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# A Literature Review of Wireless Data and Power Transmission Systems

Ivan Diaz[1*], Juan Pablo Pallo[2], Julio Cuji[3], and Carlos Gordón[4]

*Abstract* — **This paper presents a review of Wireless Power Transfer (WPT) models, classified based on various studies from scientific repositories. The aim is to create a comprehensive, detailed, and up-to-date database that identifies optimal methods and components for WPT. The collected data are organized in tables, highlighting the key characteristics of each WPT method: Inductive, Capacitive, Microwave, Laser, Ultrasonic, and RF. This information can be used to guide and inform further research aimed at improving WPT system designs. The methodology is divided into five stages: Literature review, classification of WPT methods, selection of main attributes, analysis of results, and documentation. Finally, a webpage was designed to allow researchers and those interested in WPT to access the information quickly.**

*Keywords:* **Component; Wireless power and data transmission; optical transmission systems; IoT; Inductive Coupling.**

*Resumen* — **En este documento se revisan los modelos de transferencia inalámbrica de energía (WPT), partiendo desde una clasificación obtenida con base en diferentes artículos publicados en repositorios científicos. El objetivo es desarrollar una base de datos nueva, completa, detallada y actualizada de información, la cual nos provee de los métodos y componentes óptimos para los modelos WPT, tabular los datos y determinar las mejores características en función de WPT implementado: Inductivo, Capacitivo, Microondas, láser, ultrasónico, RF, lo cual podrá ser considerado para una mayor investigación en busca de mejorar los diseños de Sistemas WPT. La metodología se divide en cinco etapas: revisión literaria, clasificación de métodos WPT, selección de principales atributos, análisis de resultados y documentación. Finalmente, con la información recopilada se diseñó una página web para que diferentes investigadores e interesados en la WPT puedan consultar de forma rápida.**

*Palabras Clave:* **Componentes; Transmisión inalámbrica de energía y datos; Sistemas de transmisión ópticos; IoT; Acoplamiento Inductivo.**

## I. INTRODUCTION

WIRELESS power transfer (WPT), also known as wireless energy transfer (WET) [1], cordless power transfer, or wireless power charging [2], has a wide range of applications, including charging biomedical implant systems [3], satellites [4], electric vehicles (EV) [5], unmanned aerial vehicles (UAV) [6], consumer electronics [7], monitoring geological hazards [8], underwater electric devices (UWPT) [9], wireless sensor networks (WSN) [10], battery less sensors [11], the Internet of Things (IoT) [12], [13] its industrial (IIoT) [14] – [16] and underwater (IoUT) [17] variations. These fields aim for independence from process interruptions caused by the need to replace or recharge batteries, with active energy harvesting (EH) through WPT being a viable alternative [14].

There are different WPT methods, each used according to its characteristics in the mentioned applications, with appropriate topologies and techniques. The terminology and abbreviations for these methods vary across studies, but the most common classification is based on transmission distance, dividing them into far-field (FF-WPT) and near-field (NF-WPT) methods, which are also referred to in some sources as radiative (RWPT) and non-radiative (NRWPT) methods, respectively [3].

The objective of this work is to answer the following question: Which methods, topologies, and techniques exhibit the best characteristics for wireless power transmission? Through an analysis of the results from various WPT systems, this study aims to determine the strategies with the best performance for different methods. The typical architecture of a WPT system generally includes, on the transmitter side: a power supply, rectifier, inverter, amplifiers, and a network compensation as shown in Fig. 1(a). On the receiver side, the system includes a receiving coil or antenna, compensation network, rectifier, current converter, and load, as shown in Fig. 1(b). Depending on the design, these components may be integrated in various combinations of architectural phases [3].

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This work was developed with equally contribution of all authors.

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The information gathered in this study will be detailed and presented through a webpage designed to compile and update scientific data in a fast, accessible, and comprehensive manner.

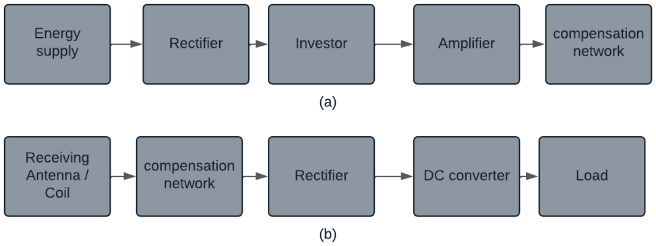


**Fig. 1.** Typical architecture of a WPT system, (a) transmitter, (b) receiver

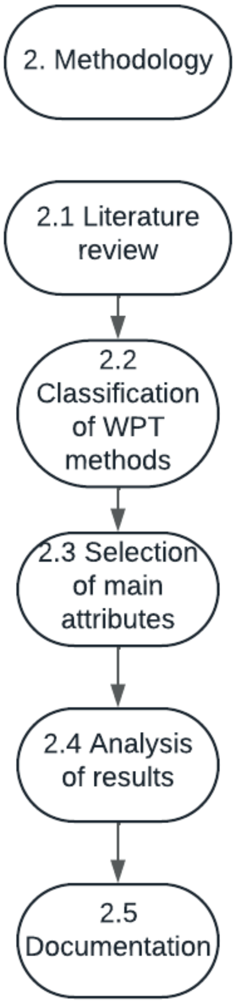


**Fig. 2.** Steps of the methodology

The present paper is organized as follows: In Section II, the methodology used in this research is described, which consists of five stages. In Stage 2.1, a literature review is conducted, where 25 scientific articles are analyzed to investigate the characteristics of various WPT methods. Stage 2.2 involves classifying the WPT methods, and Stage 2.3 focuses on selecting the main attributes of those methods. Stage 2.4 analyzes the results obtained from the reviewed systems, and finally, Stage 2.5 documents the findings and creates a webpage, as shown in Fig. 2. Section III presents discussions of the main contributions of the selected systems to their respective methods. Lastly, Section IV presents the conclusions drawn from the study.

## II. METHODOLOGY

For the articles reviewed in this study, preference was given to publications describing relatively long distances and high efficiency, with publication dates after 2019 to ensure the information's relevance. As much as possible, we sought publications that included applications related to wireless sensor networks or the Internet of Things (IoT). Although not all selected articles met all these criteria, 25 notable methods were identified, representing significant contrasts between different WPT technologies. Based on the criteria outlined in scientific documents and various sources cited, the methods are classified by how they transfer energy, and independently of their methods, they are also classified by their data transmission approach.

### *A. Literature review*

An exhaustive investigation was conducted across institutional repositories and indexed journals, selecting studies based on their power transfer efficiency (PTE), transmission distance, and power output. The systems examined describe design, topology, or circuit characteristics to determine an optimal WPT model. Below is a tabulated summary of the presented systems:

- S1: Power control method for improving efficiency of laser-based wireless power transmission system.
- S2: Laser wireless power transfer and thermal regulation method driven by transient laser grating.
- S3: Pulsed Laser Diode Based Wireless Power Transmission Application: Determination of Voltage Amplitude, Frequency, and Duty Cycle.
- S4: 9295626 wireless power transmission based on microwave beam.
- S5: A long-distance high-power microwave wireless power transmission system based on asymmetrical resonant magnetron and cyclotron-wave rectifier.
- S6: A Multimodal Modulation Scheme for Electric Vehicles' Wireless Power Transfer Systems, Based on Secondary Impedance.
- S7: A Selective, Tracking, and Power Adaptive Far-Field Wireless Power Transfer System.
- S8: A Microwave Power Transmission System Using Sequential Phase Ring Antenna and Inverted Class F Rectenna.
- S9: An Efficient Broadband Slotted Rectenna for Wireless Power Transfer at LTE Band.
- S10: Auto-Resonant Tuning for Capacitive Power and Data Telemetry Using Flexible Patches.
- S11: Compact Rectennas for Ultra-Low-Power Wireless Transmission Applications.
- S12: Compact Near Field Wireless Energy Transfer Systems Using Defected Ground Structures.
- S13: Dynamic Wireless Power Transfer for Cost Effective Wireless Sensor Networks Using Frequency-Scanned Beaming.

- S14: Efficient Rectifier for Wireless Power Transmission Systems.
- S15: Cylindrical Transmitting Coil for Two-Dimensional Omnidirectional Wireless Power Transfer.
- S16: Experiments and Modeling of 5.8GHz Microwave Wireless Power Transfer with Multiple Antennas.
- S17: Resistive Matching using an AC Boost Converter for Efficient Ultrasonic Wireless Power Transfer.
- S18: An Open-loop Double-Carrier Simultaneous Wireless Power and Data Transfer System.
- S19: Underwater Ultrasonic Wireless Power Transfer: A Battery-Less Platform for the Internet of Underwater Things.
- S20: Analysis and Design of a Simultaneous Wireless Power and Data Transfer System Featuring High Data Rate and Signal-to-noise Ratio.
- S21: A Wireless Power and Information Simultaneous Transfer Technology Based on 2FSK Modulation Using the Dual Bands of Series-Parallel Combined Resonant Circuit.
- S22: A Simultaneous Wireless Power and Data Transmission Method for Multi-Output WPT Systems: Analysis, Design, and Experimental Verification.
- S23: A dual-resonance matching circuit for magnetic resonance wireless power transfer Systems.
- S24: Analysis and Design of Inductive and Capacitive Hybrid Wireless Power Transfer System for Railway Applications.
- S25: Modeling of Capacitive Resonant Wireless Power and Data Transfer to Deep Biomedical Implants.

When analyzing each system, we proceed to explain its content and tabulate the data presented by each one:

S1: This LPT system comprises an LD, photovoltaic cell, array, laser power supply, photovoltaic energy converter, current regulator, and a step-up converter. It operates at a wavelength of 808 nm, with a maximum output of 1 W and PTE of 9.55 % at 5 m. A closed-loop power control method adjusts the LD's duty cycle, dynamically regulating power and PTE. The system uses a TMS320F28335 DSP and nRF2401 wireless communication module [18].

S2: This study introduces a laser-based BeE-LWPT system using the Seebeck effect to periodically heat a thermoelectric element with an expanded beam laser. Operating at 375 nm with a copper plate heater, the system achieves a PTE of 8.48 %, transmitting 5 W with a beam radius of 10 mm [19].

S3: Utilizing an LD with a 650 nm wavelength, this system transmits 200.2 mW over 50 cm, applying 3.41 W to the LD with a 10 % duty cycle and 6.2 V, resulting in a PTE of 7.76 % The system relies on a TMS320F28379D DSP and MOSFET for PWM signal control [20].

S4: This WPT system employs a 2.45 GHz microwave beam and 1.0 KW power, featuring a high-power magnetron, a three-stub tuner, variable attenuator, and a 36.5 dBi parabolic antenna for transmission. At 50 m, the system transmits 2.3 KW and receives 1.02 KW, achieving a PTE of 44.3 % [21].

S5: The MPT system described uses an asymmetric resonant magnetron and cyclotron wave rectifier, transmitting up to 400 KW through a highly directive antenna. Receiving antennas capture microwave power, achieving 8.5 KW with a CC-CC PTE of 1 % at 2.45 GHz over 10 Km [22].

S6: Parameter evaluation for WPT-powered electric vehicles (EV-WPT), this system utilizes mutual inductance (M) for multimode modulation and duty cycle regulation. With a power output of 10 KW and PTE exceeding 85 %, the system comprises a PFC, DC-DC converter, LCC-LCC compensation, and a transmitter coil [23].

S7: This RFWPT system integrates with passive wireless sensor networks (PWSN), dynamically adjusting the radiation pattern with an IQ modulator, DAC, and Schottky diodes. Operating at 3.6 GHz, the system achieves a power conversion efficiency of 38.1 % with data transmission at 19.2 Kbps up to 3.7 m [12].

S8: The system presented utilizes an inverted class-F rectifier (F1) with a left-handed circular polarization (LHCP) antenna at 5.8 GHz, achieving a maximum PTE of 8.8 % for multiple devices at 60 mm with 1 W transmitted [24].

S9: The slotted rectenna system, featuring a bandwidth of 2.0 to 3.1 GHz, achieves a peak efficiency of 70 % at 2.5 GHz with a 5 dBm input power [25].

S10: This article presents a resonant C-WPDT, with carrier frequency between 0.1 and 3.5 MHz up to 170 Kbps for biomedical implants at 8 mm. The transmitter consists of a power management circuit, a MSP430F5528 microcontroller, a Bluetooth transceiver and a class D controller. The receiver uses a rectifier, a power management circuit, a data decoder, a microcontroller and an electrical stimulator, flexible, conformable and biocompatible patches, reaching a power of 150 mW and an efficiency of 54 % in skin of 1.5 to 2 mm thickness [26].

S11: The compact rectenna design for 868 MHz/915 MHz WPT is presented, with a broadband planar dipole antenna and a half-wave rectifier using HSMS2850 Schottky diodes or transistors. The low-profile rectenna harvests 545 mW at 1.2 m, with an efficiency greater than 25 % for RF power densities from 0.25 µW/cm² [27].

S12: A dual-band WPDT system operating at 433 MHz and 900 MHz is proposed, using circular DGS and Rogers RO4003 dielectric material. At a distance of 15 mm between transmitter and receiver, it achieves efficiencies of 40.9 % and 49.2 % at 440 MHz and 918 MHz, respectively [28].

S13: This frequency-scanning WPT design for wireless sensor networks (WSN) includes a 5 × 5 sensor grid and a directional waveguide antenna, which scans 1 W output RF power between 2.4 GHz and 2.5 GHz to power an IEEE 802.15.4-based WSN with 25 nodes spread over a 1.2 m × 1.2 m area, utilizing its 16 channels in the 2.4 GHz band for a range of 1.5 meters [29].

S14: Describes a full-bridge rectifier and receiving antenna array for WPT, a high-power transmitter, achieving efficiencies of 86 % and 75 % for RF-to-DC rectification efficiency at 27 dBm between 40 cm and 60 cm at 1.7 GHz and 2.4 GHz, respectively [30].

S15: The system features a cylindrical transmitter coil design, two coaxial helical coils powered by a single supply, an EF2 class inverter, and a full-bridge rectifier. It achieves a transfer efficiency of 72.4 % at 6.78 MHz and 13 W output power at a distance of 10 cm from the center. Energy is transferred through magnetic coupling from the transmitter to the receiver coil, with conversion via the rectifier, without requiring active phase or amplitude control [31].

S16: The multi-antenna EM wave WPT system utilizes a 16-way phased array multi-board transmitter, which is combined to form a 64-way system, and a receiver with a 16-way phased array at 5.8 GHz. It enables phase control and on/off switching, with each RF path incorporating an RF switch (QPC6014), phase shifter (FIMC1133LP5E), and shift register (SN74FIC595B). This system achieves 16 % efficiency at 1 m, controlled via LabVIEW software [32].

S17: A design is presented that combines a HSMS282X piezoelectric receiver and a boost converter circuit, transforming the AC voltage into a pulse-width modulated square wave voltage. The PZT4 piezoelectric receiver has a maximum efficiency of 74 % at 1 mW at a resonance frequency of 0.99 MHz [33].

S18: A 50 Kbps Inductive Link SWPDT system, hollow spiral coils made of Litz wire are wound, with a conventional Class E power amplifier, based on LCC compensation with double carrier and open circuit, double-sided and parallel injection/extraction of data transmission, its switching allows varying resonance frequencies. It transmits 44 mW into 750 Ω resistive loads at carrier frequencies of 1.93 MHz and 1.44 MHz, with efficiencies of 38.3 % and 41.3 % [34].

S19: A rechargeable underwater sensor node wirelessly powered by ultrasonic waves restores 1 W of power at 1 meter in 5 minutes, using a piezoelectric composite beam and a Teensy 3.6 board for communication. Its PCB-mounted structure includes the operational amplifier AD826, the mixer AD633, and the preamplifier AD8338. It is designed to transport energy to a remote underwater modem, utilizing supercapacitors to replace traditional or rechargeable batteries, with an efficiency of 4 % [35].

S20: The multi-output SWPDT system utilizes a double-sided LCC compensation topology, injection/extraction transformers, resonant capacitors, and FSK modulation controllers. It operates at 85 KHz for power and 1.5/16.5 MHz for data, achieving 90.5 % efficiency at 290.1 W and a data rate of 150 kbps over distances ranging from 47 to 267 mm [36].

S21: The SPRC-2FSK-WPIT series-parallel resonant circuit, which uses dual SPRC resonant bands, achieved transmission speeds of up to 20 kbps and efficiencies exceeding 85 % at a 50 mm distance. The prototype operates at 6 W and 351 KHz [37].

S22: The WPDT multi-output system employs two unipolar coils with ferrite cores and an aluminum plate, transferring data with superimposed bipolar coils. It achieves 180 W transfer with 90 % efficiency and a data rate of 19.2 Kbps at a 20 mm distance and 6 MHz [38].

S23: A dual-resonance matching circuit for magnetic resonance WPT simultaneously transmits data to a single receiver. Operating at two frequencies, 1.7 MHz and 6.87 MHz, it powers a 2 W LED while transmitting 100 Kbps PRBS data, with optimal distances of 1.1 cm and 2.8 cm, respectively [39].

S24: A hybrid inductive and capacitive system, combining IPT with SS compensation and CPT with double-sided LC compensation, operates at 1 MHz with an input power of 745 W and an output of 653 W at 87.7 % efficiency. The system functions over a distance of 20 mm between the plates [40].

S25: A resonant capacitive coupling (RCC) WPT system for brain implants achieves 24.2 % efficiency for capacitive coupling and 42.21 % for resonant capacitive coupling at 25 mm. It uses a class-E power amplifier for power generation, transmission via capacitive plates, resonance, and data modulation via ASK using transistors such as the BC547. It operates at 6.78 MHz with 5 W power, as measured by a Keysight dual-channel DSO. It integrates the ThingSpeak IoT platform with the SP-12E Development KG164 controller [41].

A comparative summary of PTE, output power, frequency - Wavelength and distance for these systems can be seen in Table I.

### *B. Classification of methods*

*1) WPT:* The different sub-types of WPT methods are summarized in Fig. 3.

*a) Far-Field WPT (FF-WPT):* These methods facilitate extended transmission distances, with frequencies substantially higher than antenna size, leveraging electromagnetic waves [3]. They are predominantly applied in low-power devices, wireless sensor networks (WSN) [29], and in IoT and UAV applications [6].

- Electromagnetic propagation [4] or Radio Frequency (RF): This method uses radio frequency emitted from an antenna [1]. Its mechanism includes an antenna, low-pass filter, diode rectifier, output filter, compensation network, voltage multiplier, and capacitor [42]. Specific permissions are required for different uses [1], [43].
- Microwaves (MPT) [4]: This method requires a microwave generator, with microwaves passing through a waveguide and being radiated from the transmitting antenna towards the collection region. The receiver employs a rectenna [10], [11] to convert the microwave signal into DC power and then to the load [5]. Antennas can include dipole, patch, or horn types, and efficiency depends on the radiation pattern of the mobile antenna [44]. The microstrip line technique is based on the use of symmetric and asymmetric microstrip line structures to efficiently transfer energy [45].
- Electrostatic radiation [9]: This category is divided into Laser-based WPT (LPT) and Ultrasound-based WPT (USWPT) [9].
    - ▫ LPT**:** Also known as photoelectric WPT [4], optical WPT (OWPT) [35], or light-based WPT [9]. The transmitter utilizes a laser diode (LD) to generate a laser beam from an electric power source, passing through a collimating lens to the receiver, where it is converted back into electrical energy by a photovoltaic cell (PV) [20]. The power, efficiency, and stability of the system depend on the impedance of the photovoltaic cell [46]. This method is considered highly dangerous for humans and the environment, and is thus used in controlled environments [2].
    - ▫ USWPT: This method uses acoustic waves capable of propagating through water, air, or metal [33]. Its structure consists of a power amplifier that converts the DC signal into ultrasonic waves and transmits energy through a piezoelectric transducer (PZT) that converts electrical energy into ultrasound and vice

versa, using a full-wave rectifier to collect the energy [9]. The receiver includes a PZT, low-pass filter, matching network, rectifier, and load. Applications include UWPT [9] and medical ultrasonic capacitive parametric transducers [47].

  - Some texts consider satellite-based solar power systems (SPS) as the largest far-field WPT application, using giant solar panels [48]. However, in practice, it is more of an energy harvesting system for retransmission via another WPT method.

*b) Near-Field WPT (NF-WPT):* NF-WPT systems rely on magnetic or electric fields, offering higher efficiency at short-range distances [4].

- Capacitive WPT (CPT) [49]: Also known as electric coupling WPT (ECWPT) [9] energy is transferred via an electric field through capacitive coupling between the transmitter and receiver, limited to very short distances, such as medical implants [2]. This method appears to be unaffected by temperature in materials such as concrete [50]. Its structure is practically the same as [2].

TABLE I
TYPE, PTE, OUTPUT POWER, FREQUENCIES AND MAXIMUM DISTANCES ACHIEVED BY THE INVESTIGATED SYSTEMS

| System | WPT Type | PTE (%) | Output Power (W) | Frequency (MHz) | Transmission Distance (m) |
|---|---|---|---|---|---|
| S1 | LPT | 9.55 | 1 | 371000000 | 5 |
| S2 | LPT | 8.48 | 5 | 799900000 | - |
| S3 | LPT | 7.76 | 0.2002 | 331500000 | 0.5 |
| S4 | MPT | 44.3 | 1020 | 2450 | 50 |
| S5 | MPT | 1 | 8500 | 2450 | 10000 |
| S6 | IPT | 85 | 8500 | - | 0.05 |
| S7 | RF | - | 0.0019953 | 5800 | 3.9 |
| S8 | MPT | 8.8 | 0.0088 | 5600 | 0.06 |
| S9 | RF | 70 | - | 2000 - 3100 | - |
| S10 | CPT | 54 | 0.150 | 0.1 - 3.5 | 0.008 |
| S11 | RF | 25 | - | 868 - 915 | 1.2 |
| S12 | MPT | 40.9 - 49.2 | - | 433 - 900 | 0.015 |
| S13 | RF | - | 1 | 2400 - 2500 | 1.5 |
| S14 | RF | 86 | 0.5 | 1700 - 2400 | 0.4 |
| S15 | IPT | 72.4 | 13 | 6.78 | 0.1 |
| S16 | MPT | 16 | - | 5800 | 1 |
| S17 | USWPT | 74 | 0.001 | 0.99 | - |
| S18 | IPT | 38.3 - 41.3 | 0.044 | 1.93 - 1.44 | - |
| S19 | USWPT | 2 | 1 | 0.050 | 1 |
| S20 | IPT | 90.5 | 290.1 | 0.085 | 0.047 - 0.267 |
| S21 | IPT | 85 | 6 | 0.351 | 0.05 |
| S22 | IPT | 90 | 180 | 6 | 0.02 |
| S23 | IPT | - | 2 | 1.7 - 6.87 | 0.011 - 0.028 |
| S24 | HWPT | 87.7 | 653 | 1 | 0.02 |
| S25 | CPT | 24.2 - 42.21 | 5 | 6.78 | 0.025 |

- Inductive WPT (IPT) [49]: Energy is transferred using a magnetic field. It is based on the principles of Ampere's and Faraday's laws [2]; and is subdivided based on the transfer technique:
  - Coupled WPT (CWPT) [2]: Also known as inductive coupling WPT (IWPT) [1], ICPT or inductive coupled wireless power transfer (IWPT) [2], this method transfers energy via a magnetic field between closely coupled coils [2], [51]. It requires coil calibration [1], and its coefficient and efficiency depend on the number of turns, shape, and size of the coil [48].
  - Magnetic Coupled Resonance WPT (MCRWPT) [2], also referred to as Resonant Inductive Power Transfer (RIPT) [1] or MWPT, uses magnetic resonance coils operating at the same resonant frequency [1]. Its efficiency decreases with distance, and its range is proportional to its quality factor [52]. As this electrical system operates in resonance, it requires reactive or compensation networks on both sides, typically involving at least one capacitor. It is powered by a time-varying current, creating a dynamic magnetic field around the structure. When a receiver or secondary coil manages to concatenate part of the flux, an induced voltage is observed [5]. It employs large coils with frequencies ranging from kilohertz to tens of megahertz, over distances of several meters [11].

*c) Hybrid Wireless Power Transfer (HWPT):* In cases where various methods are combined, the system is classified as HWPT [40], and methods are sought to continuously frequency and impedance match hybrid adjustable WPT system (CFI-MHA-WPT) [53].

*2) Wireless Power and Data Transfer Systems:* In many cases, in addition to power transfer, there is a need to monitor output variables [15] or specific operational parameters, such as in Wireless Body Area Network (WBAN) [54] networks or IoT technologies [55], This enables efficient powering of low-power devices over various distances [56].

Such systems are known as Wireless Power and Information/Data Transfer (WPIT/WPDT) systems [15]. Each WPT method mentioned has a corresponding WPDT system, including hybrid systems [57] [58], the classification of these systems is determined by the method of data transmission, with the types of WPDT shown in Fig. 4.

*a) Independent Wireless Data Links:* These systems use external modules, such as Wi-Fi, Bluetooth, or Zigbee, which allow for bidirectional communication [34] but may introduce delays [7].

*b) Tightly Coupled Data Links:* These systems include wireless power and information dual transfer (WPIDT) systems, where power and data are multiplexed [15], [59].

Technologies that transfer power and data simultaneously are known as Simultaneous Wireless Power and Data Transfer (SWPIT/SWPDT), commonly referred to as SWPIT for low-power applications [59]. SSWPDT can be full duplex, but care must be taken to avoid interference with other IoT or 5G signals [57]. This requires careful topology design and the use of modulation methods such as ASK, OOK, FSK, and LSK [7].

In hardware design, it is common to employ controllers, such as FPGA, to manage flexible control, coordinating components in the network with minimal power [60].

WPDT methods can be categorized into Time Switching (TS), Power Splitting (PS), and Time-Power Switching (TS-PS) [61]. Specific techniques for SWPDT include [7]:

- Single Channel (SC-SWPDT)
- Power Carrier-based (PC-SWPDT)
- High Frequency Data Carrier-based (HFDC-SWPDT)
- Multi-Channel (MC-SWPDT)
- Multi-Channel Inductive (MICSWPDT)
- Hybrid Inductive-Capacitive Channels (ICHC-SWPDT)

An optimal SWPDT system should not affect the constant output (COC) or power transfer efficiency (PTE), while preventing over-voltage and over-current, and maintaining a high signal-to-noise ratio (SNR) [7].

*3) Circuit Configurations:* In compensation networks, depending on whether a complementary component is connected in series (S) or parallel (P), from transmitter to receiver, configurations can be classified as Series-Series (SS), Series-Parallel (SP), Parallel-Series (PS), or Parallel-Parallel (PP), or as combinations of inductors (L) and capacitors (C) in series and/or parallel represented by three-letter codes. The DC-AC conversion may require an inverter, typically of Class D, E, or EF, while the AC-DC conversion may require rectifiers of Classes D or E [3].

## C. Selection of main attributes

Once the selected articles were analyzed, the methods for wireless energy transmission were selected using those that achieved both the highest transmission efficiency and the longest coverage distance. In the event that one of these parameters was missing, distance was prioritized in far-field systems, such as RF transmission. In near-field systems, such as inductive coupling, efficiency was the most relevant criterion. If one of the selected methods had higher efficiency but shorter distance, or vice versa, output power was also considered. An additional key factor was the technology used by the method; if it also allowed data transmission, it was chosen. As a final filter, the level of detail with which each article described its system was evaluated, excluding those that were not sufficiently explicit regarding the operation of the system.

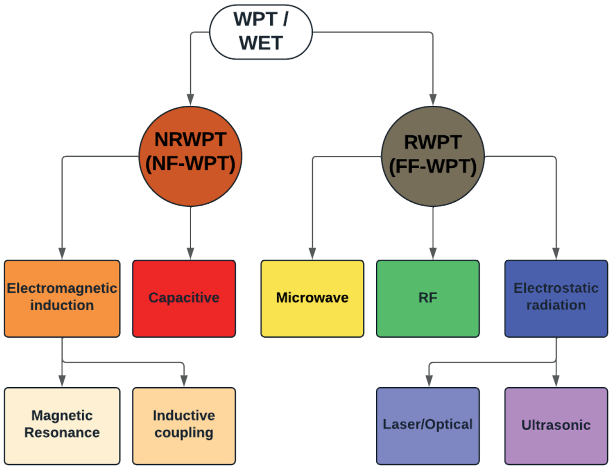


**Fig. 3.** Classification of WPT methods by their transmission distance

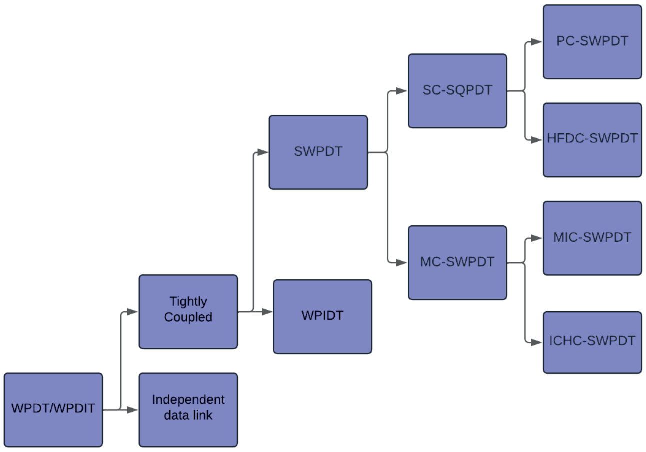


**Fig. 4.** Classification of WPDT methods according to the dependence of their data submission.

TABLE II
HIGHEST CONTRIBUTIONS PER SYSTEM

| WPT Method | Implemented Technology Highlights | PTE (%) |
|---|---|---|
| LPT [18] | Closed-loop power control. | 9.55 % |
| RF [12] | Adaptive antenna array transmitter. | 38.1 % |
| MPT [21] | Frequency selective surface (FSS) | 44.3 % |
| IPT [21] | Data injection and extraction transformers | 90.5 % |
| CPT [41] | Resonant circuits | 24.2 % |
| USWPT [35] | Sensing and transmission communication platform | 4 % |

## D. Analysis of results

After reviewing the selected articles, we considered the efficiency, distance achieved, and structural descriptions presented in the literature. The selected systems are shown in Figure 5 and their Implemented Technology Highlights and efficiency are described in Table II. The article images are sized appropriately for a two-column format. Therefore, their components have been rewritten for better understanding.

*1) Laser System:* When comparing laser systems against the criteria mentioned earlier, it is concluded that closed-loop circuit control is efficient. GaAs photovoltaic cells present higher efficiency compared to other photovoltaic technologies. Its DSP control uses the TMS320F28335 for energy management, and communication is handled via nRF2401 modules. The system architecture is illustrated in Fig. 5(a).

*2) RF-WPT:* The system includes a transmitter with a phased antenna array capable of adaptively switching antenna elements on or off based on the received signal strength (RSS) from receiving nodes. The transmitter leverages a backscattered pilot signal to dynamically adjust its radiation pattern, concentrating energy on active nodes to ensure continuous operation. The transmitter configuration is depicted in Fig. 5(b).

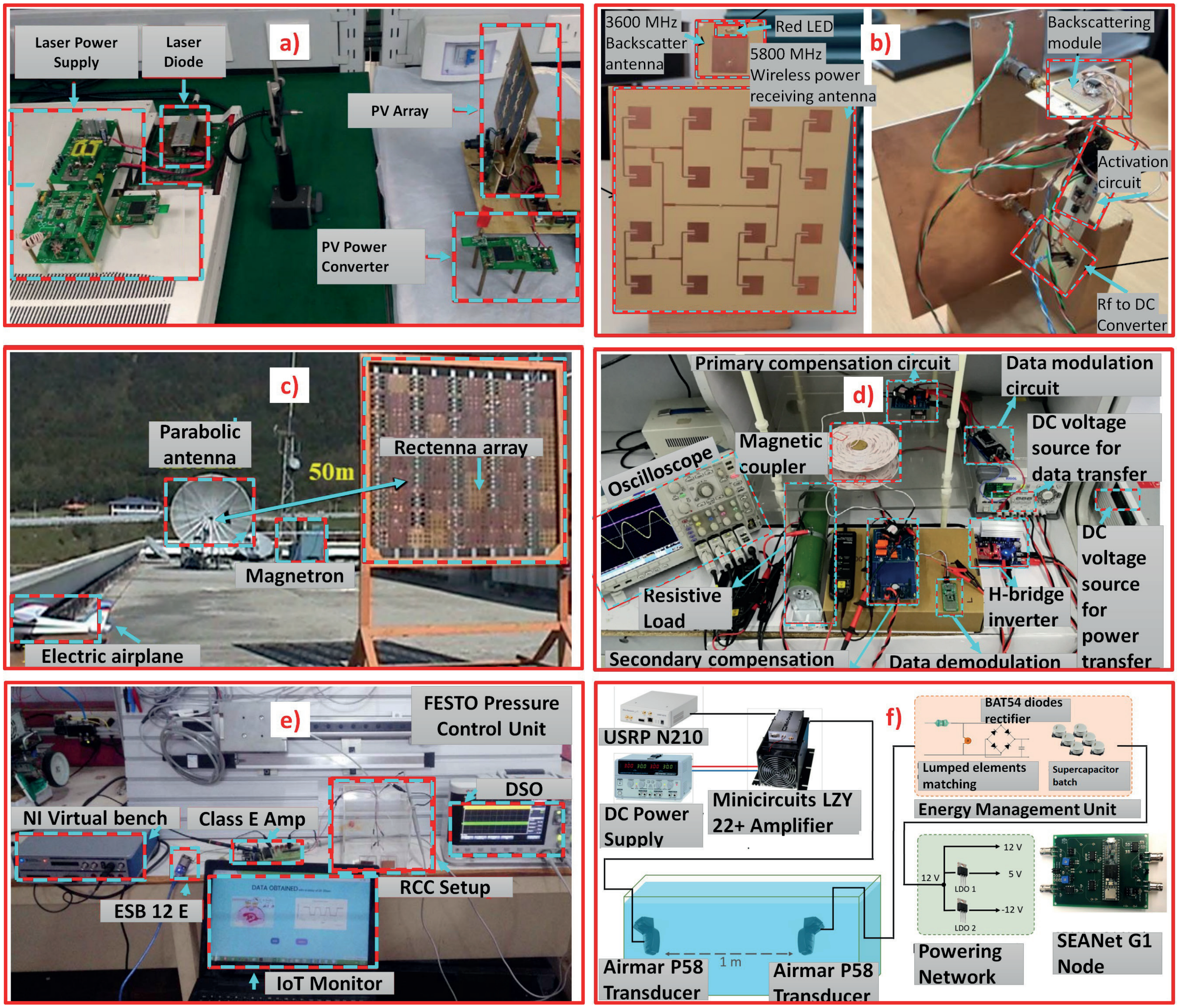


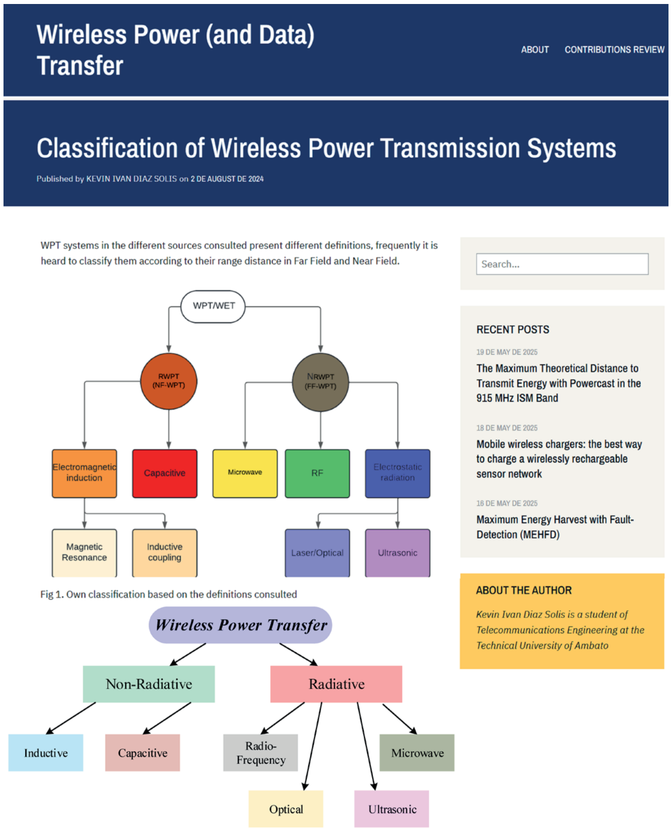
**Fig. 5.** Key contributions from selected WPT systems, illustrated as a composite schematic: (a) Closed-loop power control for laser-based WPT [18]; (b) Adaptive antenna array for RF-WPT in sensor networks [12]; (c) Frequency selective surface (FSS) for harmonic suppression in microwave WPT [21]; (d) Data injection/ extraction transformers in inductive SWPDT [36]; (e) Resonant capacitive coupling for biomedical implants [41]; (f) Integrated sensing and power platform for underwater WPT [35].

*3) Microwaves:* The selected system includes in its RX a high-power magnetron, control power supply, tuner, attenuator, coupler, power meter, dual-polarization power divider, transmitting antenna. In RX, it requires a power meter, dual-polarization square patch receiving antenna, impedance matching, filter, rectifier, and visible load. The highest efficiency is achieved with the SP Yagi antenna, whose incident angle approaches 90 degrees. The system layout, including the FSS and antenna array, is shown in Fig. 5(c).

*4) Inductive Coupling:* For inductive coupling, the best results observed in this research reached 90.5 % efficiency with the SI-SWPDT system. The system uses FSK modulation due to its noise immunity and robustness, and its compensation topology is double LCC (DS-LCC). The dual LCC compensation and data injection/extraction topology are detailed in Fig. 5(d).

*5) Capacitive Method:* The RCCI topology for implantable biomedical devices, while not the most efficient, achieved greater range and enabled efficient WPDT using an ASK-modulated resonant electric field from its plates at a rate of 50 Kb/s. Its topology includes class E power amplifiers with BC547 transistors. The resonant capacitive coupling and ASK modulation circuitry are presented in Fig. 5(e).

*6) Ultrasonic WPT:* The SEANet system can receive, convert, and store energy using only one transducer for communication and charging supercapacitors instead of traditional batteries, restoring 1 W in 5 minutes at a distance of 1 meter. This prototype works with the Internet of Underwater Things (IoUT). The sensor node uses the Teensy board for energy management and communication of the underwater sensor node, integrating and coordinating its various components. The integrated sensing and power transfer platform for underwater applications is shown in Fig. 5(f).



Wireless Power (and Data) Transfer

ABOUT CONTRIBUTIONS REVIEW

Classification of Wireless Power Transmission Systems

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WPT systems in the different sources consulted present different definitions, frequently it is heard to classify them according to their range distance in Far Field and Near Field.

Fig 1. Own classification based on the definitions consulted

RECENT POSTS

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Maximum Energy Harvest with Fault-Detection (MEHFD)

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**Fig. 6.** WPT website, in its WPT systems classification entry, adding a comparison of equivalent charts in different paper reviews. [62]

### *E. Documentation*

As a complement, the information obtained from the different WPT systems was compiled on a Web page for reviewing and visualization, presenting individual methods proposed in different scientific articles while highlighting the parameters, components, or information used. The website also includes comparisons of various works employing the same methods and definitions of concepts encountered throughout their entries. Given the relatively limited research on WPT, it was decided that the website would serve as a comprehensive database. Additionally, this site features a more detailed review of the most significant contributions from the consulted works, which can be observed in Fig. 6.

## III. DISCUSSION

Detailing the main contributions for each system:

- The contribution of the laser system [18] lies in its ability to dynamically adjust parameters based on the load, thus minimizing energy losses through an algorithm that constantly seeks the most optimal and efficient duty cycle with advanced energy management using DSP technology.
- The contribution of RFWPT is in its dynamic energy focus toward specific nodes in a sensor network, making it ideal for IoT applications. Its adaptability in sensor networks stands out, adjusting its radiation pattern based on signals received from the receiving nodes, optimizing energy delivery. This adaptive transmission topology is best suited for wireless sensor networks due to its ability to dynamically adjust the radiation pattern and focus energy on desired nodes [12].
- The contribution of the microwave system [12] is in its adjustment of transmission power to ensure the activation and continuous operation of nodes based on distance; power is maintained or reduced according to a backscattered signal sent from the loaded nodes based on their energy. The system incorporates a Frequency Selective Surface (FSS) to reduce higher-order harmonic waves, thus improving RF-DC conversion efficiency [21].
  In the receiver, antennas are connected both in series and in parallel to increase voltage and current in different zones, featuring a square loop frequency selective surface (FSS) that reduces higher-order harmonic waves. This system may have drawbacks, such as a 3-meter diameter and a weight of 20 Kg solely for transmission, resulting in high implementation costs and space requirements [21].
- The contribution of inductive coupling lies in its high transfer efficiency with FSK modulation, making it robust in noisy environments. Due to its symmetry and efficiency in bidirectional data transfer, it can operate at high power while maintaining data quality [36].
- The contribution of the capacitive method is its suitability for biomedical devices thanks to its ability to operate at greater distances with good efficiency. Its major contribution is the data recording capability using an ESP-12E Development KG164, which records information in the ThingSpeak cloud, facilitating monitoring and analysis of accurate and updated data [41].
- The contribution of the ultrasonic system is its innovative application in underwater IoT, capable of efficiently charging devices under extreme conditions. It employs a USRP (Universal Software Radio Peripheral) for transmitting and receiving ultrasonic signals, allowing easy handling of a wide frequency range [35].
  After analyzing the WPT systems, it is argued that the most suitable WPT method is RFWPT, particularly in the context of the development project for a Nano Grid device to power Internet of Things devices. This assertion is subjective and is based on a thorough review of the analyzed systems. Unlike CWPT and IWPT, which are more effective for short-range loads in enclosed devices, RF offers greater operational range. Compared to microwaves, which require relatively difficult-to-acquire components and present high energy consumption, the reviewed examples demonstrate that RF systems can operate in nano grids, allowing omnidirectional powering of multiple sensor nodes, making them an optimal choice for IoT applications. In contrast, technologies like laser-based WPT pose safety risks and impracticality in implementation, while ultrasonic WPT is more suitable for aquatic environments, limiting its applicability in terrestrial IoT scenarios.

## IV. CONCLUSIONS

This paper presents a comparative study of 25 WPT systems, encompassing various methods such as LPT, MPT, RFWPT, USWPT, IPT, and CPT. The analysis highlights their technical parameters, circuitry, components, and contributions. Through the comparison of these factors, the frequent compatibility of FF-WPT methods with sensor networks, microcontrollers, and the Internet of Things (IoT) is underscored.

This study provides an introductory overview of WPT and WPDT concepts, emphasizing the strategies implemented. While other reviews tend to focus on a single aspect, this work offers a broad perspective on WPT methods with diverse approaches, including those with data transmission capabilities and compatibility with IoT modules. By providing a comprehensive view of WPT and WPDT concepts, the analysis showcases the strategies used across various studies. Unlike many reviews that concentrate on a singular aspect of WPT, this work presents a more expansive view, incorporating methods with data transmission capabilities and IoT compatibility.

The analysis of different strategies applicable to various methods has shown that the optimization of data transfer through AM or FM modulation is feasible with the support of low-cost microcontrollers such as the ESP-12E as an alternative to FPGAs. Additionally, several consulted studies emphasize a dynamic approach, where adjusting parameters based on load conditions through external modules significantly enhances efficiency.

However, this study has certain limitations, particularly regarding energy management at the network level and potential technical challenges in integrating WPT systems in medium-range environments. Despite these limitations, the results obtained are especially relevant for future work within the project "Development of a Modular Solar Radio Frequency Nano Network Device for Powering Next Generation IoT Devices," particularly in the integration of WPT with sensor networks and IoT applications.

For future research, it is recommended to develop RFWPT or MPT systems that enable the charging and communication of nodes in smart buildings. Furthermore, exploring systems adaptable to variations in distance and position, algorithms for optimizing energy efficiency, and monitoring nodes using low-cost microcontrollers for digital signal processing (DSP) is advised.

Finally, a web page was designed, which will include all the information and results obtained through this research on WPT, seen from basic concepts, comparisons of parameters achieved by the different methods, and historical reviews. The objective of this webpage is to promote research and offer concise information on Wireless Power Transfer (WPT) categorized by year, method, or application for interested stakeholders or to arouse the curiosity of the reader, always respecting copyright and linking to the original sources. This page will be updated quarterly with the most recent advances, ensuring that it remains a relevant and up-to-date source for the scientific and industrial community.

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