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RESEARCH ARTICLE

REVIEW OF PARAMETERS INFLUENCING WIRELESS ENERGY TRANSMISSION BY MAGNETIC INDUCTION

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Abstract

In this review article, we present a detailed study and discussion of wireless energy transfer systems based on studies in the literature, with the help of Python programming software. Starting from the basic element of wireless transmission by magnetic induction, i.e. the coil, through a magnetostatic study we have highlighted the impact of geometry, coil misalignment and coil loss factors on these transmission systems. We have also shown that parameters such as coupling coefficient and frequency can improve transmitted power and efficiency. A summary of the latest research in this field will also be given.

Introduction:-

In recent years, research in the field of wireless energy transmission by magnetic induction has increased due to the diversity of applications such as medicine, electronics and transportation [1-3] that require this technology. However, despite its maturity to date, this technology has struggled to establish itself due to limited transmission distance and transmission efficiency.

In our daily lives, we use devices that require frequent charging, limiting our freedom of movement. These devices use special chargers that have to be changed, causing pollution problems. Also, the use of conductive cables and wires in installations increases the risk of short-circuits and fire. Also, some medical implants often require charging due to the batteries embedded in the body, so surgery is necessary every time they need charging.

The oil crisis and the pollution caused by greenhouse gases have led to the search for alternatives in the automotive sector, notably the use of electric cars. These cars run on batteries that have to be charged.

As a solution to these problems, the transmission of energy by magnetic induction is of interest in many fields, including those mentioned above: medicine [1], transport [2], electronics [3].

However, the transmission of energy by magnetic induction is experiencing difficulties in establishing itself because of the short transmission distance and also because of the difficulty of maximizing both the power transmitted and the efficiency, which to date have not yet been mastered.

In this document, we present the following points:
- Analytical calculation of the self-inductance of some coil geometries and the mutual inductance,
- Optimization parameters influencing self and mutual inductance.

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- Analytical extraction of electrical parameters such as transmitted power and system efficiency.
- Synthesis of research work carried out over the decades to improve performance.

Magnetostatic study of coils

Impact of coil geometry on self and mutual inductance

The transmission of energy by magnetic induction is based on two magnetically coupled coils, either by means of a magnetic support in the case of transformers, or by means of air, which is the case studied in this article.

So transmitting energy wirelessly requires a coil, which is simply a winding of conductive wire that can be given a given shape. There are several coil geometries, such as circular, square, hexagonal and others. [4-6].

A coil is characterized by its self-inductance. This inherent inductance depends on the geometry. There are several analytical formulas in the literature for calculating the self-inductance of coils as a function of geometry.

Coil self-inductance

The inductance of a coil is the key parameter characterizing it. It depends on the number of turns, the space between turns, the conductor cross-section and the coil diameter. The formulas for calculating the inductance of square, circular, triangular, rectangular and spiral coil geometries are summarized in Table 1 [7].

Table 1:- Self-inductance of coils.

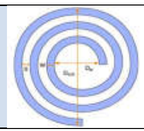
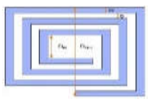
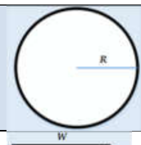
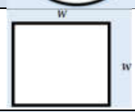
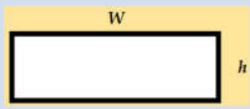
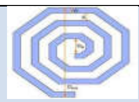
	Geométry	Inductance	shape
1	Flat spiral circular	$L = \frac{N^2A^2}{30A - 11D_{in}}$ $A = \left(D_{in} + N(w+s)\right)/2$	
2	Rectangular flat spiral	$L = 27.10^{-10}\left(\frac{D^{8/3}}{w^{5/3}}\right)(1+R^{-1})^{5/3}$ $R = w/s$ D: coil outside diameter s : conductor cross-section, w : space between spirals	
3	Circular	$L = \frac{\mu N^2 R}{2\pi}\left(\ln\left(\frac{8R}{r}\right) - 2\right)$ R:coil radius; a: conductor radius	
4	Square	$L = \frac{2\mu N^2 w}{2\pi}\left(\ln\left(\frac{w}{r}\right) - 0.774\right)$	
5	Rectangular	$L = \frac{2\mu N^2 w}{2\pi}\Big[-2(w+h) + 2\sqrt{h^2+w^2} - h\,ln\left(\frac{h+\sqrt{h^2+w^2}}{w}\right) - w\,ln\left(\frac{w+\sqrt{h^2+w^2}}{h}\right) + h ln\left(\frac{2h}{r}\right) + w ln\left(\frac{2w}{r}\right)\Big]$	
Coil inductance on printed circuit boards			
6		$L = \frac{\mu n^2 D_{avg} C_1}{2}\left(ln\left(\frac{C_2}{\rho}\right) + C_3\rho + C_4\rho^2\right)$ C_1 , C_2, $C_3 et C_4$ are constants given in Table 2	

Table 2:-Values of constantsC_1 , C_2, $C_3 et C_4$

Geometry	C_1	C_2	C_3	C_4
Square	1,27	2,07	0,18	0,13
Hexagonal	1,09	2,23	0	0,17
Octagonal	1,07	2,29	0	0,19
Circular	1	2,46	0	0,20

Circular, rectangular and especially octagonal flat spiral geometries are the most widely presented in the literature, due to their flexibility in relation to applications [8]. Figure 1 shows the evolution of inductances for different coil shapes, varying parameters such as coil diameter, number of turns, inter-turn spacing and conductor cross-section. Figure 2 shows that the square geometry has the highest inductance in all cases.

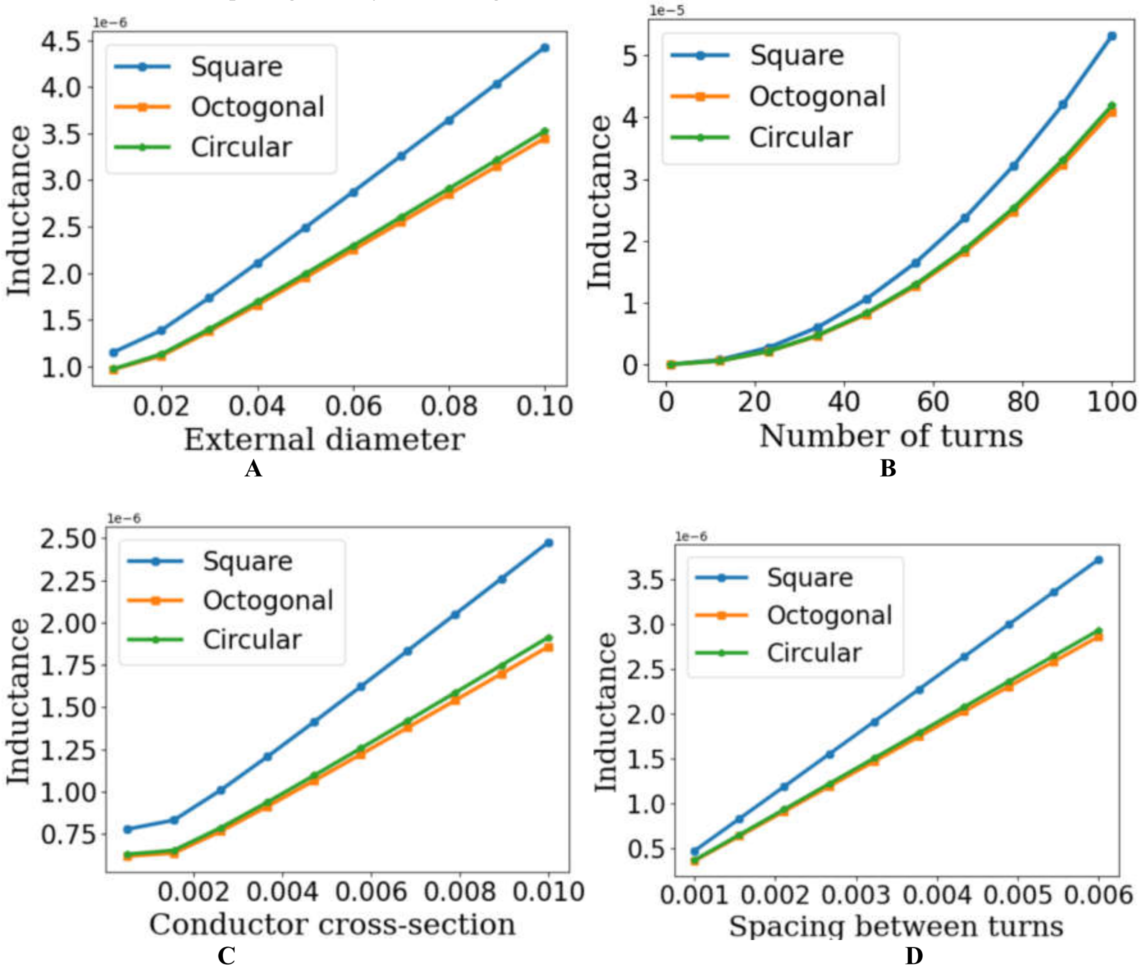


Figure 1:- Parameters influencing coil self-inductance.

Mutual inductance

Mutual inductance is defined as the magnetic flux shared by two coils. It reflects the magnetic link between the transmitting and receiving coils.

Mutual inductance can be calculated taking into account only the axial distance between the two coils. It can also be calculatedtaking into account misalignment or angular misalignment [4, 9-11]. Figure2 shows the three different cases.

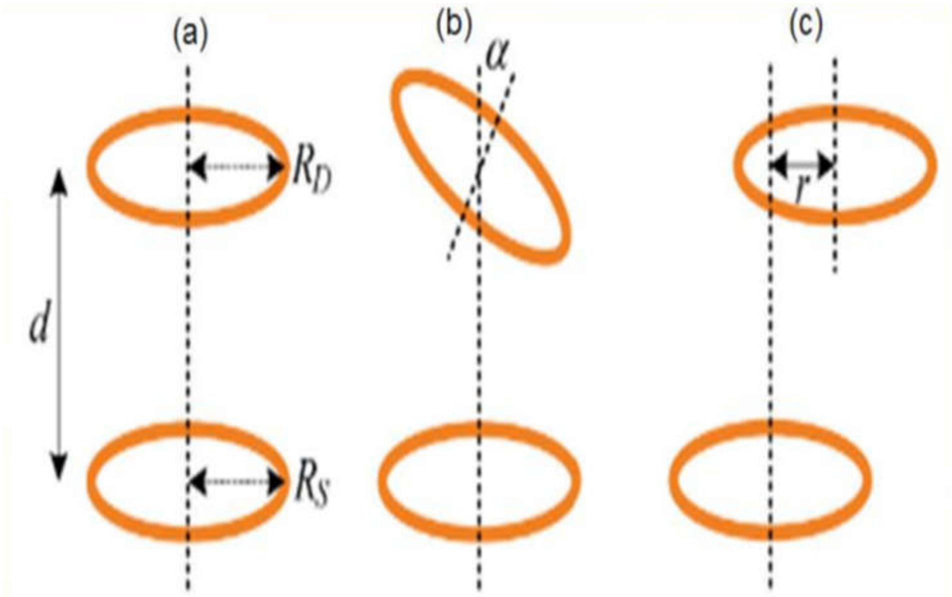


Figure 2:- Transmitter and receiver coil alignment.

In the general case of unobtrusive geometries, a compact analytical model for calculating the mutual inductance between two square and flat circular (spiral) coils, taking into account the axial distance separating the two coils and the lateral misalignment, has been proposed [5] and is as follows:

$$M_{ij} = \frac{\mu\pi a_i^2 b_j^2}{2\left(a_i^2 + b_j^2 + d^2 + x^2\right)^{\frac{3}{2}}}\left[1 - \frac{3}{2}\delta_{ij} + \frac{15}{32}\gamma_{ij}^2\left(1 - \frac{21}{2}\delta_{ij}\right) + \frac{15}{16}\left(\alpha_{ij}^2 + \beta_{ij}^2\right)\left(1 - \frac{7}{4}\delta_{ij}\right)\right] \quad (1)$$

$$\delta_{ij} = x^2/(a_i^2 + b_j^2 + d^2 + x^2)$$
$$\gamma_{ij} = 2\, a_i b_j/(a_i^2 + b_j^2 + d^2 + x^2)$$
$$\alpha_{ij} = 2\, a_i x/(a_i^2 + b_j^2 + d^2 + x^2)$$
$$\beta_{ij} = 2\, x b_j/(a_i^2 + b_j^2 + d^2 + x^2)$$
$$a_i = r_{out_p} - (n_i - 1)\left(w_p + s_p\right) - w_p/2$$
$$b_j = r_{out_s} - (n_i - 1)(w_s + s_s) - w_s/2$$

Total mutual inductance M is:

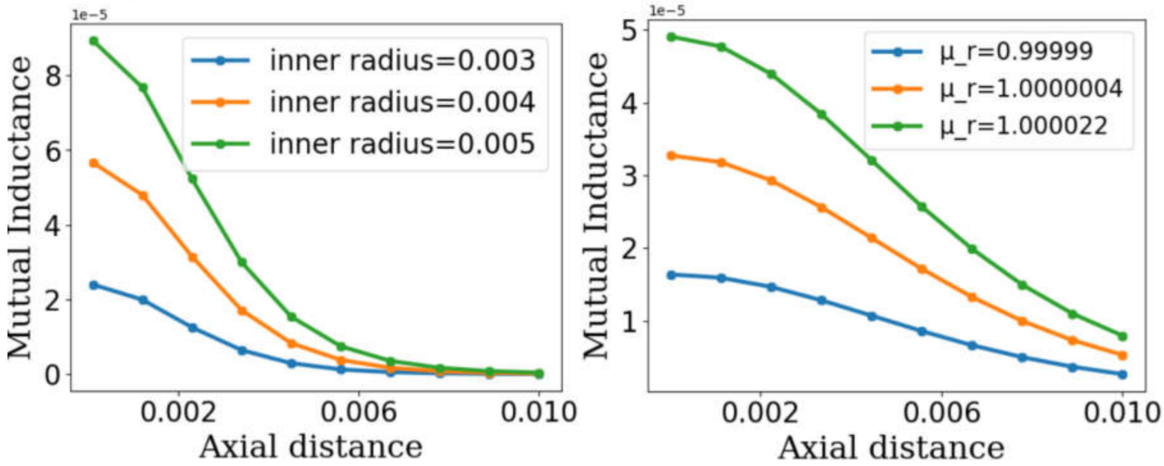
$$M = \rho \sum_{i=1}^{n} \sum_{j=1}^{N} M_{ij} \quad (2)$$

With ρ the correction factor taken equal to 1 for circular geometry and equal to a $\rho = \left(\frac{4}{\pi}\right)^2$ for rectangular or square shapes [5].

Figure 3 shows the influence of parameters such as axial distance, coil radius and lateral separation on mutual inductance.

It can be deduced from Figure 3 that mutual inductance is influenced by parameters such as the axial and lateral distance between the two coils, and the diameter of the coils. The greater the axial distance separating the two coils, the smaller the mutual inductance, as well as the lateral distance. On the other hand, when the coil diameter is large, the mutual inductance is high.
However, the mutual inductance is negative when the lateral distance is greater than the coil radius. This is because the two coils share no flux. Three cases can be distinguished:
- Total coupling: the magnetic field lines emanating from the transmitting coil are totally intercepted by the receiving coil.

- Partial coupling: part of the field lines is intercepted by the receiving coil.
- Non-coupling: no magnetic flux is intercepted by the receiving coil.



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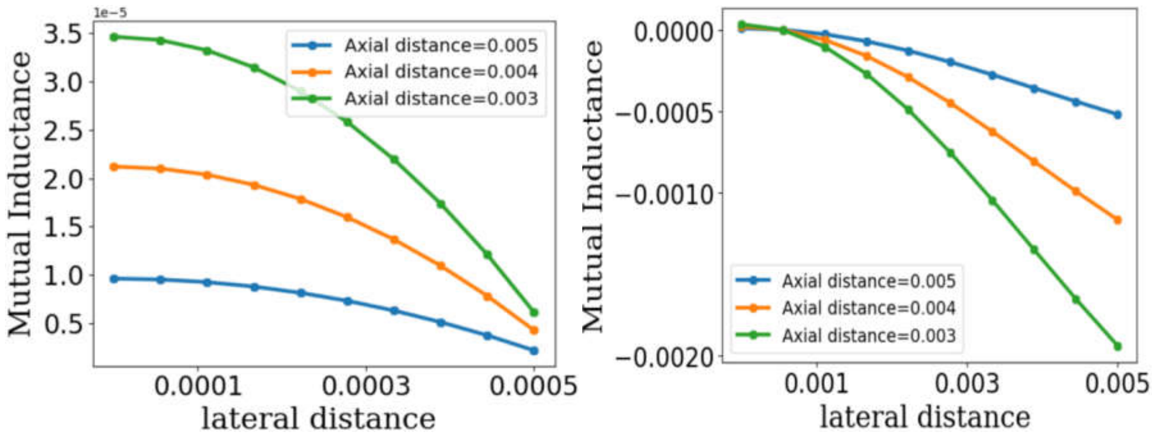

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Figure 3:- Parameters influencing mutual inductance.

Based on these findings, we define a new quantity called the coupling coefficient.

The coupling coefficient represents the proportion of effective field lines shared by the two coils. This coupling ratio is also a function of coil geometry and the distance separating the coils. It is defined from the coils' self-inductance and mutual inductance [2] as follows:

$$k = \frac{M}{\sqrt{L_p L_s}} \tag{3}$$

Coil loss factors

The main loss factors in coils are the skin effect, the proximity effect and the capacitive effect, which occur when the coil is energized and carrying an alternating current.

Skin effect

The skin effect is an electromagnetic phenomenon that causes current to flow across the surface of the conductor at high frequencies.

The skin effect is characterized by the skin thickness (δ), which determines to a first approximation the depth of the zone where the current is concentrated in the conductor.

It is expressed as follows [12]:

$$\delta = \sqrt{\frac{\rho}{\mu_0 \mu_r \pi f}} \tag{4}$$

ρ, μ_0, μ_r and f are respectively material resistivity, vacuum permeability, material permeability and operating frequency.

Figure4a shows that the skin thickness decreases at high frequencies. The direct consequence of the skin effect is an increase in variable-speed resistance Figure 4b. For a cylindrical conductor, the resistance per unit length is expressed as follows:

$$R_{skin} = \frac{1}{\pi\sigma\delta\left(1 - e^{-\frac{r}{\delta}}\right)\left[2r - \delta\left(1 - e^{-\frac{r}{\delta}}\right)\right]} \tag{5}$$

The skin effect is associated with an insulated conductor. For a coil made up of several concentric turns, the proximity effect comes into play.

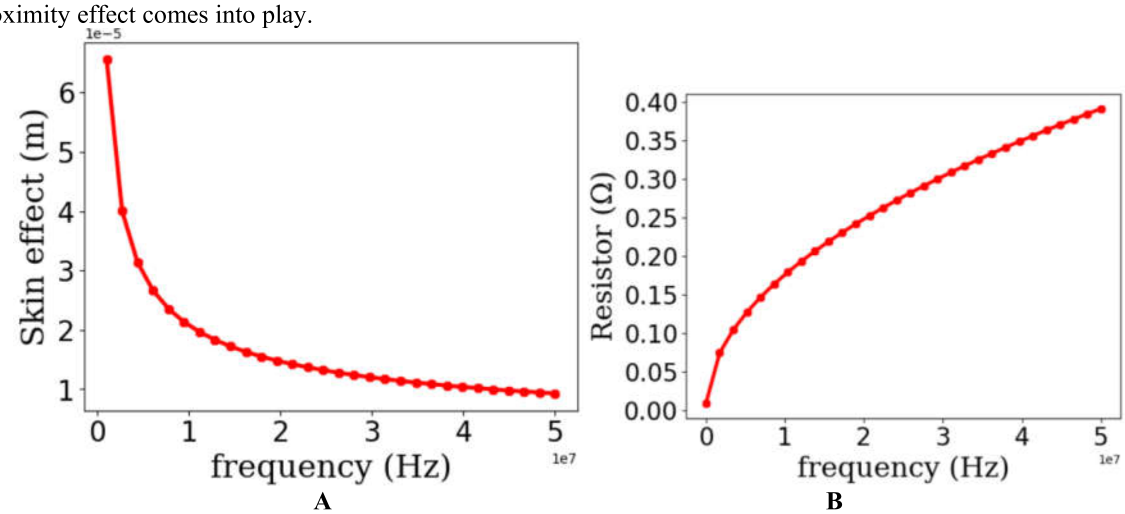


Figure 4:- Evolution of the skin effect (a) and resistance (b) in AC operation.

Proximity effect

A current flowing through a conductor will generate a magnetic field. This magnetic field will disturb the current density within a neighboring conductor. This disturbance of the current density by the magnetic field is known as the proximity effect.

This proximity effect diminishes as the space between turns becomes larger.

The proximity effect also influences the resistance of conductors in variable regime and is expressed by equation 7 [8]:

$$R_{prox} = 2R_{DC}\pi^2 r_0^2 \left(\frac{2r_0}{\delta} - 1\right)\frac{H^2}{I_0^2} \tag{6}$$

$$R_{DC} = \frac{1}{\sigma\pi r_0^2} \tag{7}$$

R_{prox} is the resistance taking into account the proximity effect, R_{DC} the continuous wire resistance, δ the skin thickness, σ the wire conductivity, r_0 the wire radius, r_0 the current flowing through the inductor and H the magnetic field generated by a wire influencing neighboring conductors.

In sum, the total resistance R of the coil is the sum of the resistance due to the skin effect and the proximity effect defined as follows [8]:

$$R = l\left(R_{skin} + R_{prox}\right) \tag{8}$$

$$l = 2\pi \left[n r_{int} + \sum_{2}^{n-1} (w + p) \right] \quad (9)$$

l is the total length of the coil, n is the number of turns, w is the interspace, p is the conductor thickness, r_{int} is the coil's internal resistance.

Capacitive effect

The capacitive effect is the totality of disturbances between the coil and its surrounding medium, such as air, substrate, etc. The capacitive effect is a function of the inter-coil space, geometry and number of turns.

The capacitive effect depends on the inter-turn space, the geometry and the number of turns.

The simplified expression of this capacitive effect is defined in relation to the coil's operating frequency and inductance [13], expressed by equation 11:

$$C(F) = \frac{1}{(2\pi f)^2 L} \quad (10)$$

$f et L$are the operating frequency and total coil length, respectively.

Summary of magnetostatic study

The use of wireless energy transmission in certain fields gives rise to very specific constraints. Some applications require toroidal coils, others helical and others flat [2]. The question is which geometry offers the best flexibility in terms of energy and efficiency.

Studies have been carried out to improve or identify the geometry that offers the greatest flexibility in magnetic flux distribution [5, 14].

Thus, planar geometries offer better magnetic flux distribution with a large radius, and planar geometries are less dependent on axial distance than narrow geometries. It has also been established that the circular spiral coil offers better coupling when the two coils are perfectly aligned, whereas the square spiral coil offers better coupling with respect to lateral misalignment [14].

When considering the coupling coefficient, it should be noted that the coupling coefficient of square coils decreases while that of circular coils increases with the spacing increment [6].

Wireless energy transmission systems

In order to optimize the coupling coefficient, the magnetostatic study presented above took into account the number of turns of the coils, the space between the turns, the geometry of the coils and their arrangement.

In this section, we'll focus on the impact of operating frequency, load independence and circuit design in the process of optimizing transmitted power and efficiency. Indeed, these variables affect both power and transmission efficiency. These two parameters need to be considered separately, as it is possible to increase transmitted power without increasing efficiency, and vice versa.

To illustrate this, we will begin to present the non-resonant transmission system and do a literature review to expose the different work carried out with a view to improving the performance of the system.

Non-resonant magnetic coupling

Figure 5 below illustrates the principle circuit of a non-resonant coupling, taking winding resistance into account.

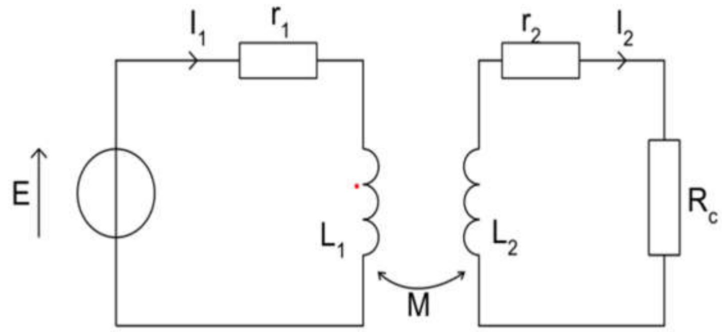


Figure 5:- Non-resonant magnetic coupling.

Using the law of meshes, we can express currents I and powers P as follows

$$I_1 = \frac{E}{r_1 + jL_1\omega + \frac{M^2\omega^2}{jL_2\omega + r_2 + Rc}} \quad (11)$$

$$I_2 = -\frac{jM\omega E}{(r_1 + jL_1\omega)(jL_2\omega + R_c + r_2) + (M\omega)^2} \quad (12)$$

$$P_{en} = Re(V_{in} * I_{in}^*) \quad (13)$$

$$P_{out} = R_L I_2^2 \quad (14)$$

Figure 6 shows the variation of power as a function of frequency and distance between the two coils.

Non-resonant magnetic coupling is dependent on distance, load and frequency. The transmitted power drops drastically when the distance between the two coils exceeds 1/5 of the coupler size [15].

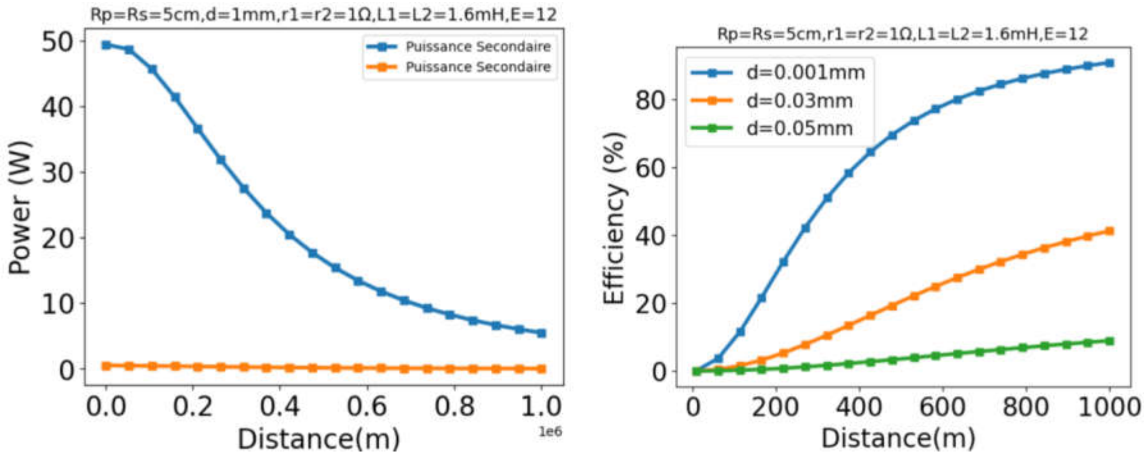
To improve the performance of wireless transmission by magnetic induction, magnetic resonance transmission was introduced by a team of MIT researchers who were able to light a 60W lamp 2m away [16].

This resonant transmission technique involves adding a capacitor to the circuit model shown in Figure 6.

There are several resonant systems, each with its own particularities, which will be discussed later. In summary, four (04) types of resonant system are the most widespread: Series-Serial (SS), Series-Parallel (SP), Parallel-Serial (PS) and Parallel-Parallel (PP) resonant systems [17], as shown in Figure 7.

To demonstrate the impact of resonance on magnetic induction transmission, we'll start with the SS-type system and proceed as follows: first, we'll present the study with a capacitor in the primary, then in the secondaryof Figure 6, and we'll finish with the SS-type resonant system.

As we go along, a comparison will be made with the non-resonant system in order to highlight the impact of capacitor positioning on system performance.



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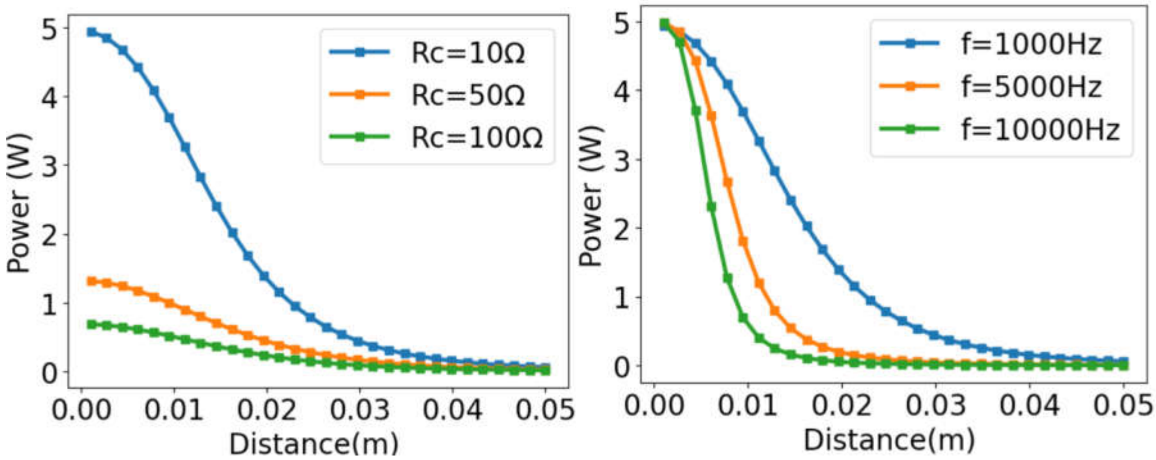

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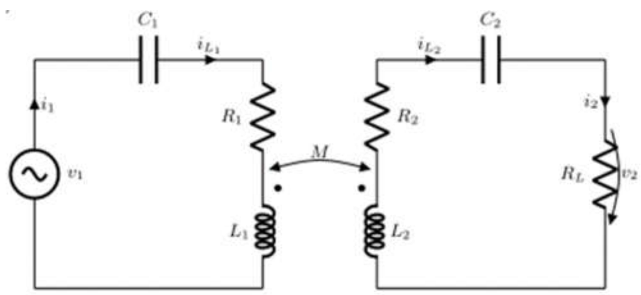
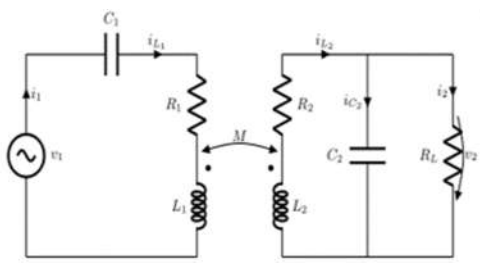
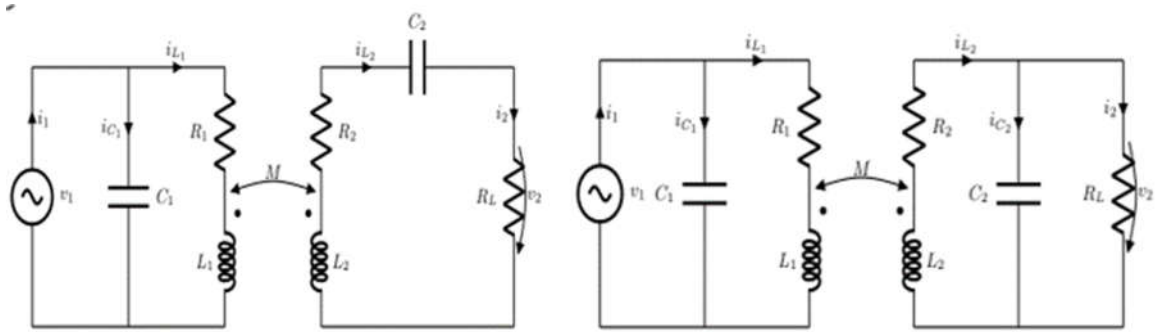
Figure 6:- Transmitted power and efficiency of non-resonant coupling.





(a) SS Compensation Topology **(b) SP Compensation Topology**



(c) PS Compensation Topology **(d) PP Compensation Topology**

Figure 7:- Resonant coupling systems.

Resonant magnetic coupling

The circuit of the resonant system with primary capacitor is shown in Figure 8 with the resulting equations(15) and (16):

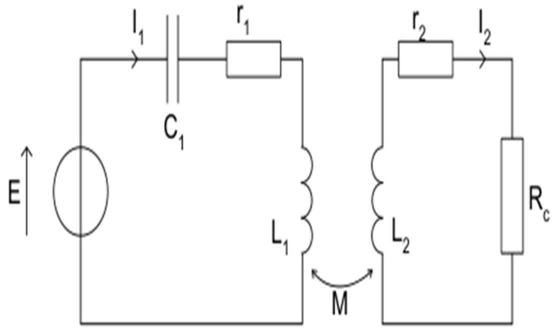


Figure 8:-Resonant coupling to the primary.

$$E = (j\omega L_1 - j\frac{1}{C_1\omega} + r_1)I_1 + j\omega M I_2 \quad (15)$$

$$(j\omega L_2 + R_c + r_2)I_2 + j\omega M I_1 = 0 \quad (16)$$

In the case study shown in Figure 9, maximum power is reached at a precise frequency of 45kHz and 4kHz for inter-coil distances of 2mm and 5cm respectively. These are resonant frequencies.

As the distance between coils increases, a lower coupling coefficient is obtained. Power is maximized at the resonant frequency, which also impacts the transmission distance.

For the case of resonance on the secondary side, Figure 10, the transmitted power as a function of frequency and distance are shown in Figure 11.

Figure 11 shows that the power transmitted with a secondary capacitor is not maximized at the resonance frequency. Unlike the primary resonant circuit, which maximizes power at low coupling, the secondary-only capacitor coupling does not maximize power at low coupling.

To get a clear idea of the impact of these study cases, let's refer to the comparative performance with the non-resonant case through Figure 12 and Figure 13.

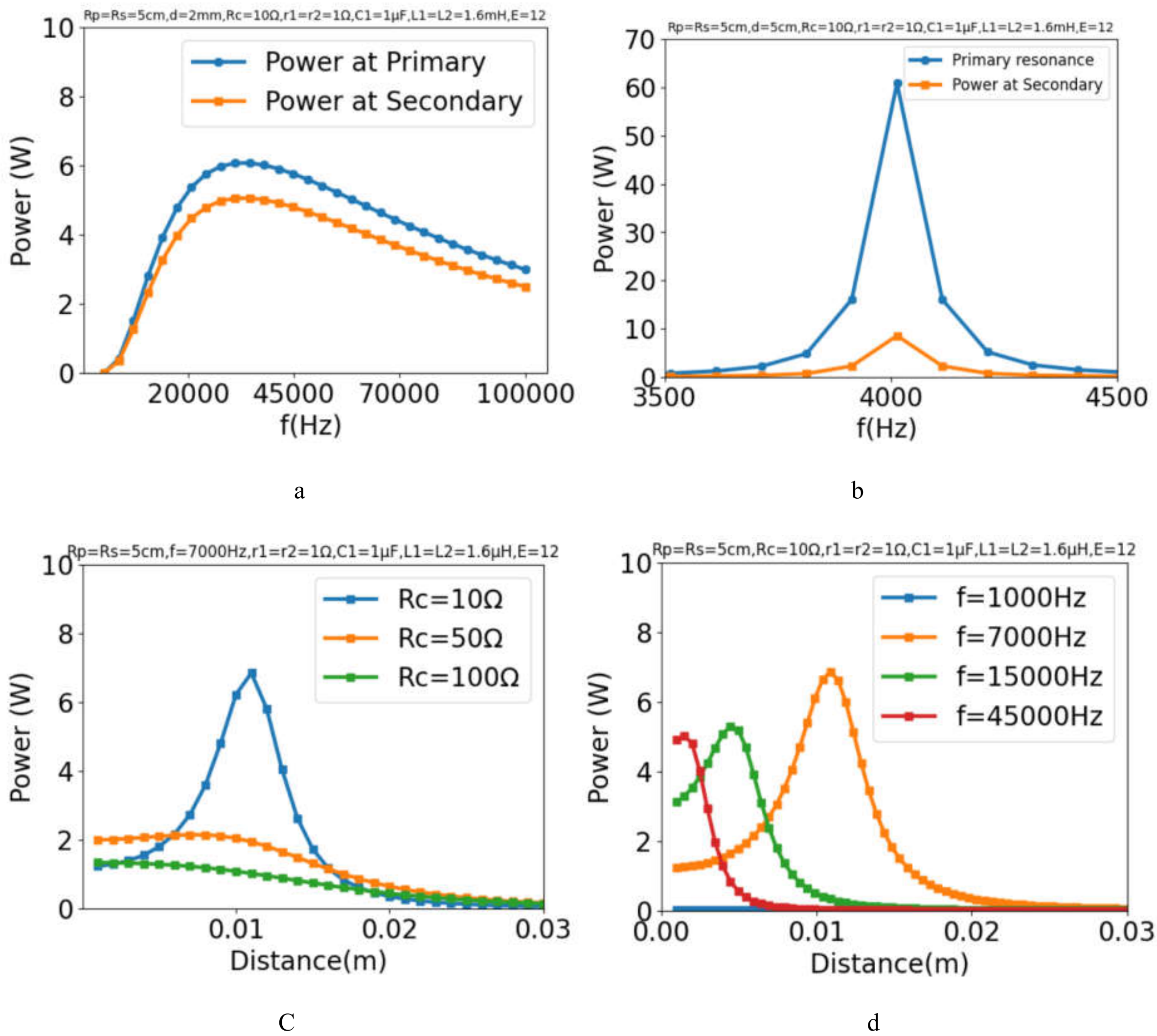


Figure 9: Transmitted power from the resonant coupling to the primary

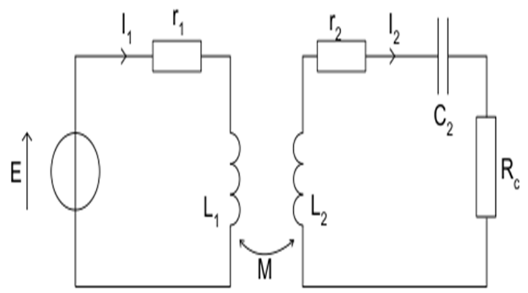


Figure 10:- Resonant coupling at the secondary.

Using the law of meshes we have

$$E = (j\omega L_1 + r_1)I_1 + j\omega M I_2 \tag{17}$$

$$(j\omega L_2 - j\frac{1}{C_2\omega} + R_c + r_2)I_2 + j\omega M I_1 = 0 \quad (18)$$

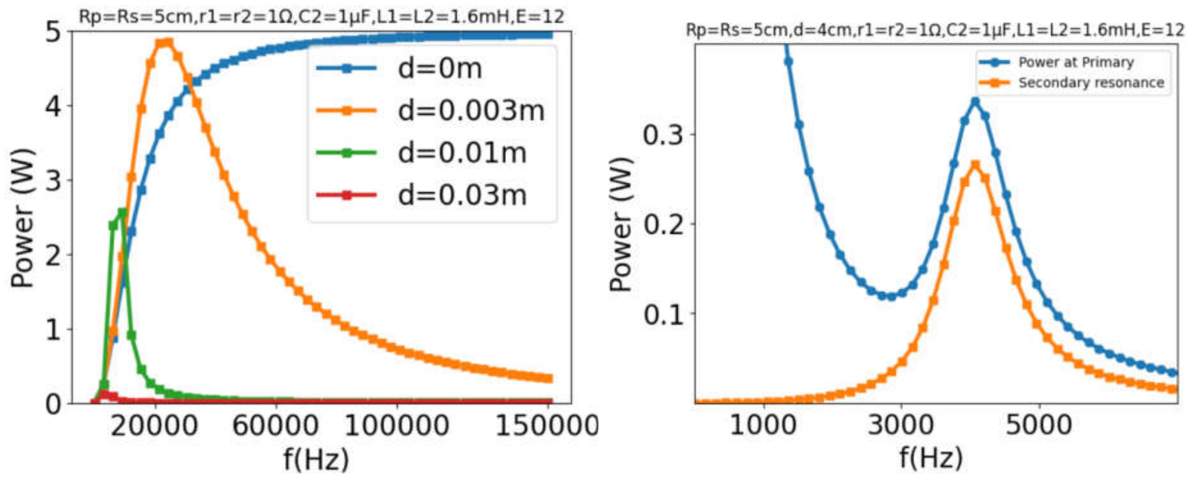


Figure 11:-Transmitted power from resonant coupling to secondary circuit.

Note that the efficiency of the primary resonant system compared to the non-resonant system remains the same for strong and weak coupling, while that of the secondary resonance increases efficiency. We therefore conclude that primary resonance increases power, while secondary resonance increases efficiency. It should therefore be said that transmitted power and system efficiency are two parameters to be treated separately.

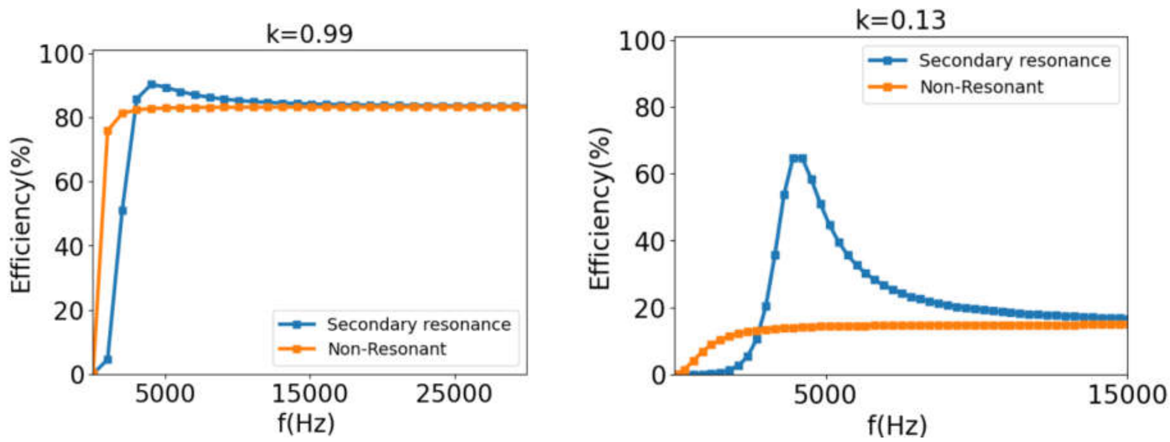


Figure 12:- Comparison of the efficiencies of non-resonant coupling and secondary resonance.

Now that the benefits of a capacitor placed in series with the primary and secondary are clear, let's note that the combination of the two improves both the power and efficiency of the SS system, as shown in Figure 14.

Figure 15 shows transmitted power as a function of frequency, distance, resistive load value and their influence on transmitted power.

There is an optimum distance and frequency at which the transmitted power is maximized (Fig. 15 a). Moreover, within a certain distance range, the variation in transmitted power is not significant. For resonant systems, the optimum distance is defined in relation to the coil radius [15].

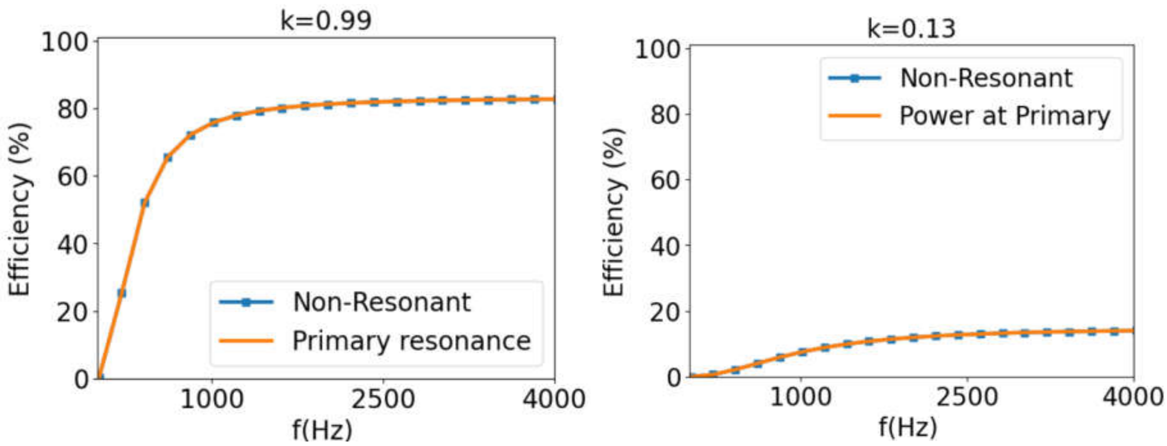


Figure 13:- Comparison of non-resonant and primary resonant coupling efficiencies.

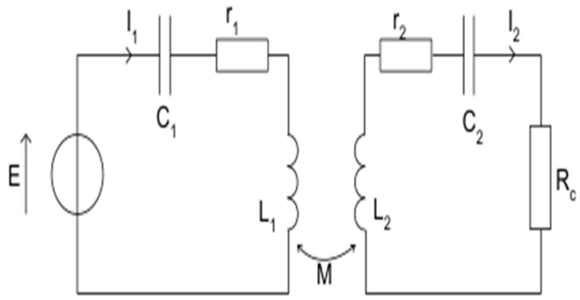
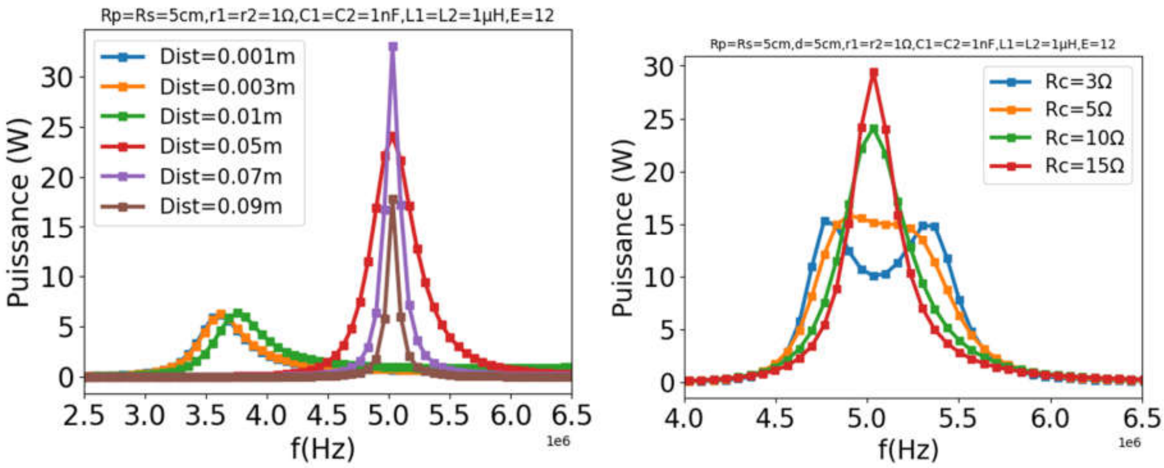


Figure 14:-Series resonant coupling.



a b

Figure 15:-Transmitted power of series-series resonant coupling.

$$E = (j\omega L_1 - j\frac{1}{C_1\omega} + r_1)I_1 + j\omega M I_2 \quad (19)$$

$$0 = (j\omega L_2 - j\frac{1}{C_2\omega} + R_c + r_2)I_2 + j\omega M I_1 \quad (20)$$

The second Figure 15 b) shows the variation in transmitted power as a function of load and frequency. We can deduce that, starting from an optimum load, power is maximized. Also, for given loads and coupling, there are two frequencies at which power is maximized. This phenomenon is frequency splitting, due to the system being operated at a distance below the critical coupling distance.

For a better comparison of the transmission systems shown in Figure 7, we present the primary and transmitted power using equations (21) and (23).

The power transferred from primary to secondary is equal to the reflected resistance multiplied by the square of the primary current, equation (21) [18].

$$P_2 = Re(Z_r)I_1^2 \quad (21)$$

With

$$Z_r = \frac{(\omega M)^2}{Z_2} \quad (22)$$

Impedance $Z_r$is the impedance reflected from the secondary to the primary, or the impedance of the secondary as seen by the primary and $Z_2$is the impedance of the secondary.

Primary power is defined as follows [18]:

$$P_1 = \frac{V_1^2}{Z_T} \quad (23)$$

With $Z_T$the total or equivalent impedance seen from the primary defined by:

$$Z_T = Z_2 + Z_r \quad (24)$$

Table 3 summarizes the total impedance of the resonant transmission system topologies shown in Figure 7 [17, 19].

Table 3:-Impédance totale des systèmes résonant.

Types of resonance	TotalImpedance
Serie-Serie (SS)	$Z_T^{ss} = r_1 + j\left(\omega L_2 - \frac{1}{\omega C_1}\right) + \frac{\omega^2 M^2}{R_L + r_2 + j\left(\omega L_2 - \frac{1}{\omega C_2}\right)}$
Serie-Parallel (SP)	$Z_T^{sp} = r_1 + j\left(\omega L_2 - \frac{1}{\omega C_1}\right) + \frac{\omega^2 M^2}{r_2 + j\omega L_2 + \frac{R_L}{1+j\omega R_L C_2}}$
Parallel-Serie (PS)	$Z_T^{ps} = \left(\frac{1}{r_1 + j\omega L_1 + \frac{\omega^2 M^2}{R_L + r_2 + j\left(\omega L_2 - \frac{1}{\omega C_2}\right)}} + j\omega C_1\right)^{-1}$
Parallel-Parallel (PP)	$Z_T^{pp} = \left(\frac{1}{r_1 + j\omega L_1 + \frac{\omega^2 M^2 (1+j\omega R_L C_2)}{(r_2+R_L+j\omega L_2)(1+j\omega R_L C_2)}} + j\omega C_1\right)^{-1}$

In order to ensure maximum power transmission, the equivalent or total impedance reactance seen from the primary side $I_m(Z_T)$, which symbolizes reactive power, must be cancelled:

$$I_m(Z_T) = 0 \quad (25)$$

Compensation capacitors are deduced from this condition. Table 4 gives the formulas for calculating these capacitors.
Based on the series-series system in Table 3, the transmitted power is a function of the mutual inductance, load and coil resistance at the resonant frequency.
A number of studies have been carried out to improve power transmission or transfer efficiency. This can be

Table 4:- Calculating compensation capacitor values for resonant systems.

Serie-Serie	Serie-Parallel	Parallel-Serie	Parallel-Parallel
$\frac{1}{\omega^2 L_1}$	$\frac{1}{\omega^2\left(L_1 - \frac{M^2}{L_2}\right)}$	$\frac{L_1}{\left(\frac{\omega^2 M^2}{R_L}\right)^2 + \omega^2 L_2^2}$	$\frac{L_1 - \frac{M^2}{L_2}}{\left(\frac{M^2 R_L}{L_2}\right)^2 + \omega^2\left(L_1 - \frac{M^2}{L_2}\right)^2}$

achieved

by increasing the quality factor [20-22], impedance matching [23], or reducing winding resistance [23].
To increase the quality factor, the inter-turn spacing, trace thickness and trace width are varied to reduce coil AC resistance [24]. A comparative study between litz wire and magneto-plated aluminum shows a 23% reduction in the resistance of magneto-plated aluminum coils due to the magnetic support [20, 25, 26].

In order to achieve a compromise between high magnetic permeability and low hysteresis loss, and to improve stresses on the field lines, shielding has been proposed in the literature [21].

The coupler frequency changes when the distance between the couplers changes, resulting in the frequency splitting mentioned above. The load voltage changes with the change in coupler position, as does the resonant frequency, a method based on fuzzy logic and PI control to match the system frequency to the resonant frequency when the coupler position changes [27].

Table 5 shows the advantages and disadvantages of each topology [28].

Depending on the application, one topology may be preferred to maximize power transmission and efficiency. However, it's difficult to predict the efficiency of one geometry over another, as different applications have different requirements, such as medical implants, where energy must be transmitted via the body [1], or the mobile electronics sector [29], where couplers must be fabricated on integrated circuits with associated insulators. These different environments and associated materials also impact on system performance. It is therefore important to take them into account in the design phase for proper optimization.

Coupling systems with two coils, one transmitting and one receiving, are presented here. However, there are also relay systems [30, 31], multi-receiver systems [32] and systems based on metamaterials [33-35].

So, in the interests of greater flexibility and therefore improved power transmission, and better magnetic field distribution with the need to charge or feed several receivers at once, several studies have converged on systems with several primary coils or sources [36-38].

The use of multiple emitter sources shows that power transfer efficiency can be improved whether or not the coils are aligned, due to the diversity of emitter sources. It has been established that over short distances, both the efficiency and the transmitted power are the same for a single-emitter system as for a multiple-emitter system, whereas the efficiency is significantly higher over long distances for a multiple-emitter system than for a single-emitter system [31].

A comparative study has also been carried out for multi-transmitter systems for square and spiral geometries [39], on the basis of which it was found that square coils deliver lower load power and efficiency than circular coils across the whole frequency range and whatever the geometry variants analyzed.

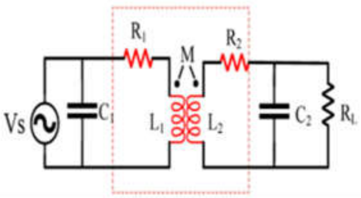
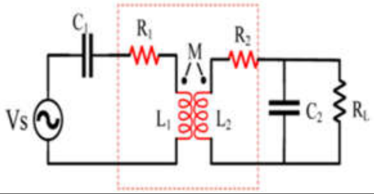
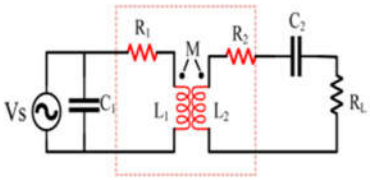
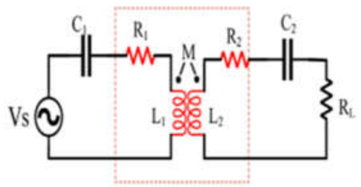
Multi-transmitter transmission systems with relay coils have also been proposed to increase system efficiency by improving the coupling coefficient [40].

One of the problems of multiple-receiver systems is that receivers closer to the transmitter tend to absorb more power than receivers further away. Impedance matching and power distribution on the receiver side only improve efficiency [22].

The use of negative-index metamaterials in wireless transmission improves system efficiency by converging the magnetic field lines and thus focusing them on the receiver coil [33].

Energy transmission by magnetic induction based on meta-materials is confronted with a problem of too high a frequency. In fact, the function frequency for structures based on meta-materials operates at MHz frequencies, yet the semiconductors used in the system have operating limits in the kHz range. To overcome this problem, we need to act on the number of turns and the space between them [33].

Table 5:- Advantages and disadvantages of resonant systems.

Topologies	Advantages / Disadvantages
Serie-Serie (SS)	**Advantages**
	• Under resonant frequency conditions, variations in coupling coefficient and load will not affect C1 and C2.
	Disadvantages
	• Voltage transfer ratio depends on load
Serie-Parallel (SP)	**Advantages**
	• Under resonant frequency conditions, variation in coupling coefficient and load will not affect C1 • C2 ensures load current stability • Requires smaller secondary inductance than SS
	Disadvantages
	• C1 depends on k • Variation in mutual inductance affects power factor
Parallel-Serie (PS)	**Advantages**
	• High efficiency and power factor are achieved by varying the mutual inductance and load. • Reflected reactance is zero
	Disadvantages
	• A current source on the primary side is necessary to avoid instantaneous voltage variations. • High primary resistance for high primary control voltage to transfer maximum power.
Parallel-Parallel (PP)	**Advantages**
	• - Capable of transferring power and achieving high efficiency over long distances
	Disadvantages
	• High primary current • Low system power factor • Requires high load resistance • C1 depends on k and load.

Conclusion:-

This work presents the main geometries and structures of wireless energy transfer whose configurations are more oriented towards domestic and medical applications. The calculation of the inductance of some coils is presented, as well as the parameters on which the inductance and mutual inductance of the coil depend.

Coil loss factors are mentioned, so that these can be taken into account when sizing systems and optimizing transmitted power and transmission efficiency.

The electrical model and the parameters to be taken into consideration to optimize the transmitted power and the efficiency of a transfer system are also presented, emphasizing that the study of these two quantities must be distinct.

A summary of the improvement work carried out in this area is presented, with a view to situating progress in the field of magnetic induction power transmission research.

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