistance of the coils LRX

L_{TX} : Inductance of the transmitting coil

L_{RX} : Inductance of the receiving coil

N_{TX} : Number of turns LTX

N_{RX} : Number of turns LRX

V_{TX} : Sine wave signal generator

V_{RX} : Received sine wave signal

Z_S : Signal generator resistance

Z_L : Load resistance

Wireless power transmission through magnetic coupling utilizes the Biot-Savart theory because the goal is to place the two coils (transmitting and receiving) at a distance from each other.

The constraint of wireless power transmission relies on the distance as well as the alignment of the transmitter and receiver. In a perfect alignment, the efficiency of the transmission is rigorously defined by Yates' equation [4].

$$\eta = \mu_0 \, \omega^2 \pi^2 \frac{N_{TX}^2 N_{RX}^2 a^4 b^4}{\mathrm{R_{TX} R_{RX} (a^2+d^2)^3}} \quad (8)$$

μ_0 : Magnetic permeability of free space

ω : Pulsation

a, b : Respective diameters of the transmitting and receiving coils

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 47 No. 1 October 2024, pp. 77-92

Wireless power transmission through simple magnetic coupling offers the possibility of transferring substantial power but with a very limited transmission distance.

To extend the transmission distance, scientists have introduced new methods that exploit magnetic resonance.

- Wireless power transmission through resonant magnetic coupling

Wireless power transmission through magnetic resonance relies on the resonance of a transmitting LC circuit, generating a magnetic field. A resonator, placed at a fixed distance, acts as a distance multiplier, establishing the transmitting coupling. Two similarly configured resonator circuits form the receiving coupling, positioned at a significantly greater distance. This principle allows for optimizing energy transfer over long distances by exploiting the magnetic coupling between the coils. Precise adjustments of resonance frequencies and circuit positions are necessary to maximize system efficiency.

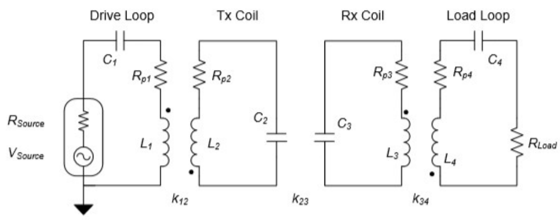

Figure5 :Principle diagram of resonant coupling energy transmission [5].

The four LC circuits are magnetically linked by coupling coefficients $k12$, $k23$, $k34$. It is therefore possible to couple multiple resonant LC circuits to the same frequency.

The following equation gives the power transmission efficiency through resonant coupling under ideal conditions [6].

$$\eta = \frac{k^2 Q_1 Q_2}{\left(1+\sqrt{1+k^2 Q_1 Q_2}\right)^2} \quad (9)$$

Q_1, Q_2 : represent the quality factors of the transmitting and receiving coils, respectively

k: represents the coupling coefficient

In the case of multiple receivers, the energy supplied by the source is divided by the number of interacting receivers.

The transmission efficiency then becomes:

$$\eta = \frac{K^2 \frac{\Gamma_w}{\Gamma_S \Gamma_D^2}}{\left[\left(1+\frac{\Gamma_w}{\Gamma_D}\right)\frac{K^2}{\Gamma_w \Gamma_D}\right]+\left(1+\frac{\Gamma_w}{\Gamma_D}\right)^2} \quad (10)$$

Γ_w : Decay rate considering only the external load loss

Γ_s :Decay rate considering only the external source loss,

Γ_D : Resonator decay rate

In equation (9), K is defined as:

$$K = \omega \frac{k}{2} \ (11)$$

In the case of multiple receivers, the energy supplied by the source is divided by the number of interacting receivers.

Power transmission efficiency is optimized when we have [7]:

$$\Gamma_W = \Gamma_D \cdot \sqrt{\left(1 + \frac{K^2}{\Gamma_W \Gamma_D}\right)} \ (11)$$

A thorough review of all theories on wireless power transmission through resonant magnetic coupling shows that this type of transmission strictly depends on the following three parameters: the spatial configuration of the entire system, the geometric shape of the resonators, and the operating frequency of the circuit.

We will develop a new approach to maximize the reception angle of the wireless power receiver through resonant magnetic coupling. For wireless power transmission via resonant magnetic coupling, the necessary condition for ideal transmission is the arrangement of the resonators in a symmetry plane and parallel with a well-defined distance.

Figure (6) clearly shows the shape of the magnetic induction field emitted by the primary coil.

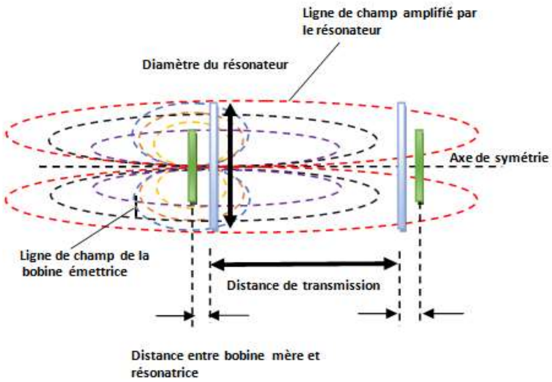

Figure 6: Image of the magnetic field lines for the primary coil and resonator

II- Enoncée de la proposition

Generally, theories initiated by Yates focus on maximizing the transmission distance under ideal conditions. Changes in the emission or reception angle significantly reduce the transmission efficiency. From a geometric perspective, we can write the following mathematical equation: By incorporating the deviation angle θ equation (9) becomes:

$$\eta(\theta) = \eta_0 \ Cos^2(\theta) \ (12)$$

Où

- $\boldsymbol{\eta(\theta)}$:Efficiency at an angle θ
- $\boldsymbol{\eta_0}$: Maximal Efficiency
- $\boldsymbol{\theta}$: Angle between the axes of the coils

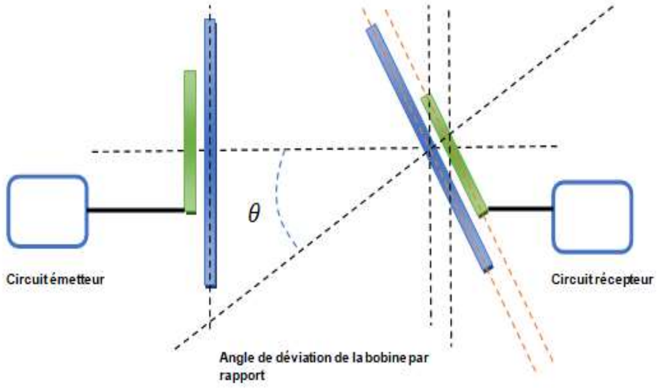

Figure 7 : Shows the deviation of the receiving coil relative to the transmitting coil

The function $\cos^2(\theta)$ represents the decrease in magnetic coupling with an increase in the angle θ.When $\boldsymbol{\theta = 0}$°, $cos^2(\theta) = 1$ and thus equation (12) becomes:":

$$\eta(\theta) = \eta_0 \quad (13)$$

Which corresponds to the perfect alignment of the transmitter and receiver

The efficiency is then minimal when $\theta = 90°$ making cos 90 = 0, This means that there is virtually no energy transmission when the coils are perpendicular to each other. We can then graphically plot the efficiency as a function of the angle according to the table below.

Tableau : Variation of efficiency as a function of the angle θ

θ	$\eta(\theta)$
0°	η_0
30°	$\eta_0 \boldsymbol{Cos^2}(30°)$
60°	$\eta_0 \boldsymbol{Cos^2}(60°)$
90°	0

By adding an angle ϕ ranging from 0 to 360 degrees, a surface can be created that shows how the efficiency varies around the central axis, even though the efficiency remains constant for all values of ϕ The axes are defined as follows:

X-axis: ϕ (Angle from 0 to 360 degrees)

Y-axis: θ (Angle from 0 to 90 degrees)

Z-axis: Efficiency $\eta(\theta, \phi)$

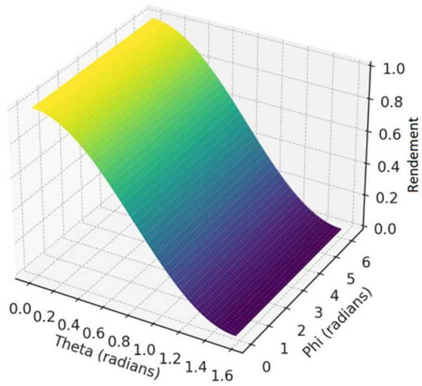

Figure 8 : 3D representation of the variation of $\eta\ (\theta, \phi)$

Let us now understand how the angle affects the magnetic coupling between the two coils. The mutual inductance between two coils depends on the orientation of the coils relative to each other.

If the axes of the coils are tilted by an angle θ, the mutual inductance can be expressed as:

$$M\ (\theta) = M_0\ cos\ \theta \ (14)$$

Where M_0 is the maximum inductance when the coils are in perfect parallel symmetry, in other words, when $\theta = 0$

The coupling coefficient k is defined by

$$k(\theta) = \frac{M\ (\theta)}{\sqrt{L_1 L_2}} = \frac{M_0}{\sqrt{L_1 L_2}} cos\ \theta = k_0\ cos\ \theta \ (15)$$

We can then write the relationship between efficiency and the coupling coefficient. Since the transmission efficiency using the resonant magnetic coupling method is defined by equation (9), substituting the coupling coefficient (15) into the efficiency equation yields:

$$\eta\ (\theta) = \frac{(\ k_0\ cos\ \theta)^2 Q_1 Q_2}{(1+\sqrt{1+(\ k_0\ cos\ \theta)^2 Q_1 Q_2})^2} \ (16)$$

The expression for the quality factor of the transmitting coil (Q_1) and receiving coil (Q_2)

The expression for the quality factor of the transmitting and receiving coils are defined as :

$Q_1 = \omega \frac{L_1}{R_1}$ et $Q_2 = \omega \frac{L_2}{R_2}$ (17)

where L_1 and L_2 are the inductances, R_1 and R_2 are the internal resistances, and ω is the angular frequency of operation.

We can mathematically determine the minimum reception limit of the receiver as a function of the angle θ.

Let us note that η_0 is the maximum efficiency under ideal transmission conditions according to Yates [8]. Assuming that under these conditions $\eta_0 \approx 1$, or 100%, we then consider a minimal acceptable efficiency of 50%, that is, $\eta_{min} \approx 0,5$.

Let's start from the equation (12)

$$\eta\ (\theta) = \eta_0\ Cos^2(\theta)$$

Define the minimal acceptable efficiency as η_{min} such that:

$$\eta_{min} = f(\theta_{min}) \ (18)$$

if and only if :

$$\eta_{min} = \eta_0 \ Cos^2(\theta_{min})$$

θ_{min} is then:

$$\frac{\eta_{min}}{\eta_0} = Cos^2(\theta_{min})$$

$$\theta_{min} = \arccos\left(\sqrt{\frac{\eta_{min}}{\eta_0}}\right) \ (19)$$

$\theta_{min} \approx 45°$

Indeed, for optimal reception, the receiver's capture angle must be within what we define as the operating range:

$$\theta_{max} = 0 \ \leq (\theta) \ \leq \theta_{min} = 45° \ (20)$$

But in practice, it is challenging to maintain the capture angle within the optimal operating range, especially when the receiver is in motion.

To create an environment where a receiver can operate efficiently at any angle, it is necessary to design a wireless energy transmission system that maintains good efficiency regardless of the alignment between the transmitting and receiving coils.

Let's define the mathematical aspects involved, the number of coils required, and their arrangement in space. We need a field covering a three-dimensional space, which implies using three coils to generate a Tri-Flux, or in other words, a field dome.

Two cases can be considered:

- **Case 1** :

The three coils independently generate magnetic induction fields.

- **Case 2** :

The three coils operate relationally, that is, in resonance.

Let's study the first case :

For a spherical configuration with three orthogonal coils, each coil along the x, y, and z axes can be modeled by its magnetic field. $\overrightarrow{B_x}, \ \overrightarrow{B_y}, \ \overrightarrow{B_z}$. The resulting magnetic field $\overrightarrow{B_r}$ at the receiver point is the vector sum of the fields generated by each coil, as follows:

$$\overrightarrow{B_r} = \overrightarrow{B_x} + \overrightarrow{B_y} + \overrightarrow{B_z} \ (21)$$

In this case, the reception efficiency for each coil is defined by equation (12) such that:

$$\eta_i(\theta_i) = \eta_0 cos^2(\theta_i)$$

The reception efficiency η_r in the 3D space is the sum of the individual efficiencies weighted by the relative orientations of the receiver, such that :

$$\eta(\theta) = \eta_0 cos^2(\theta_x) + \eta_0 cos^2(\theta_y) + \eta_0 cos^2(\theta_z)$$

The total efficiency can be calculated by considering the contributions of each coil and their orientation relative to the receiver :

$$\eta(\theta) = \eta_0 \sum_{i=1}^{3} cos^2(\theta_i) \ (22)$$

The three coils oscillate differently with three non-multiple frequencies to avoid harmonics.

Let us note the operating conditions according to the following equations:

The mutual inductance is defined by relation (15).:

$$M\ (\theta) = \ k(\theta) \sqrt{L_1 L_2} \ (23)$$

The couplings between the three coils can be expressed as:

Coupling between coil X and coil Y:

$$V_y = \ -M_{xy}(\theta) \frac{dI_x}{dt} \ (24)$$

Coupling between coil X and coil Z :

$$V_z = \ -M_{xz}(\theta) \frac{dI_x}{dt} \ (25)$$

Coupling between coil Y and coil Z :

$$V_z = \ -M_{yz}(\theta) \frac{dI_y}{dt} \ (26)$$

These expressions show that the coupling between each coil is a function of mutual inductance.

o minimize the coupling between the coils, the mutual inductance should approach zero :

$$M\ (\theta) = \ k(\theta) \sqrt{L_1 L_2} \ \rightarrow 0 \ \ <=> \ k(\theta) \rightarrow 0$$

Since $k(\theta) = k_0 \cos\theta$

Thus $k(\theta) \rightarrow 0 \ <=> \ \theta \ \rightarrow \frac{\pi}{2}$

Therefore, we can write : $M\ (\theta) \rightarrow 0$ lorsque $\theta \ \rightarrow \frac{\pi}{2}$

Practically $\theta \ \rightarrow \frac{\pi}{2}$, means that the two interacting coils are in an orthogonal position.

Alternatively, the magnetic field B generated by a coil of radius R t the position of a second coil of the same radius placed at a distance r is given by Biot-Savart's law for a current loop [9] :

$$B = \ \mu_0 \frac{N_1 I_1 R^2}{2(R^2+r^2)^{3/2}} \ (27)$$

This implies the expression for mutual inductance:

$$M = k \ . \mu_0 \frac{N_1 \ N_2 I_1 R^2 \ A_2}{2(R^2+r^2)^{3/2}} \ (28)$$

Since the mutual inductance in our case is a function of the angle θ between the transmitting coil and the receiving coil, we can write :

$$M(\theta) = k(\theta) \ . \mu_0 \frac{N_1 N_2 I_1 R^2 \ A_2}{2(R^2+r^2)^{3/2}} \ (29)$$

This new relation shows that:

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 47 No. 1 October 2024, pp. 77-92

$$M(\theta) \to 0$$

When :

$\theta \to \frac{\pi}{2}$ ou $(R^2 + r^2)^{3/2} \to \infty$

$(R^2 + r^2)^{3/2} \to \infty$ Practically, this means that as the distance between the two coils increases, the mutual inductance decreases.

These calculations emphasize the arrangement of the three coils in three-dimensional space, as well as their distance, to maximize the emission and reception of the three-dimensional magnetic induction field.

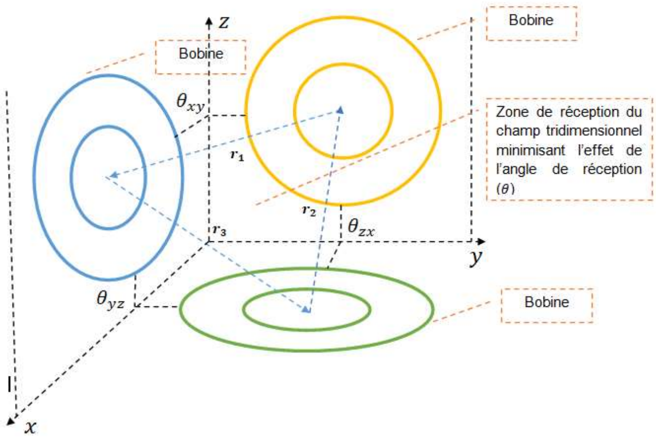

Figure 9 : Optimized Coil Arrangement

The following graph illustrates the results of a simulation conducted using Python on the Google Colab compiler.

The table below provides the data used in the simulation.

Frequency	Capacity	Inductance
$f_x = 100kHz$	0,47μF	5,39 μH
$f_y = 110kHz$	0,47μF	4,45 μH
$f_z = 120kHz$	0,47μF	3,74 μH

Distances r_1, r_2, r_3 are all fixed at 0,5 meters

Angles : $\theta_{xy} = \theta_{yz} = \theta_{zx} = \frac{\pi}{2}$,

The three figures below illustrate the magnetic fields emitted by each coil in the 3D coordinate system according to their placement in the following planes (XY, ZY, ZX).

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 47 No. 1 October 2024, pp. 77-92

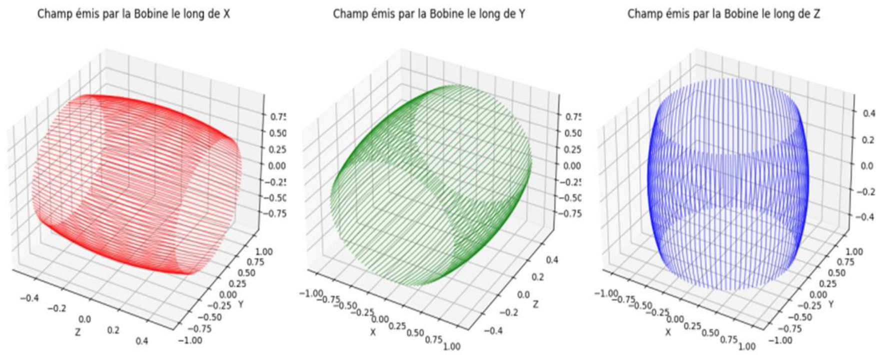

Figure 10: Overall Shape of the Magnetic Field Emitted by the 3 Coils in the ZY, ZX, and XY Planes in a 3D Space

Now, we will merge the three fields into a single space. The result of the simulation will yield the following figure.

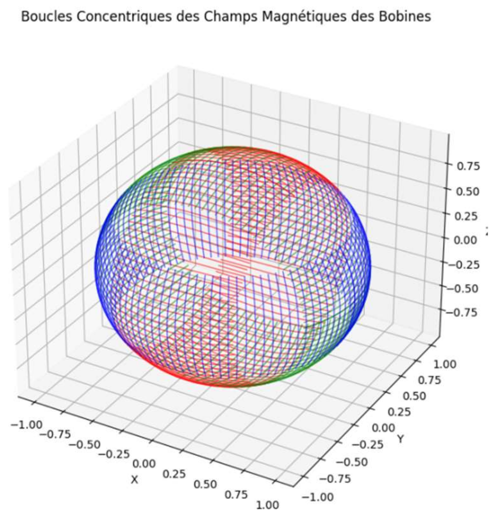

Figure 11: Shape of the 3 fields emitted in the same 3D space

Figure 11 illustrates the distribution of the fields emitted by the three coils in a 3D space (X, Y, Z). This representation shows that the field forms a Tri-Flux configuration, allowing the receiver to capture the field regardless of the angle of incidence, thus reducing the effect described by equation (19).

Since we used three coils oscillating at different frequencies to form the Tri-Flux, we need to configure the receiver circuit so that it can capture all three fields.

Theoretically, the following relationship allows us to calculate the inductance value of the coil, given the resonance frequency f and capacitance C

$$f = \frac{1}{2\pi\sqrt{LC}} \quad (30)$$

Impliquant :

$$L = \frac{1}{(2\pi f)^2 C} \quad (31)$$

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 47 No. 1 October 2024, pp. 77-92

This allowed us to calculate the inductance values for each coil used in the simulation data in the table above with a fixed capacitance value.

Now, for the receiver coil to operate in a wideband mode, meaning it can accept 3 different resonance frequencies, we need to associate 3 resonant branches in parallel, oriented in the same direction and superimposed.

The principle diagram is illustrated in the figure below

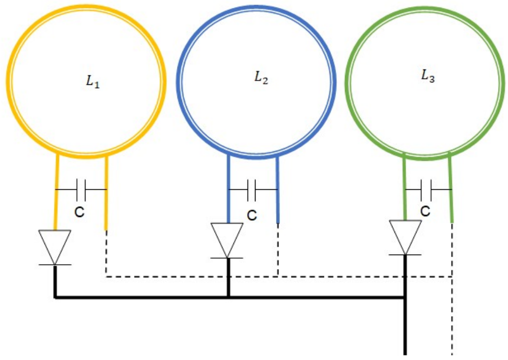

Figure 10 : Figure 10: Principle Diagram of the Tri-Flux Reception Circuit

The superposition of the three coils does not affect the reception efficiency of each coil, as each resonates at a distinct frequency. For a more optimized arrangement of the three coils, they can be interlocked as illustrated in Figure 11 below

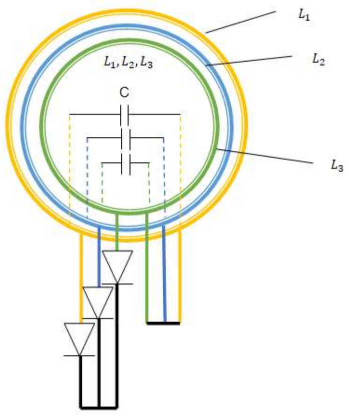

Figure 11: Optimized Arrangement of Reception Coils

Let's study the second case:

Now, if the three coils operate synchronously, using the principle of resonance enables efficient energy transmission. In this case, generating a tri-flux is not limited to using three coils placed in space as in the first case. To achieve a three-dimensional field, the three coils must be arranged orthogonally in space, which introduces magnetic coupling constraints according to the previously mentioned equation (23). Therefore, a new configuration is proposed for the second case

According to equations (19) and (29), we must respect an inter-coil angle (θ_i) within the operating range :

$$\theta_{max} = 0 \le (\theta_i) \le \theta_{min} = 45°$$

And also a very small inter-coil distance

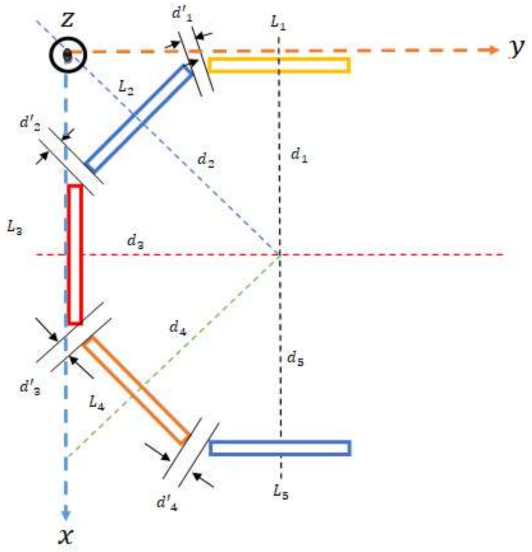

Figure 12 : Configuration des bobines en forme de pentagone dans le plan ZX, ZY

The optimal configuration is then arranging the coils in a Petagonal pattern in 3D space

d_1 to d_5: Represents the distance from the center of the space to each coil, generally identical.

d'_1 to d'_4: Represents the inter-coil distance.

In this configuration coil L_3 is the field emitter, and the other coils resonate at a resonance frequency f. This setup allows a receiver placed vertically in the ZX or ZY plane to have a degree of freedom for field reception ranging from 0 to 360°.

Equation (29) clearly shows the relationship between mutual inductance, the coupling coefficient, and the distance between the coils. The term $(R^2 + r^2)^{3/2}$ should be minimized

From this relationship, we can observe that a small inter-coil distance and a high coupling coefficient result in a high mutual inductance, contributing to effective resonance of each coil.

The following figure shows the shape of the field emitted by each coil in 2D

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 47 No. 1 October 2024, pp. 77-92

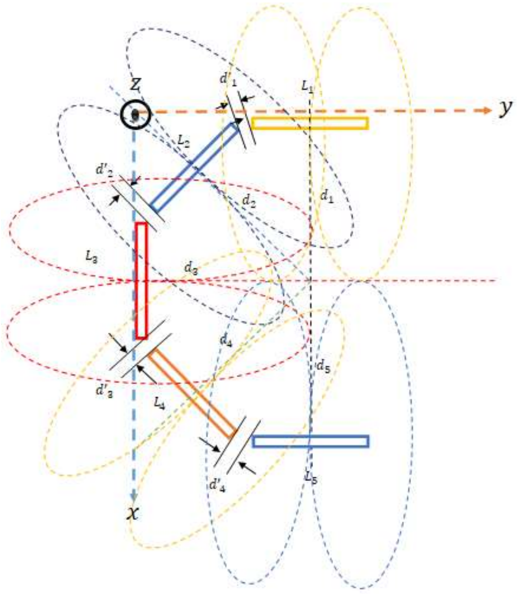

Figure 13: Representation of the Field Emitted by the 5 Coils

The advantage of the configuration using the resonant magnetic coupling method is that the magnetic field is amplified and can propagate effectively. The energy provided by the primary resonant coil is divided among the number of resonant coils. In a network of resonant coils, the energy transferred by one coil can be partially redirected to another resonant coil through the shared magnetic field. This can lead to a more balanced energy distribution within the system. In this case, the energy received by the receiver is given by the following relation:

$$E_{receiving} = \frac{E_{emetted}}{N_b} \quad (32)$$

III - Conclusion

Wireless energy transmission through resonant magnetic coupling offers an optimal balance between efficiency, usability, and safety, making it particularly suitable for specific applications such as wireless charging of electronic devices, medical implants, and electric vehicles. This paper explores possible improvements and aims to overcome major constraints of wireless energy transmission via resonant magnetic coupling, particularly the need for perfect alignment between the transmitter and receiver, by proposing new coil configurations. The proposed new configurations could help overcome these constraints and significantly enhance the performance of wireless energy transmission. These innovations not only provide greater flexibility in coil positioning but also pave the way for more robust and versatile systems, suitable for a wider range of applications. As a result, the reliability and efficiency of wireless energy transmission could be greatly increased, allowing for its adoption in even more diverse fields.

References

[1] : "Antennas and Propagation for Wireless Communication Systems" by Simon R. Saunders and Alejandro Aragon-Zavala

[2] : "Analysis, Experimental Results, and Range Adaptation of Magnetically Coupled Resonators for Wireless Power Transfer" Alanson P. Sample, Student Member, IEEE; David T. Meyer, Student Member, IEEE; and Joshua R. Smith, Member, IEEE, p3, March 2011

[3] :Rectifying Loose Coils, Microwave magazine.

Antennas and Propagation for Wireless Communication Systems" by Simon R. Saunders and Alejandro Aragon-Zavala

[4] : K. Fotopoulou and B. Flynn, “Wireless power transfer in loosely coupled links: Coil

misalignment model,” IEEE Trans. Magn., vol. 47, no. 2, pp. 416–430, 2011.

[5] :Analysis, Experimental Results, and Range Adaptation of Magnetically Coupled Resonators for Wireless Power Transfer Alanson P. Sample, Student Member, IEEE; David T. Meyer, Student Member, IEEE; and Joshua R. Smith, Member, IEEE, p3, March 2011

[6]: Analysis, Experimental Results, and Range Adaptation of Magnetically Coupled Resonators for Wireless Power Transfer Alanson P. Sample, Student Member, IEEE; David T. Meyer, Student Member, IEEE; and Joshua R. Smith, Member, IEEE, p4, March 2011

[7] : J.Gozalvez, “WiTricity - The Wireless Power Transfer,” IEEE Vehicular Technology Magazine (IEE/IEEE), Vol. 2, Issue 2, 38-44, June 2007

[8] : K. Fotopoulou and B. Flynn, “Wireless power transfer in loosely coupled links: Coil misalignment model,” IEEE Trans. Magn., vol. 47, no. 2, pp. 416–430, 2011.

[9] : ScienceFacts.net