Enhancing Pacemaker Battery Life with Wireless Power Transfer Technology

Wireless Power Transfer

Figure 1 *- An image from Tesla's patent for an "apparatus for transmitting electrical energy," 1907. [1]*

Wireless power transmission technology is rapidly growing globally. In 2012, the market was under 1 billion, but by 2022, it's projected to exceed 5 billion. Consumer electronics dominate, with sectors like automotive and defense also expanding [2].

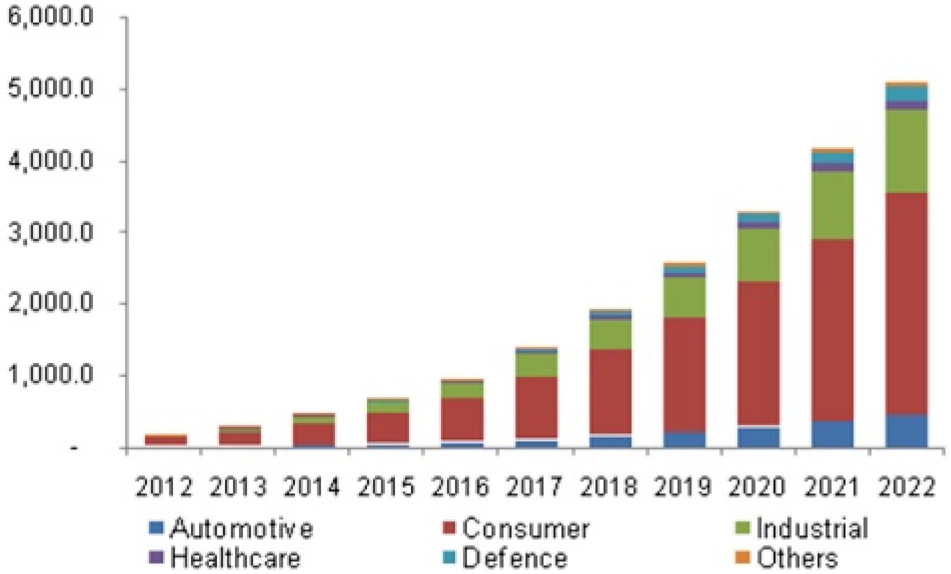

Figure 2 *- Market trends for wireless power [2]*

This article examines Inductive Power Transfer (IPT), a method of wireless power transfer. IPT utilizes a transmitter and receiver winding to form a transformer with an air gap. The transmitter, powered by a converter, generates high-frequency currents, inducing an EMF in the receiver winding through Faraday's law of induction. These currents are transferred to the load directly or through a power system.

Figure 3 *- Inductive coupling principle [3]*

Given its reliability, efficiency, and speed, IPT finds applications in various fields, including electric vehicles. It enables wireless charging for electric cars, which can also wirelessly charge smartphones and laptops.

Figure 4 - *Wireless battery charging of electric vehicle[4]*

IPT technology, particularly in wearable and implanted medical devices (WIMD), revolutionizes healthcare by monitoring and regulating vital organs, thus extending and saving lives.

Pacemakers regulate irregular heartbeats like Arrhythmia with electrical impulses. Rechargeable and battery-less models, powered wirelessly or via RF systems, offer increased longevity and flexibility while reducing the need for surgeries.

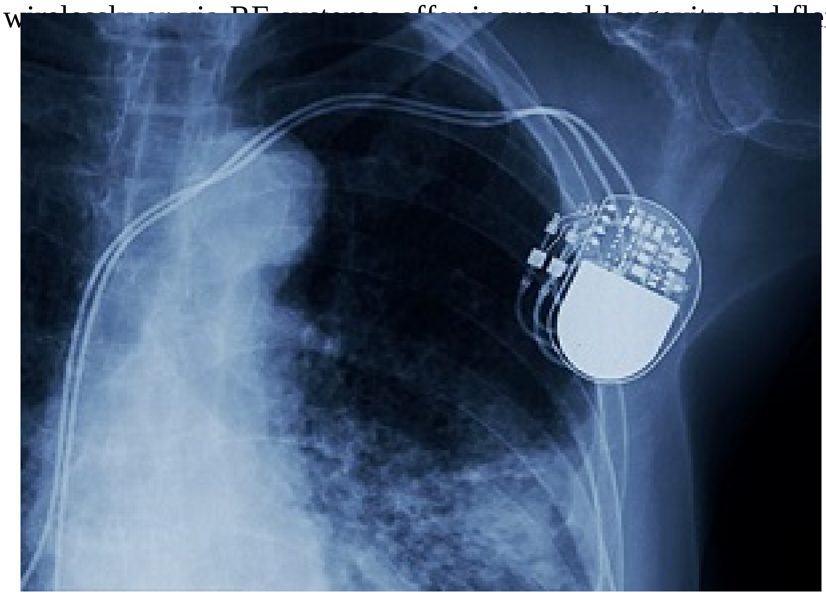

Figure 5 - *Traditional implanted pacemaker [7]*

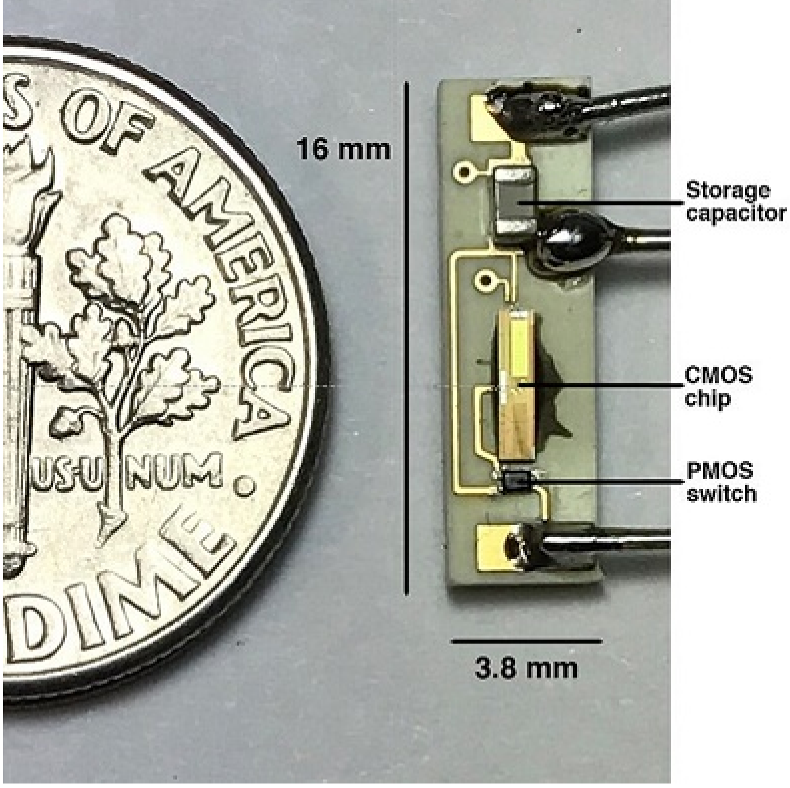

Figure 6 - *New developed pacemaker [7]*

Analysis of a WPT for pacemaker battery charging

The proposed model [6] demonstrates inductive coupling for pacemaker battery recharging. Figure 5 illustrates the composed elements, including transmitter and receiver coils, aluminum plates, and ferrite cores. Operating at a low frequency (20kHz) ensures EMF standards compliance, although it reduces wireless power transfer efficiency. To mitigate this, aluminum plates and ferrite cores are incorporated to enhance system efficiency.

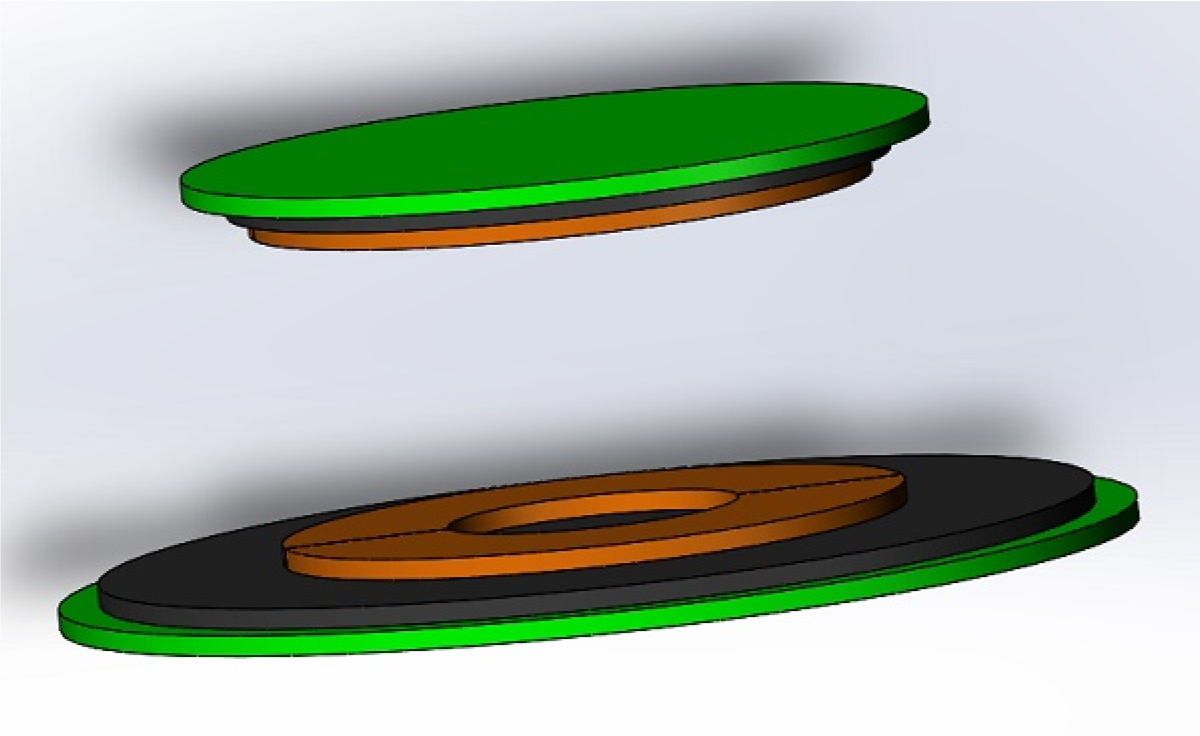

***Figure 7** - 3D CAD model of the simulated WPT system*

This article will analyze and compute the parameters of the wireless power transfer (WPT) system using EMS's AC Magnetic module coupled with an external circuit. Table 1 outlines the key simulation properties for reference.

Table 1: Main analysis properties

	Aluminum plates	**Iron cores**	**Copper**	**Transmitter and Receiver Coil**
Electrical conductivity (S/m)	3.86e+7	0	5.8e+7	-
Relative permeability	1	2400	0.99998	-
Number of turns	-	-	-	10

Pacemaker for WPT and Shielding effects

Figures 7-10 illustrate the magnetic flux density under various scenarios. Without shielding components, the flux density is symmetrical around the primary coil (Figure 7), with significant leakage into the air. Introducing aluminum plates reduces the field conducted to the receiver (Figure 8), while adding iron cores

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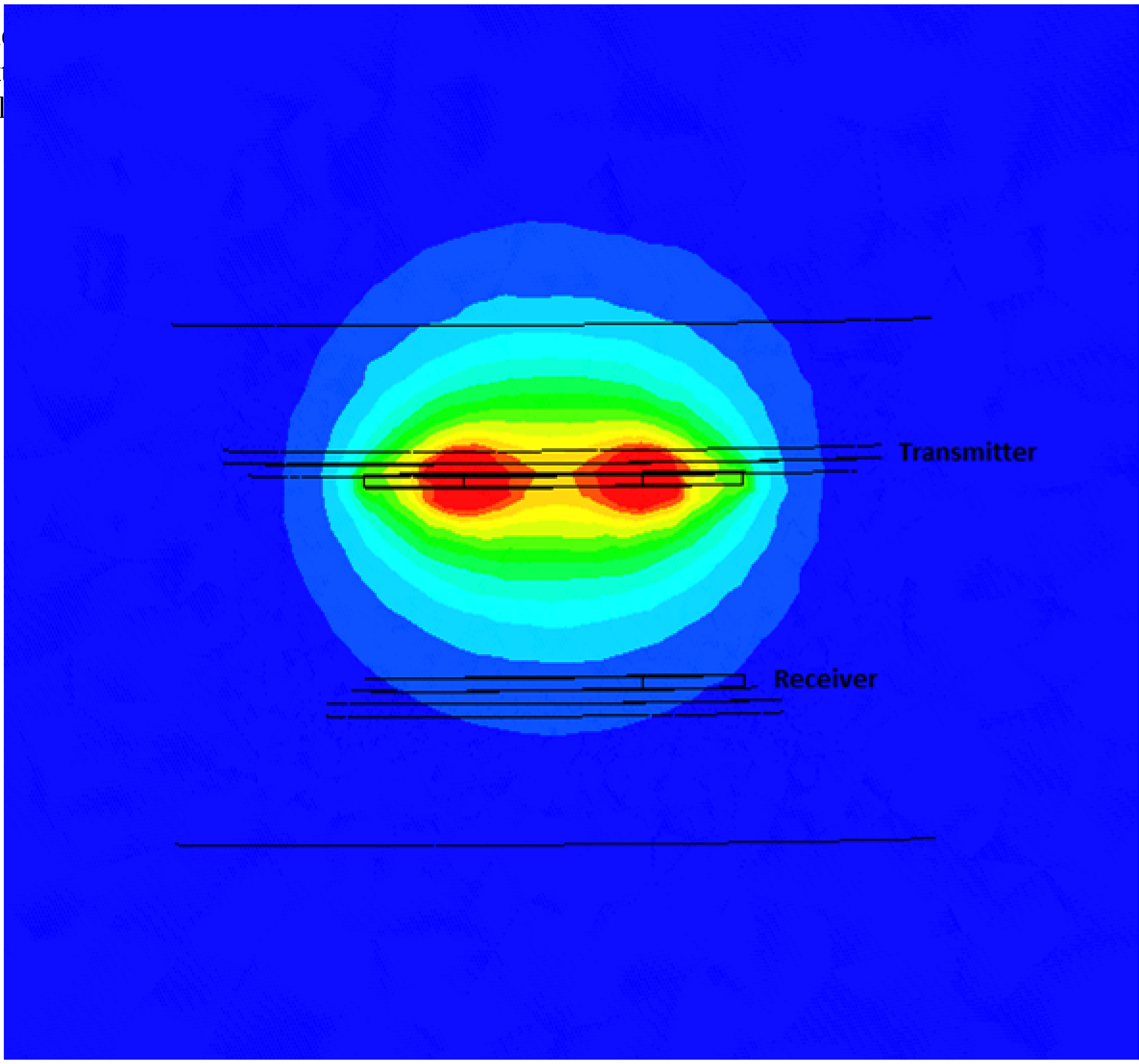

Figure 8 - *Magnetic flux density distribution-without iron cores and aluminum plates*

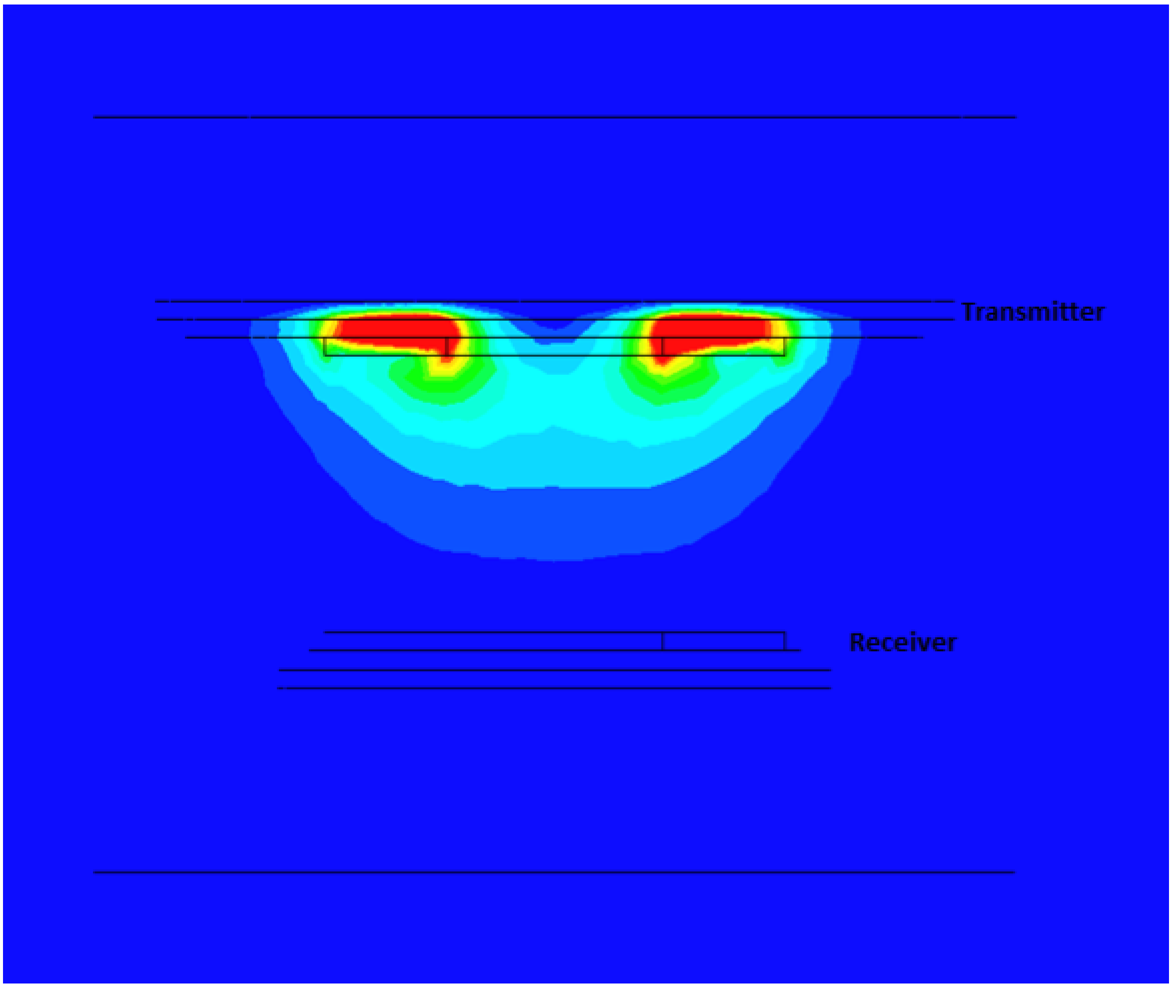

***Figure 9** - Magnetic flux density distribution- without iron cores*

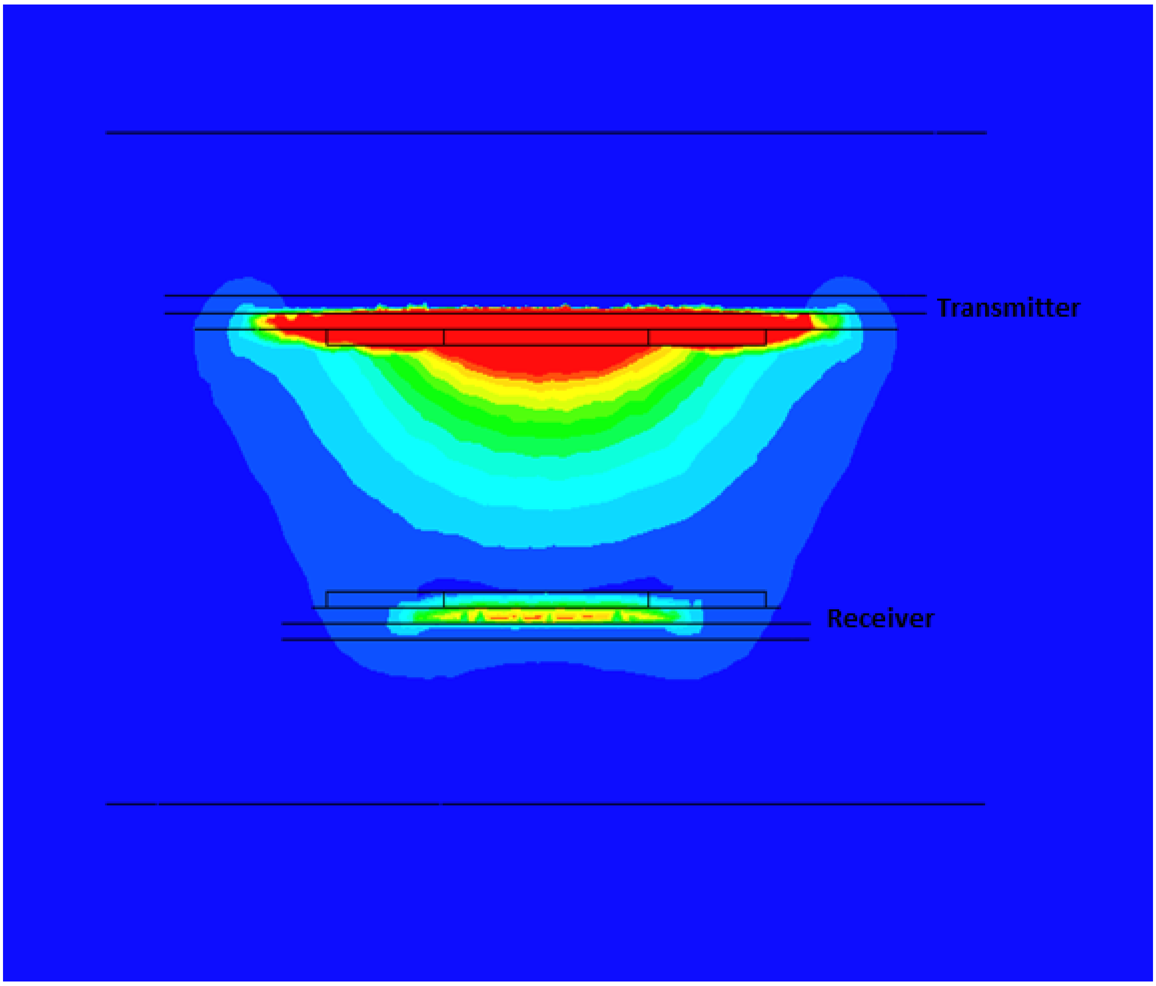

Figure 10 - *Magnetic flux density distribution-without aluminum plates*

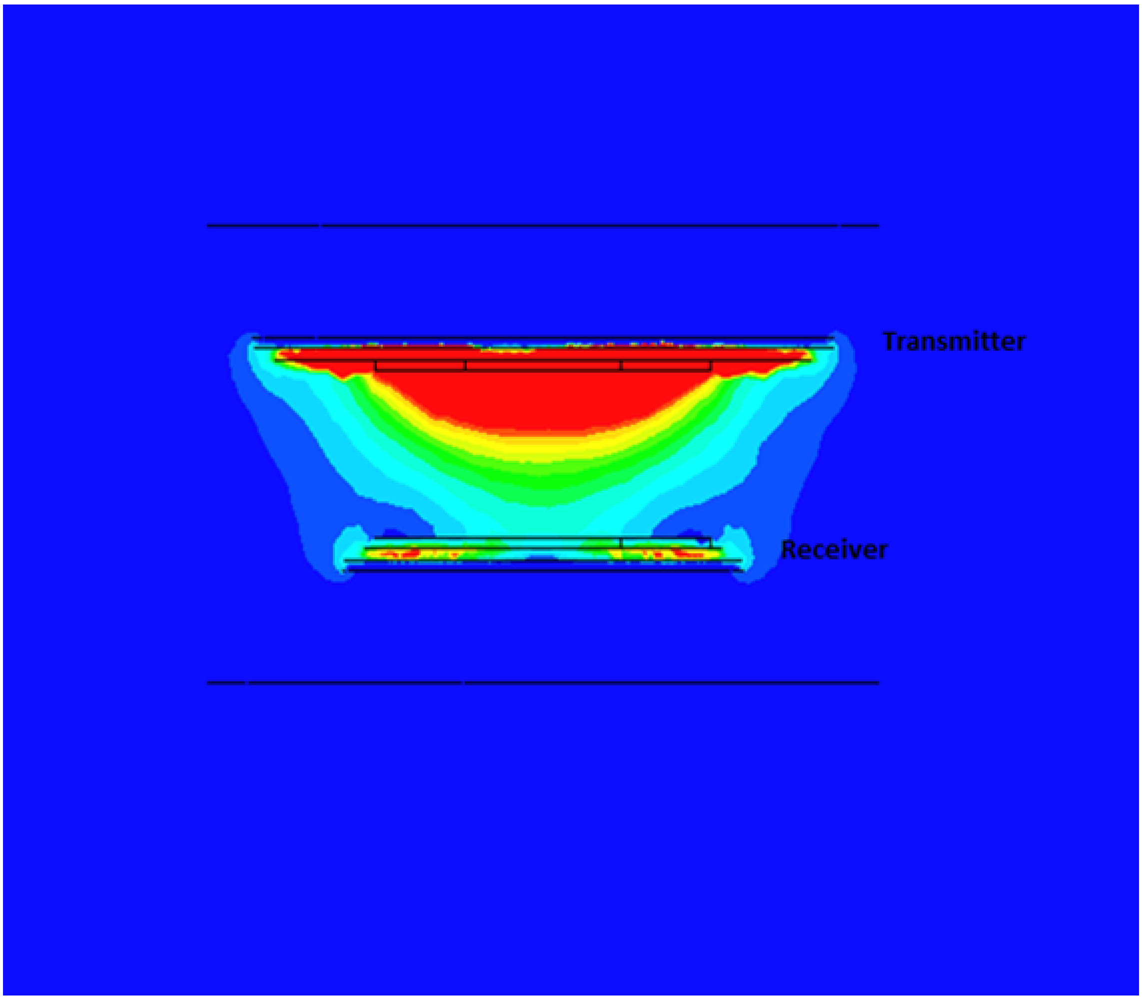

Figure 11 *- Magnetic flux density distribution- with aluminum plates and iron cores*

The WPT model's circuit parameters at a frequency of 20kHz are calculated using EMS. Table 2 provides a summary of these results.

Table 2: Results comparison of the studied WPT

	Inductance L_{Tx} (uH)	**Inductance L_{Rx} (uH)**	**Resistance R_{Tx} ($$ \mathbf{ m\Omega } $$)**	**Resistance R_{Rx} ($$ \boldsymbol{m\Omega} $$)**	**Mutual Inductance M_{TxRx} (uH)**	**Coupling Coefficient**
EMS	4.278	3.787	16.05	19.23	51.80	0.128
Ref [3]	4.1685	3.7002	18.78	21.89	52.26	0.133

Influence of the air gap distance on the coupling coefficient

The coupling coefficient formula for the WPT system is: $$ k = \frac{M}{\sqrt{L_T \times L_R}} $$ .. The efficiency of WPT increases with the coupling coefficient. Perfect coupling ($k = 1$) occurs when all flux lines of one coil cut all turns of the second coil, resulting in mutual inductance equal to the geometric mean of the two individual inductances. This leads to induced voltages satisfying the relation $$ \frac{V_1}{V_2} = \frac{N_1}{N_2} $$.
Figure 11 presents an animated visualization showcasing the magnetic flux density's response to changes in the air gap distance between the transmitter and receiver coils. A parametric AC Magnetic study vividly demonstrates the inverse relationship: as the air gap distance increases, the magnetic flux density reaching the secondary coil diminishes, and vice versa.

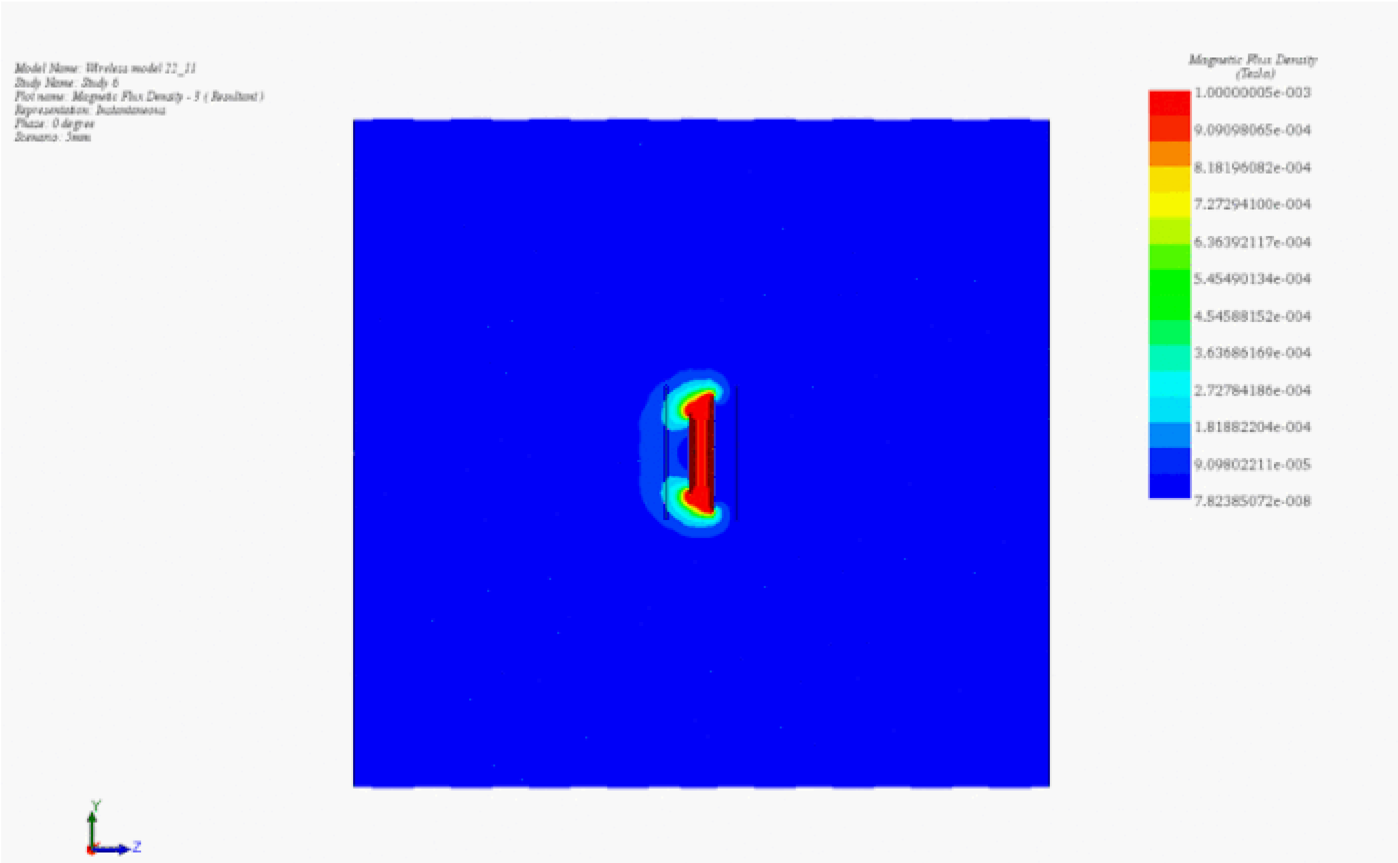

Figure 12 - *Animation of the magnetic flux density versus air gap distance*

Figures 12 and 13 display the curves depicting the mutual inductance and coupling coefficient concerning the air gap between the primary and secondary coils. In both cases, as the air gap distance increases, both parameters exhibit a decrease, indicating a weakening coupling between the coils.

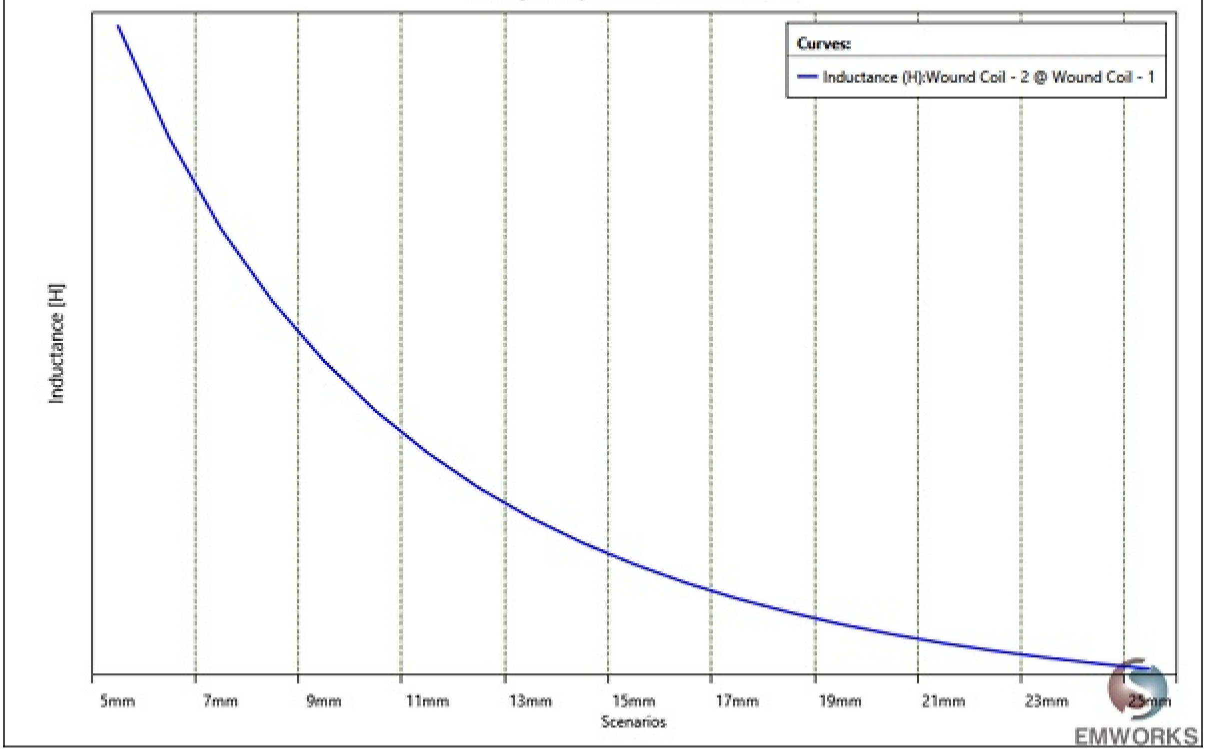

Figure 13 - Mutual inductance versus air gap distance

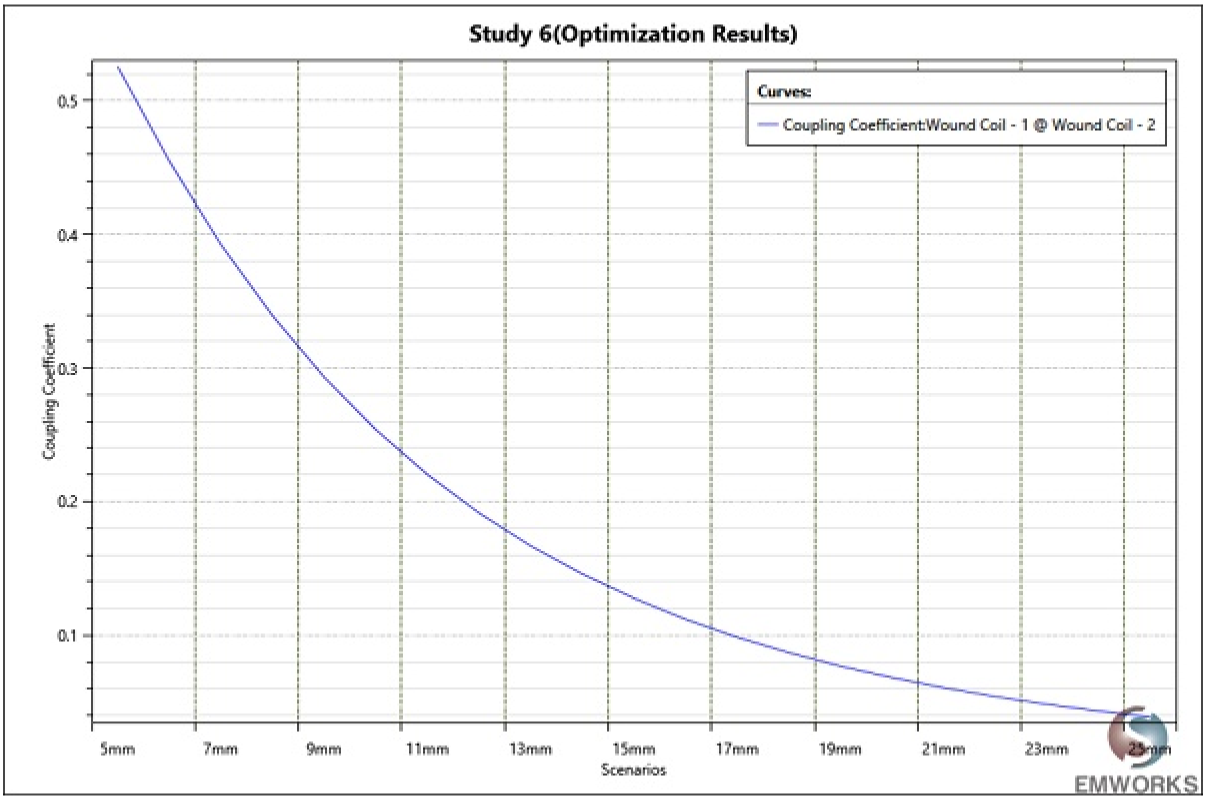

Figure 14 - Coupling coefficient versus air gap distance

Figure 14 illustrates the induced voltage in the secondary coil, mirroring the behavior of the coupling coefficie[...] the air gap wid[...] between primary

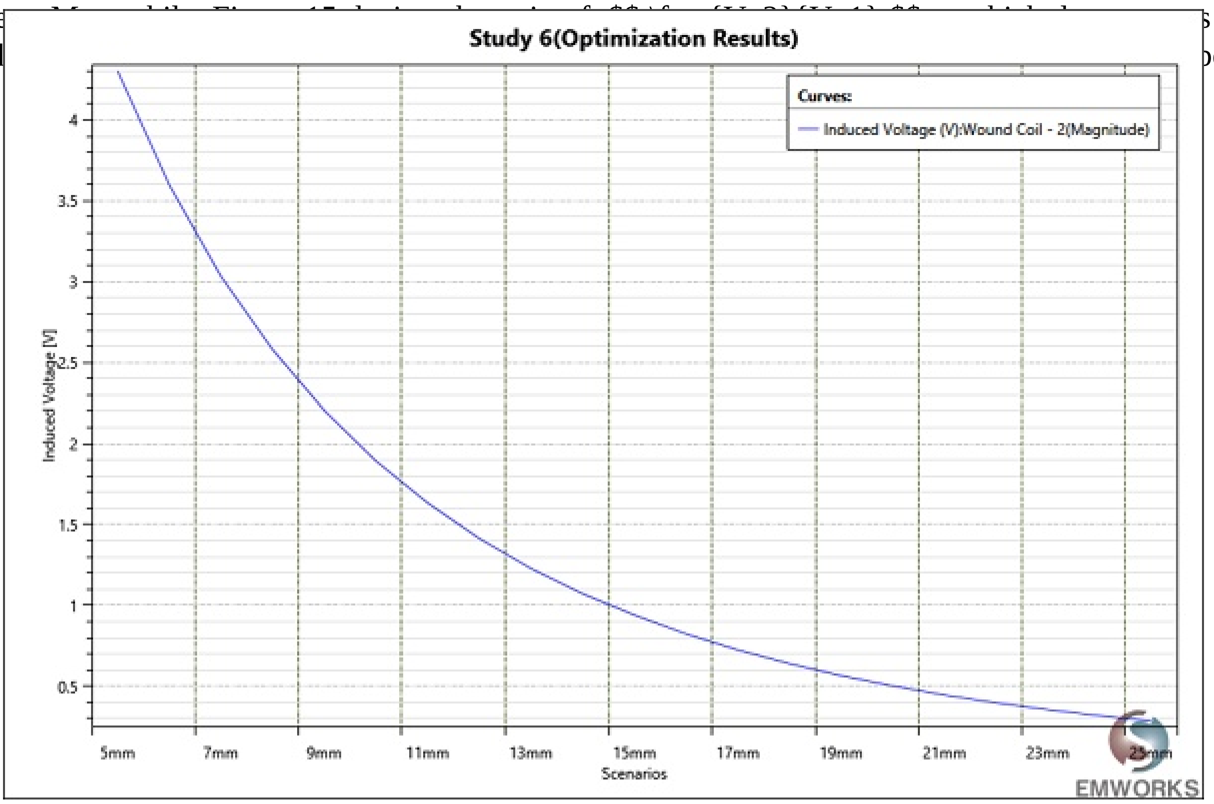

Figure 15 - *Induced voltage versus air gap distance*

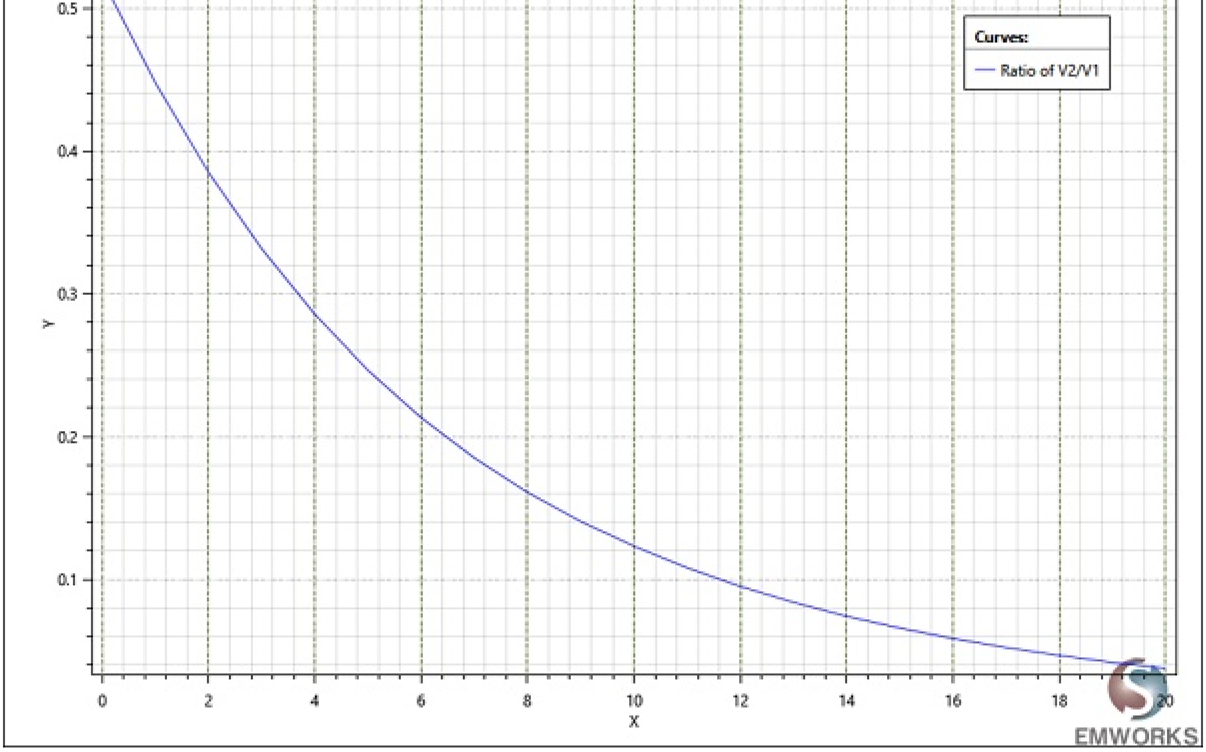

Figure 16 - Ratio of the voltages $$ \frac{V_2}{V_1} $$

WPT operating at the resonance

The WPT system achieves its peak efficiency when operating at resonance, facilitated by the addition of resonant capacitances on both primary and secondary sides. The external circuit, integrated within EMS, is depicted below. In this circuit representation, the source is ideal (R=0), while the DC resistance of the windings is internally accounted for within EMS and not explicitly modeled.
The resonant capacitance values are computed using the following formula : $$ \omega_r = \frac{1}{\sqrt{LC}} $$

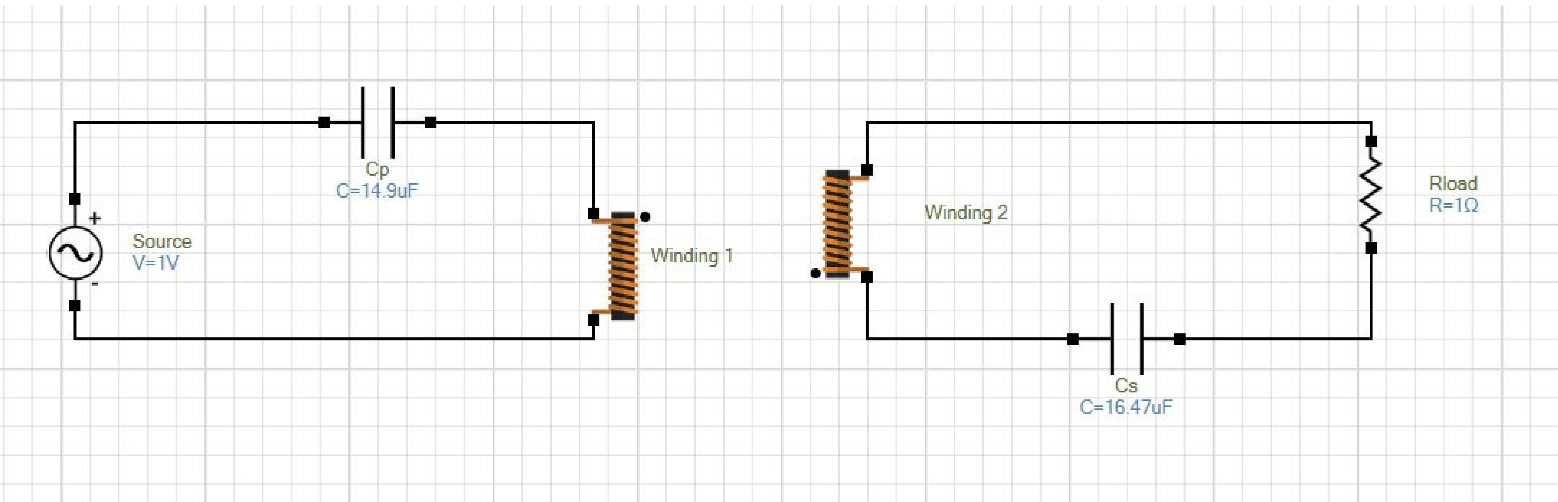

Figure 17 - *Resonant circuit modeled inside EMS for the pacemaker WPT system*

Figure 17 illustrates the variation of both transmitter and receiver currents across different operating frequencies. It's evident that the maximum current is achieved at the resonant frequency of 20kHz.

Figure 18 - *Currents in the transmitter and receiver coils versus frequency*

WPT system inside human body

In this section, we explore the scenario where a receiver is implanted within a human body, while the transmitter remains external, positioned just a few millimeters beneath the skin. Due to the body's low electrical conductivity, which increases with frequency, induced eddy currents are minimal at the system's low operating frequency. Figures 18a) and 18b) illustrate the front and right views of the meshed model, with a finer mesh applied to the aluminum components to capture any eddy currents within the skin depth. The EMS mesher adeptly follows component curvature, resulting in finer meshing in specific areas.

Figure 19 - *Meshed model: a) Front view, b) Right view*

Figures 19a) and 19b) display cross-sectional views of the magnetic flux distribution within the human body. The flux is predominantly concentrated around the receiver due to the shielding components. The maximum magnetic field strength is a few microtesla, well below the standard limit of 27 microtesla published in [11].

Figure 20 - *cross-section view of the magnetic flux density distribution; a) Front view, b) Isometric view*

Conclusion

This application note explores the innovative realm of Wireless Power Transfer (WPT), showcasing its transformative impact on technology and everyday life. It delves into the principles of Inductive Power Transfer (IPT), a key method of WPT, which utilizes a transmitter and receiver winding to form a transformer with an air gap, facilitating the wireless transmission of power across various applications, notably in electric vehicles and wearable or implanted medical devices (WIMD).

The focus on electric vehicle charging and medical devices like pacemakers illustrates IPT's versatility and its potential to revolutionize energy consumption and healthcare. The study presents a detailed analysis of a WPT system designed for pacemaker battery charging, operating at a low frequency to comply with EMF standards while optimizing system efficiency through the use of aluminum plates and ferrite cores.

Through EMS's AC Magnetic module coupled with an external circuit, the study analyzes the system's electromagnetic parameters, demonstrating how shielding components can significantly enhance efficiency and safety. The findings highlight the coupling coefficient's role in determining WPT efficiency, emphasizing the system's peak performance at resonance and its adaptability to human body constraints.

In Conclusion, the application note underscores the significance of WPT in pushing the boundaries of energy transmission and medical technology, pointing towards a future where power delivery is more seamless and integrated into our daily lives, thereby supporting the ongoing shift towards renewable energy and advanced medical care.

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