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From Nanogenerators to WPT: More Tantalizing High-Density Apps

Check out how high power density enhances the efficiency of energy-harvesting wearables and novel wireless-power-transfer systems.

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What you'll learn:

- How nanogenerators are used to harvest power.
- How inductive power-transfer systems deliver high power density.

What unique applications targeting consumers and the industry at large are leveraging highly efficient power-density designs? Read on.

Harvesting Energy with Enhanced Power-Density Nanogenerators

Believe it or not, runners will soon be able to harvest energy via wearable technology, thanks to nanotechnology developed by the University of Surrey Advanced Technology Institute (ATI) in the UK.[1,8]

When venturing out in the early morning for your daily run, you will soon be able to harvest plenty of energy for your wearable devices because of nanotechnology. Highly energy-efficient and uniquely flexible nanogenerators will be able to drive a 140X increase in power density when compared to conventional nanogenerators.

ATI researchers are betting on this development, which could lead the way for nano-devices that will be at least as efficient as most modern solar cells.

The ATI is working on new device technology that will be able to convert small amounts of mechanical energy, such as motion, into a substantially greater amount of electrical power, similar to the way an amplifier can boost sound in an electronic system. For example, a traditional nanogenerator typically produces 10 mW of power. This latest technology would be able to boost that output to more than 1,000 mW. Such a power increase will be much more suitable for energy harvesting in numerous everyday applications.

High-Power-Density Coupling Mechanism with Zero Air Gap

Wireless-power-transfer designs, which are very closely coupled, can offer highly energy-efficient transfer by employing compact receiver and transmitter coils in close proximity. This design method uses a transformer-type design that significantly increases both power density and system efficiency, leading to a reduction in overall wireless-power-transfer system losses.[5]

Such inductive-power-transfer (IPT) systems help ensure that an efficient, cost-effective, and lightweight system can be achieved. The necessary coupling between the primary and secondary coils uses the smallest amount of ferrite. What has been shown is that there's a maximum 10% difference between a finite element model of these systems and the measured results.

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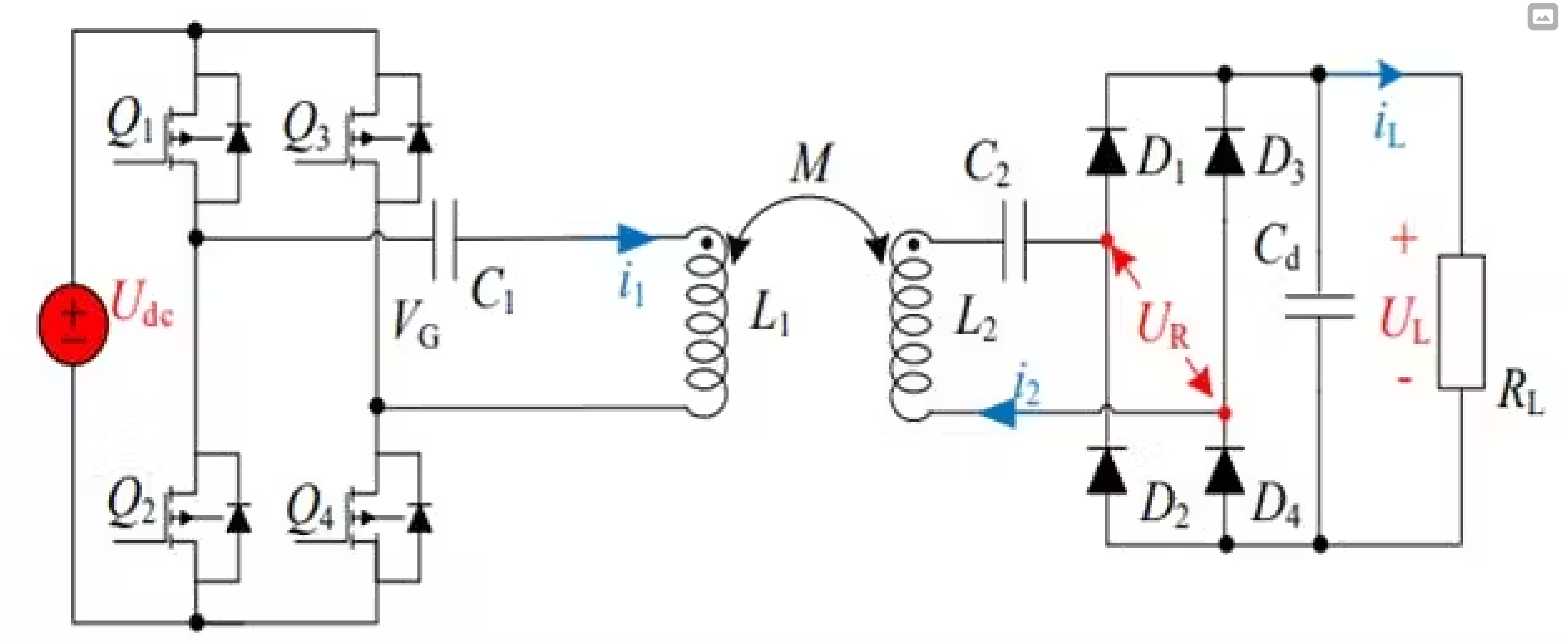
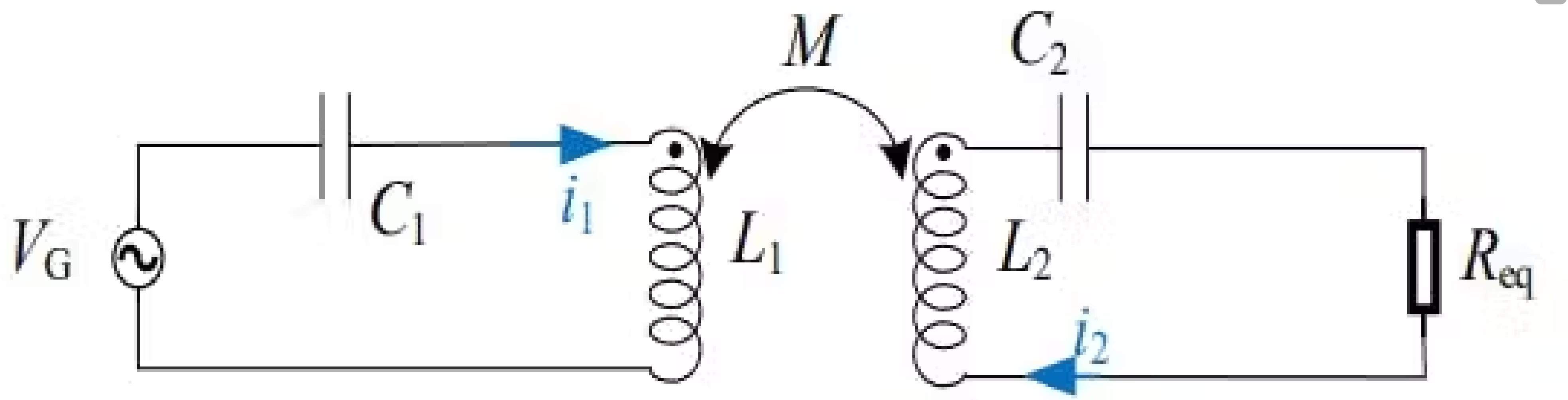
Next, we'll analyze the power density of a wireless energy-transmission system based on a series-series (SS)-type of topology *(Fig. 1)*,[5] where:

- U_{dc} is the DC input
- Q_1-Q_4 is a full-bridge inverter
- D_1-D_4 is a full-bridge rectifier
- C_1 is the primary resonant capacitance
- C_2 is the secondary resonant capacitance



1. Shown is a series-series (SS) type of wireless-power-transfer system. (Courtesy of Reference 5)

Figure 2 shows a simplified circuit.



2. This is the simplified structure of the system in Figure 1. (Courtesy of Reference 5)

Below are the system parameter relationships:

$$\begin{cases} Z_1 = j\omega L_1 + \dfrac{1}{j\omega C_2} \\ Z_2 = j\omega L_2 + \dfrac{1}{j\omega C_2} + R_{eq} \\ Z_r = \dfrac{(\omega M)^2}{Z_2} \\ Z_{in} = \dfrac{Z_1 Z_2 + R_{eq} Z_1 + (\omega M)^2}{Z_2 + R_{eq}} \end{cases}$$

Z_1 is the primary side impedance, Z_2 is the second side impedance of the system, Z_r is the reflected impedance of the secondary side to the primary side, Zin is the input impedance of the system, and R_{eq} is the equivalent load of the system.

How IPT Systems Deliver High Power Density

Electric vehicles, deep-sea intelligent equipment, and consumer electronics are some of the applications that take advantage of inductive-power-transfer systems. One example of a novel IPT system has a full range soft-switching action along with a magnetic integrated structure based on the dual-decoupling concept.

The dual-decoupling concept design often integrates a resonant inductor, within the auxiliary circuit and compensation network and into the transmitter coil, sharing a set of magnetic cores.

IPT systems with multiple resonant inductors will:

- Reduce the system’s volume.
- Improve the magnetic core utilization within the system.
- Increase the system’s power density.
- Balance the magnetic-core losses of different magnetic-core components.

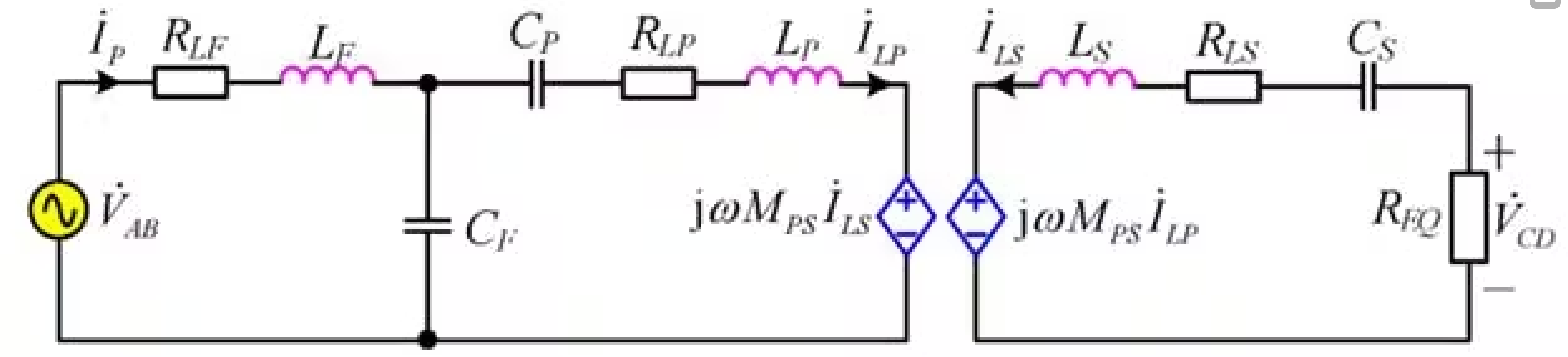
Magnetic integration technology between power transmission coils and resonant inductors is required in this case.

Designers are now able to align the center lines of two bipolar pad coils to achieve magnetic integration between the compensation inductor and the receiver coil. However, the solutions mentioned earlier will have the following limitations:

- The magnetic flux of the integrated inductor coil will diverge into the space. This will enhance the stray magnetic flux.
- Since the integrated inductor is parallel to the current direction in the power transmission coil, stacking the coils may enhance the proximity effect between the high-frequency currents.

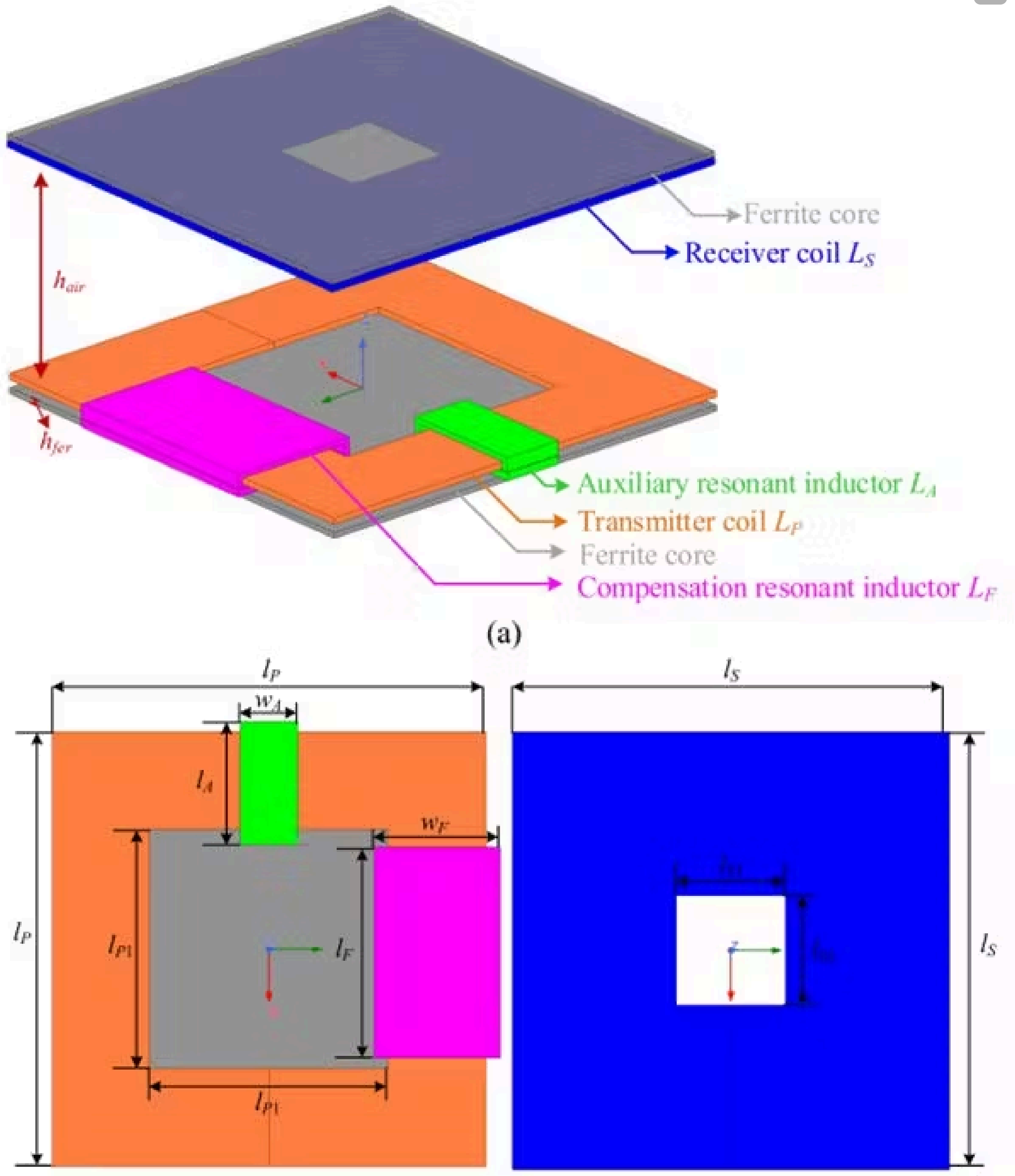
Designers must guarantee that the IPT system will be able to implement soft-switching within the entire power range, dramatically increasing the system power density in conjunction with balancing the magnetic flux density.

A proposed IPT system model *(Fig. 3)* addresses the challenges with a full-range soft-switching operation and magnetic integration, based on a dual-decoupling idea, for power-density optimization and efficiency.



3. Here's an equivalent model of the proposed IPT system. (Courtesy of Reference 9)

Figure 4 shows the proposed magnetic integration coupler structure. Both the transmitter coil and receiver coil are designed as a square structure. They're equipped with ferrite magnetic cores that can reduce magnetic resistance and improve coupling coefficient.

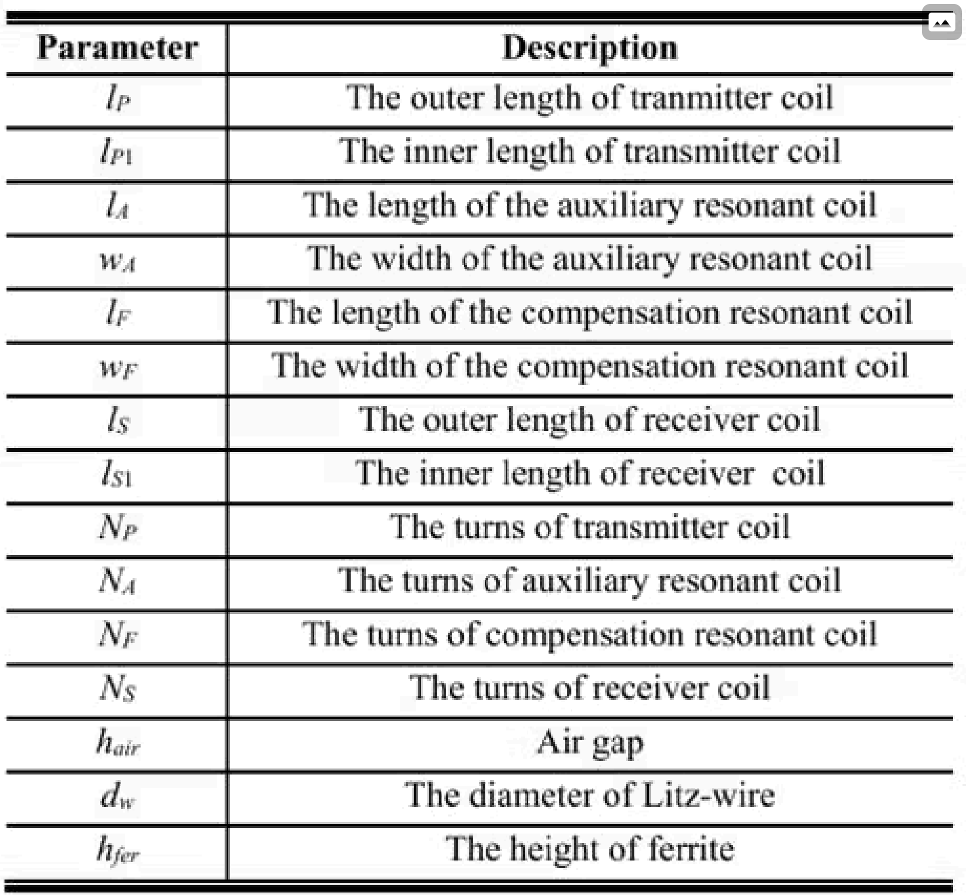
Ferrite core
Receiver coil L_S
h_{air}
h_{fer}
Auxiliary resonant inductor L_A
Transmitter coil L_P
Ferrite core
Compensation resonant inductor L_F
(a)
l_P
w_A
l_A
w_F
l_P
l_{P1}
l_F
l_{P1}
l_S
l_{S1}
l_{S1}
l_S

(b)

(c)

4. The schematic of the proposed magnetic integration coupler structure: overall view (a), transmitter coil and integrated inductor coil (b), receiver coil (c). (Courtesy of Reference 9)

The relevant parameters and their meanings are listed in *Figure 5*.



Parameter	Description
l_P	The outer length of tranmitter coil
l_{P1}	The inner length of transmitter coil
l_A	The length of the auxiliary resonant coil
w_A	The width of the auxiliary resonant coil
l_F	The length of the compensation resonant coil
w_F	The width of the compensation resonant coil
l_S	The outer length of receiver coil
l_{S1}	The inner length of receiver coil
N_P	The turns of transmitter coil
N_A	The turns of auxiliary resonant coil
N_F	The turns of compensation resonant coil
N_S	The turns of receiver coil
h_{air}	Air gap
d_w	The diameter of Litz-wire
h_{fer}	The height of ferrite

5. Parameters of the components in the proposed magnetic integration coupler structure of Figure 4. (Courtesy of Reference 9)

To provide the magnetic flux of the integrated inductor coil with a low magnetic resistance path, significantly reducing the magnetic potential applied to the integrated inductor coil, designers decided to cover the entire coil with ferrite magnetic cores. Both integrated resonant inductor coils have adopted the solenoid structure.

The two resonant inductors are able to achieve decoupling with the transmitter coil. The auxiliary resonant inductor and the compensation resonant inductor are also in a relatively decoupled state. Therefore, only the coupling between the main coils (LP and LS) will need to be considered. Moreover, the additional active auxiliary network doesn't affect the power transmission of the main coils and may now be separately considered, thus simplifying the complexity of this design.

Future research will focus on optimizing the magnetic integrated structure, which will be able to further improve the power density and migration adaptability of the system.

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