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Original Article

Design of a Low-Cost Wireless Power and Data Communication System for a Small-Scale Vacuum Oven

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Abstract - *Vacuum drying is an effective method for food preservation that maintains high product quality, but its adoption is limited by the high cost of commercial equipment and the engineering challenges of creating reliable vacuum seals around wired components. This study presents the systematic design of a low-cost, wireless-powered vacuum oven that eliminates the need for physical wire feedthroughs. Following the VDI 2221 design guideline, several design concepts were developed and evaluated using a technical value analysis to select the optimal solution. The selected design features a fully contactless system, employing inductive Wireless Power Transfer (WPT) for internal electronics and bidirectional radio frequency communication for data transfer. A power budget analysis showed that the WPT system can deliver 22.5 W to the internal components, far exceeding their estimated maximum demand of 1.65 W. Furthermore, a cost analysis of the essential electronic components resulted in an estimated total of approximately $158 USD. The results demonstrate that the proposed design has a significant power safety margin and is economically feasible.*

Keywords - *Wireless Power Transmission (WPT), Wireless Sensor Networks, Vacuum oven, Small-scale.*

1. Introduction

Fresh foods such as fruits, vegetables, and meats have high moisture content, making them highly susceptible to microbial spoilage. Drying processes effectively reduce this water content, thereby inhibiting microbial activity and extending shelf life [1]. Beyond preservation, drying adds value to food products, reduces storage space, and lowers transportation costs. These benefits are particularly significant in regions with inadequate transportation infrastructure, where on-site drying at the point of production can drastically reduce post-harvest losses and directly benefit small-scale producers [2]. Several drying technologies have been developed to achieve these goals. Convection drying is one of the most established methods. For instance, Madhankumar et al. [3] designed a convection oven enhanced with infrared radiation for heat transfer, while Wagiman et al. [4] proposed a hybrid design incorporating a solar collector to dehydrate fruits and vegetables. To optimize energy usage, Quiñones-Reyes et al. [5] investigated a suitable control strategy for a hybrid convection oven powered by both a solar collector and electric heating elements. To accelerate the drying process, convection has been combined with microwave radiation, which leverages the polarity of water molecules for rapid internal heating. Zarein et al. [6] studied a microwave-assisted convection system for drying apple slices, and Hakim et al. [7] designed a similar system for seaweed. Hybrid systems combining solar collectors, microwaves, and convection have also been explored, as Mangalla et al. [8] demonstrated for drying potatoes and grains. However, a significant drawback of microwave heating is its non-uniformity, which can negatively impact food quality. This issue often stems from the design and characteristics of the magnetron itself [9]. As an alternative, induction heating has been integrated with convection drying. Bowornprasittikun et al. [10] proposed such a configuration for drying bananas, determining the resonant frequency required to achieve maximum heating efficiency.

Other advanced methods focus on preserving food quality. Freeze-drying (lyophilization) involves freezing the product and then sublimating the ice under low pressure, which minimizes undesirable changes in the food but is prohibitively energy-intensive and costly [11]. A more accessible alternative is vacuum drying without a freezing step, which reduces both the time and temperature required for dehydration. Roratto et al. [12] implemented a vacuum chamber heated by steam generated from a solar collector and electric resistors. Do et al. [13] optimized the vacuum drying process for bananas using electric heating. Despite its advantages, the widespread adoption of vacuum drying is limited by the high cost of commercial equipment. Addressing this, Hubbard et al. [14] designed and fabricated a low-cost vacuum oven using an engine block heater and a simple Arduino-based temperature controller, demonstrating a viable, affordable alternative.

A critical challenge remains in combining the high efficiency of induction heating-which can exceed 90% [15] -with the quality-preserving benefits of a vacuum environment. In existing convection-induction ovens, the electronic components are hardwired, making the integration of a sealed vacuum chamber mechanically complex and difficult to implement [10]. Wireless power transfer, which also utilizes the phenomenon of induction, offers a compelling solution to this problem. This technology enhances durability and robustness, as the absence of physical connectors allows for fully sealed, waterproof, and dustproof enclosures.

Considering the high cost of commercial vacuum ovens and the lack of studies on integrating wireless power technology into such systems, this study details the design of a low-cost, wireless-powered vacuum oven, developed following the VDI 2221 guideline. The design wirelessly powers all internal electronic components-including sensors, an Arduino board, and transceiver modules. This paper presents the design specifications, an evaluation of the selected components, and a technical value analysis. Subsequently, it details the oven's physical dimensions and the strategic placement of electronic components. The study also explains the signal evaluation within the wireless power system and concludes with an analysis of the system's power consumption and implementation costs.

2. Materials and Methods

The design of the wireless-powered vacuum oven was systematically conducted following the VDI 2221 guideline, a structured methodology for engineering design [16]. This study encompasses the first three of the four main phases outlined in the guideline: Task Definition, Conceptualizing, and Embodiment, as illustrated in Figure 1. The Task Definition phase established a comprehensive list of requirements and design specifications for the oven. Subsequently, the Conceptualizing phase involved identifying core functions, structuring them, and evaluating principal solutions. Finally, during the Embodiment phase, the selected solution was subdivided into realizable modules, leading to the development of a preliminary layout for the oven and its components.

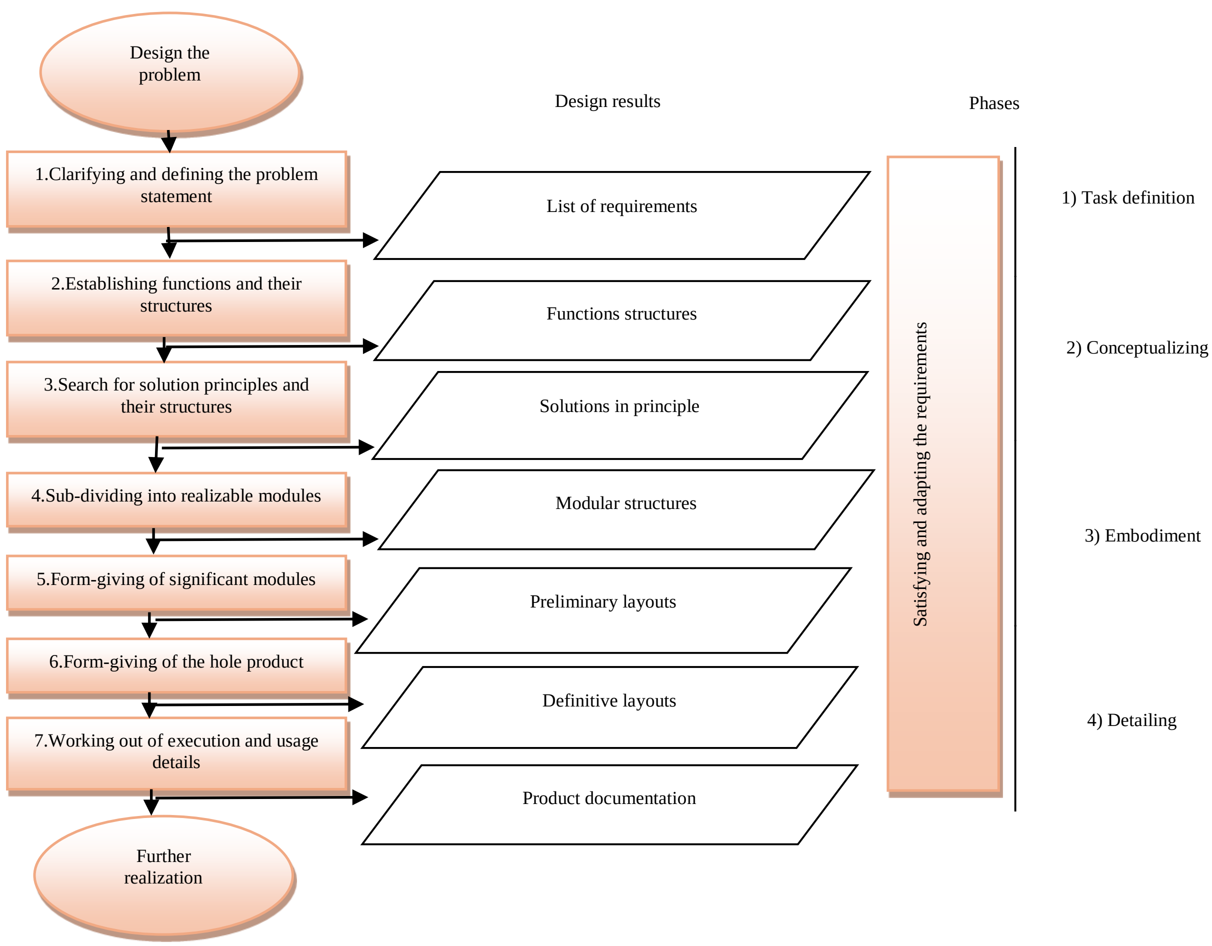

Fig. 1 Design methodology according to VDI 2221 [17]

Table 1. Key design specifications for the wireless-powered vacuum oven

List of Specifications		
1	Design	Proposed vacuum oven dimensions are based on commercial ovens
2	Functionality	Real-time data on temperature, pressure, and moisture content must be obtained.
3	Materials	All non-electronic components exposed to the vacuum environment and in direct contact with the food product must be fabricated from food-grade stainless steel.
4	Energy	The oven chamber must incorporate a non-metallic, pressure-resistant window (tempered glass) to enable efficient magnetic flux coupling between the external (transmitter) and internal (receiver) power coils.
5	Data	The chamber window must also be transparent to radio frequencies to ensure reliable, bi-directional data communication between the internal sensor suite and the external control unit, operating within the Industrial, Scientific, and Medical (ISM) band.

2.1. Specification

Following the Task Definition phase of the VDI 2221 guideline, a comprehensive list of requirements was established to guide the design of the wireless-powered vacuum oven. These key specifications, which define the constraints and objectives of the project, are summarized in Table 1.

2.2. Function Structures

As part of the conceptual design phase, the overall system was decomposed into its core functions. The resulting functional structure, depicted in Figure 2, illustrates the primary transformations and flows within the proposed oven by separating them into three parallel subsystems: material, energy, and information.

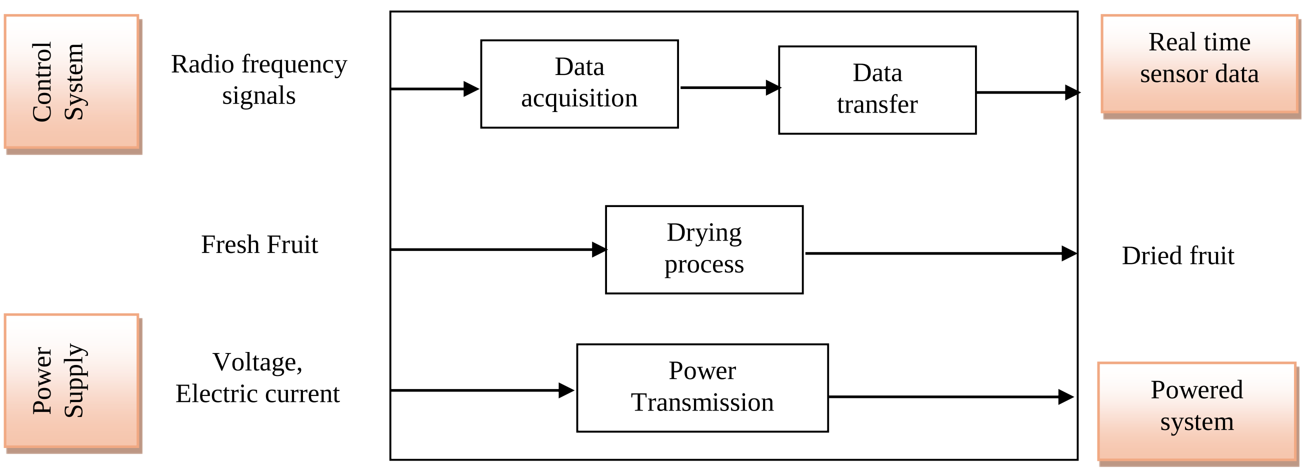

Fig. 2 Function structures

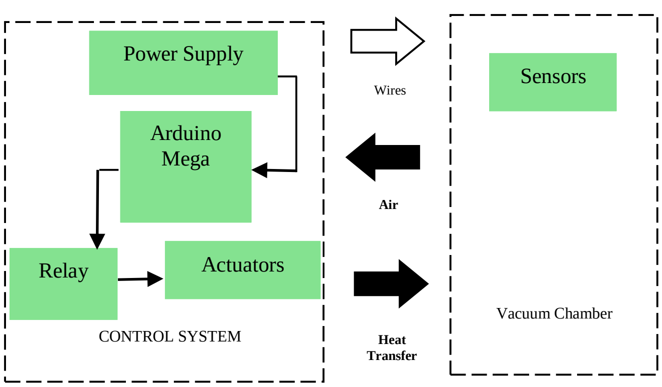

Fig. 3 Proposed first solution

2.3. Principal Solutions

2.3.1. Concept A: Conventional Hardwired Design

The first concept, illustrated in Figure 3, represents a conventional hardwired approach. In this configuration, an external control system, built around an Arduino Mega microcontroller, is directly connected to the sensors inside the vacuum chamber via physical wires. The controller processes the sensor data and activates the external oven actuators through a relay. The entire system is powered by a single external power supply. The primary drawback of this design is the requirement for physical feedthroughs in the vacuum chamber wall, which significantly complicates the engineering challenge of maintaining a reliable, long-term vacuum seal.

2.3.2. Concept B: Wireless Data Communication with Internal Power

To overcome the sealing challenges of the wired concept, a second solution was developed, as shown in Figure 4. This design decouples the internal and external systems by implementing wireless communication and an independent internal power source. The internal system is housed completely within the vacuum chamber. This autonomous module consists of an Arduino Nano, the necessary sensors, a battery for power, and an nRF905 transceiver. In the external system, the main control system uses an Arduino Uno to manage the oven's actuators. It communicates with the internal module via a matching nRF905 transceiver.

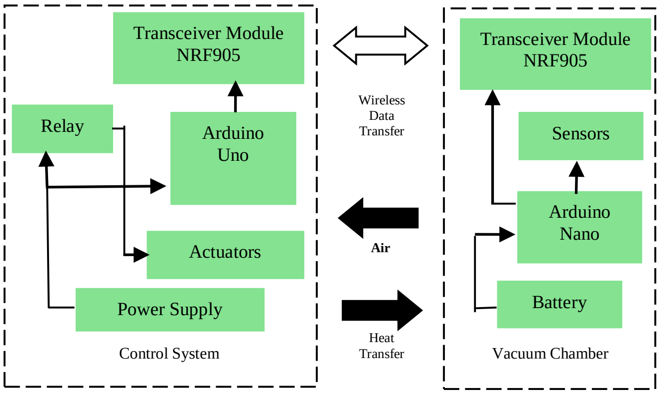

Fig. 4 Proposed second solution

2.3.3. Concept C: Fully Wireless Power and Data System

The final proposed solution, detailed in Figure 5, enhances the previous concept by incorporating Wireless Power Transfer (WPT), thus creating a truly contactless system and overcoming the limitation of a finite battery life. This architecture enables continuous, long-term operation without breaching the vacuum seal. The system is comprised of an external power/control unit and an internal sensing module. The external Power System utilizes a Primary Coil to inductively transfer energy to a Secondary Coil located within the vacuum chamber. This power energizes an internal Arduino Micro, which acquires data from the Sensors. The collected data is then transmitted via an nRF24L01 transceiver to the external Control System. This external unit, managed by an Arduino Uno, processes the real-time data to activate the oven's actuators through a relay while streaming the information to a connected computer for real-time monitoring and data logging.

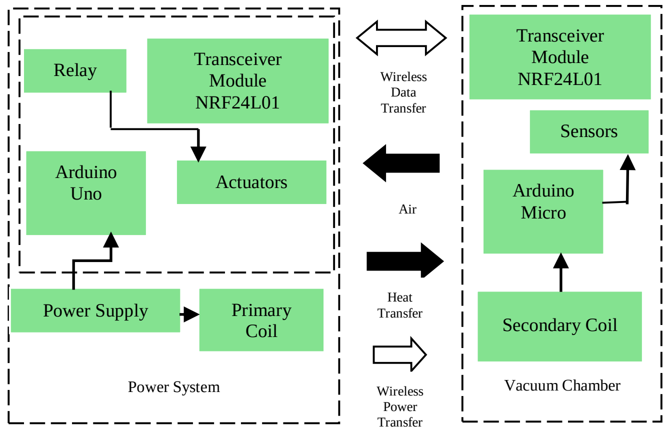

Fig. 5 Proposed third solution

A technical value analysis was conducted to select the optimal design from the three proposed concepts. This quantitative evaluation method assesses each solution against the five key specifications previously established (Design, Function, Material, Energy, and Data). As detailed in Table 2, each specification was first assigned a weighting factor (g) to reflect its relative importance to the project's objectives. Subsequently, each of the three solutions was given a performance score (p) from 0 to 4, indicating how well it fulfilled each specification. The final "Technical Value" for each concept was then calculated by normalizing its total weighted score (Σ g·p) against that of a theoretical "Ideal" solution, which is defined as having a perfect technical value of 1. The analysis clearly indicates that the third solution (fully wireless power and data) achieves the highest Technical Value of 0.7. Because it most closely approximates the ideal benchmark, this concept was selected for further development in the embodiment phase.

Table 2. Technical value analysis

Solution		1st		2nd		3rd		Ideal	
Specification	g	p	gp	p	gp	p	gp	p	gp
Design	0.5	2	1	2	1	3	1.5	4	2
Function	0.9	2	1.8	3	2.7	3	2.7	4	3.6
Material	0.2	2	0.4	2	0.4	2	0.4	4	0.8
Energy	0.9	1	0.9	2	1.8	3	2.7	4	3.6
Data	0.7	2	1.4	3	2.1	3	2.1	4	2.8
Total Score		9	5.5	12	8	14	9.4	4	12.8
Technical value		0.45		0.6		0.7		1	

3. Module Structures

3.1. Mechanical Structure

Figure 6 presents the preliminary layout and overall dimensions of the proposed wireless-powered vacuum oven. The design was benchmarked against commercial laboratory-scale vacuum ovens to ensure practical capacity and a standard footprint [18].

The proposed oven features an integrated side cabinet on the left, which is designed to house all external electrical and electronic components. This includes the main power supply, the wireless power transmitter coil, the control system microcontroller Arduino Uno, and the data transceiver, effectively consolidating the entire external system into a single, self-contained unit.

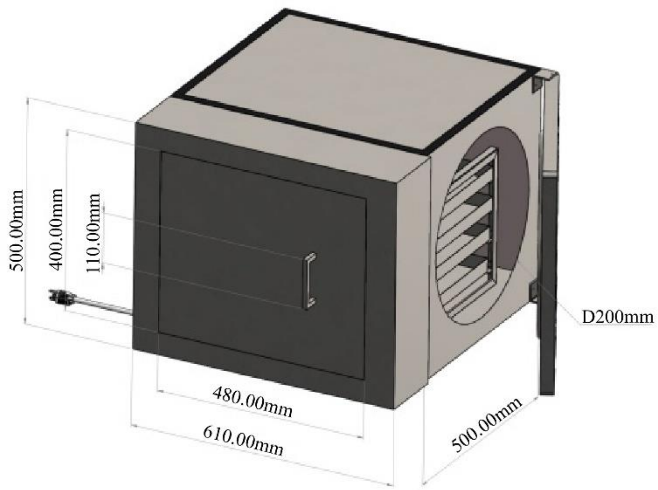

Fig. 6 Proposed vacuum oven dimensions based on commercial ovens

3.2. Electrical and Control Structure

The electrical architecture of the proposed oven is divided into two main subsystems: the Wireless Power Transfer (WPT) system and the control/data communication system. An exploded view illustrating the physical placement of all components is provided in Figure 7, and a detailed list of these components is presented in Table 3. The WPT system is designed to power the internal electronics without breaching the vacuum chamber.

As shown in Figure 8, the process begins with an external pulse generator that drives the primary coil, generating a time-varying magnetic field. This field permeates the chamber wall and induces a current in the secondary coil located inside. The induced current, which is initially alternating, is first rectified to a pulsating DC signal using a high-efficiency Schottky diode. Subsequently, an LM2596 buck converter steps down and regulates this signal to a stable DC voltage, providing a suitable power source for the internal Arduino Micro and its connected sensors. Bi-directional wireless communication is established using a pair of nRF24L01 transceiver modules operating in the 2.4 GHz ISM band. The internal module, controlled by the Arduino Micro, is responsible for acquiring real-time data from the sensors inside the vacuum chamber.

This data is then wirelessly transmitted to the external module connected to an Arduino Uno. The Arduino Uno processes the incoming data and manages the oven's actuators (e.g., heating elements, vacuum pump) via a relay system, thereby closing the control loop. The external Arduino Uno also interfaces with a host computer for real-time data visualization and logging.

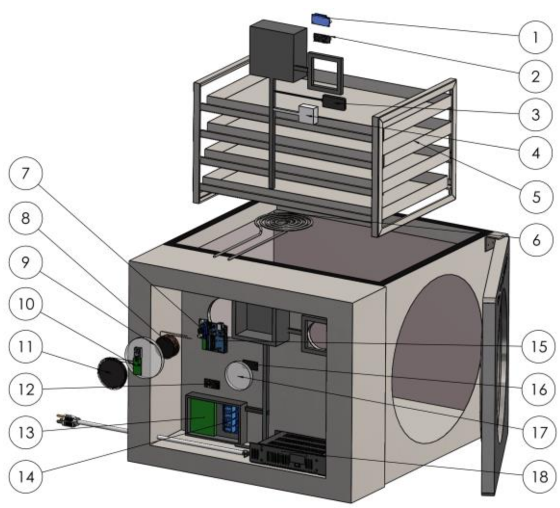

Fig. 7 Vacuum oven exploded view

Table 3. List of components

Number	Part	Number	Part
01	LM2596 regulator	**10**	Pulse generator
02	Arduino Micro	**11**	Primary coil
03	Temperature sensor	**12**	nRF24L01 module
04	Pressure sensor	**13**	Heater controller
05	Tray	**14**	Relay
06	Heater resistance	**15**	Arduino Uno
07	LM2596 regulator	**16**	nRF24L01 module
08	Secondary coil	**17**	Tempered glass
09	Tempered glass	**18**	Power supply

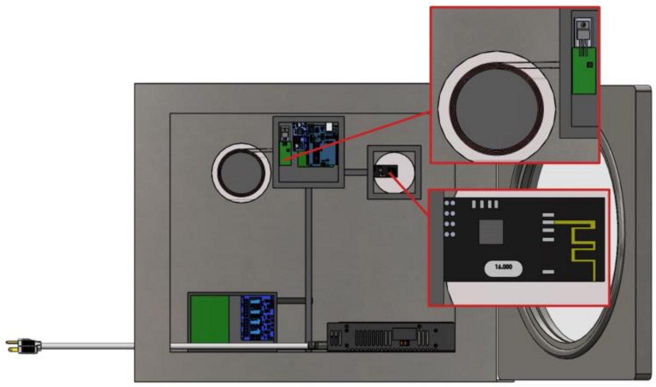

Fig. 8 Pulse generator and transceiver nRF24L01

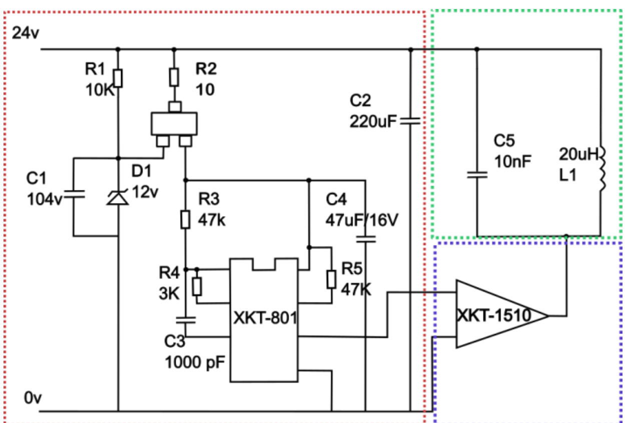

Fig. 9 Pulse generator circuit

Fig. 10 The hardware module for the WPT transmitter. This board integrates the XKT-801 oscillator IC, the XKT-1511 power driver (the transistor on the heat sink), and associated passive components.

The detailed schematic of the pulse generator circuit, which forms the core of the WPT transmitter, is presented in Figure 9. The circuit's design can be understood as three distinct functional stages. The first stage (outlined in red), built around the XKT-801 integrated circuit, functions as a high-frequency oscillator, generating the primary control signal for the system. This signal is then fed to the second stage (outlined in blue), a power driver (XKT-1510) that acts as a high-speed switch, converting the low-power oscillator signal into a high-current square wave by rapidly switching the 24V supply. Finally, this high-power square wave excites the third stage (outlined in green), which is a parallel resonant LC tank circuit. This tank, comprising the primary transmitter coil (L1, 20uH) and a parallel capacitor (C5, 10nF), is designed to resonate at a frequency of 223.5 kHz to maximize the efficiency of the wireless power transfer. The physical hardware module realizing this circuit is shown in Figure 10.

4. Results

4.1. Integrated System Schematic and Signal Waveforms

Figure 11 presents the comprehensive schematic diagram of the final integrated system, illustrating the architecture of both the power and control subsystems. The diagram also displays key voltage waveforms at critical points within the Wireless Power Transfer (WPT) chain. The external Power System (outlined in orange) begins with a pulse generator that produces a high-frequency square wave to drive the primary coil. Concurrently, the Control System (outlined in green) demonstrates the closed-loop operation. The internal Arduino Micro acquires real-time temperature, load, and pressure sensor data. This data is wirelessly transmitted to the external Arduino Uno, which in turn manages the system's actuators-including the vacuum pump, valves, and heater resistance-via a relay bank, while also interfacing with a computer for monitoring and data logging.

4.2. WPT System Signal and Power Analysis

The functionality of the Wireless Power Transfer (WPT) system was validated by analyzing both voltage signals and power levels at key stages. The process is initiated by a 24V DC power supply capable of delivering up to 2.5A (60W). This input drives the pulse generator, which outputs a 24V amplitude square wave, as depicted in Figure 12. Due to this waveform's 50% duty cycle, the effective power delivered to the primary coil is approximately 30W. This signal energizes the primary coil, generating a time-varying magnetic field that propagates across the vacuum barrier. This magnetic field induces a corresponding voltage in the secondary coil. The green trace in Figure 13 shows that the induced signal is a sinusoidal AC waveform with a peak voltage of approximately 18V. The power available at the secondary coil's output under these conditions is approximately 22.5W. This raw AC voltage is unsuitable for directly powering the digital logic of the control system. Therefore, it is first processed by a Schottky diode, which performs half-wave rectification. The resulting signal (red trace in Figure 13) is a pulsating DC waveform. After accounting for the forward voltage drop across the diode, the peak voltage of this rectified signal at the input of the LM2596 regulator is measured at 6.92V, providing a suitable input for the final voltage regulation stage.

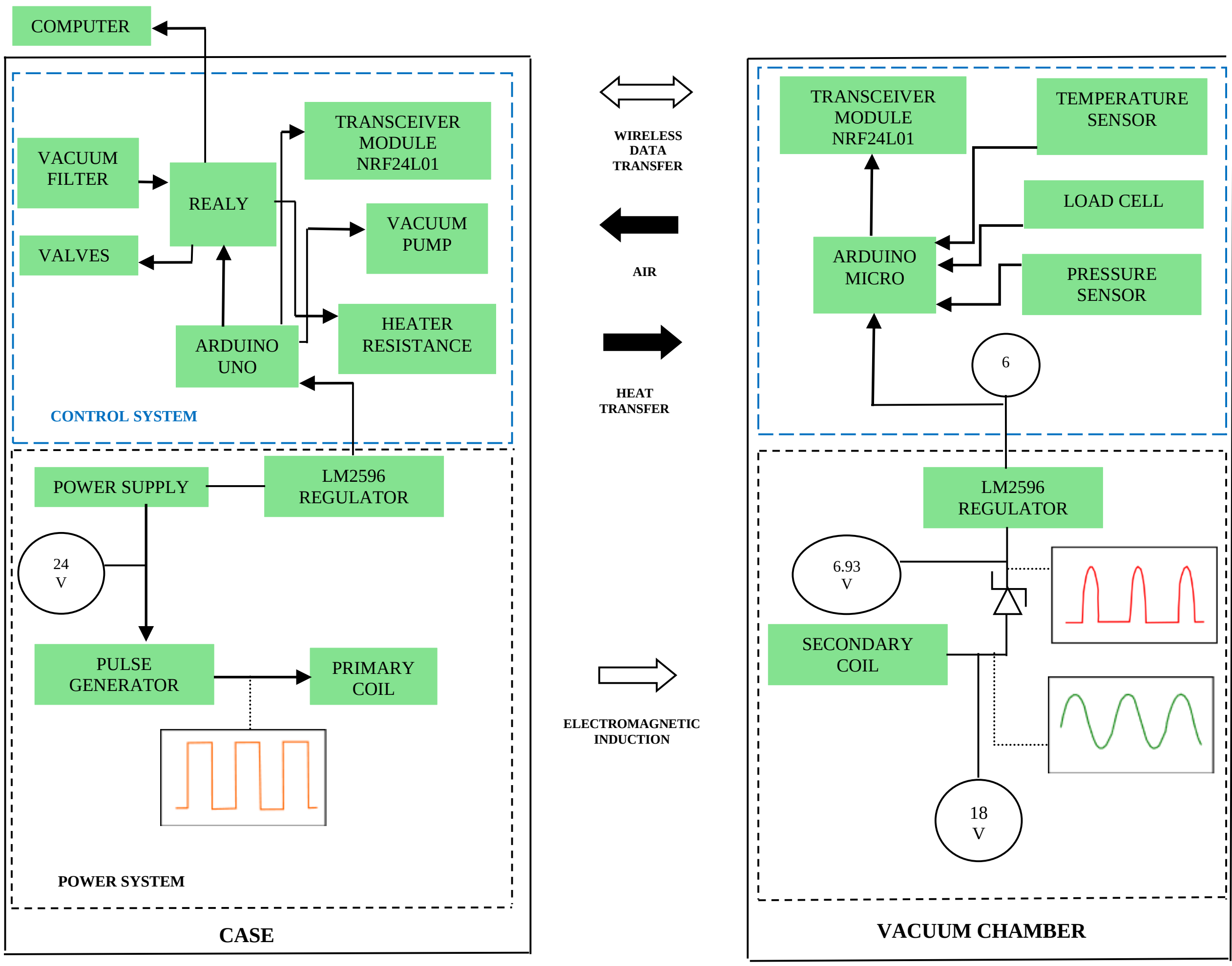

Fig. 11 Wireless power and data transfer system schematic diagram

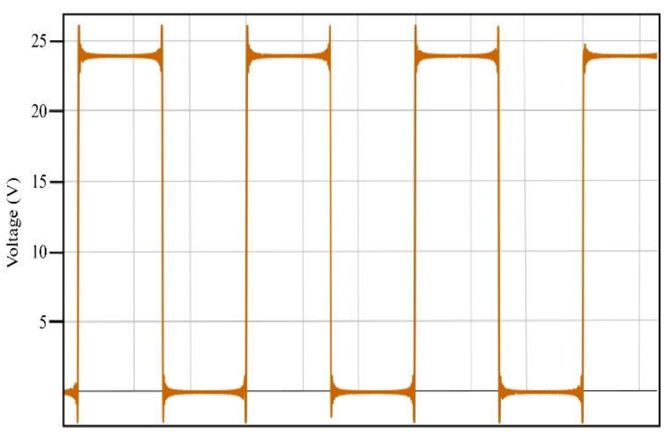

Fig. 12 Pulse signal

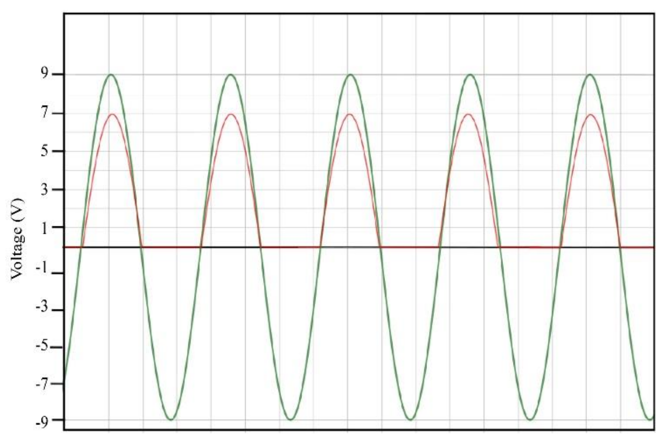

Fig. 13 Secondary coil voltage signal and half-wave rectified signal

A detailed power budget analysis was performed to validate the viability of the Wireless Power Transfer (WPT) system. The objective was to ensure that the power delivered to the secondary coil would be sufficient to meet the maximum operational demand of all electronic components housed within the vacuum chamber.

Table 4 summarizes this analysis, detailing the power requirements of the internal load and the power available at each stage of the WPT system. The total power demand of the internal electronics was estimated based on the maximum (peak) operational consumption of its key components, notably the Arduino Micro controller and the nRF24L01 transceiver during data transmission, resulting in a subtotal of 1377 mW. An additional overhead of 276 mW was included to account for power conversion losses in the LM2596 regulator, bringing the total estimated load to 1.653 W. On the supply side, the analysis begins with the 60 W available from the 24V DC main power supply. It is important to note that the power delivered to the primary coil is effectively halved to 30 W due to the 50% duty cycle of the pulse generator's square wave output. After transmission across the air gap, the power available at the secondary coil is approximately 22.5 W.

The analysis confirms that the available power at the secondary coil, 22.5 W, is more than sufficient to meet the estimated maximum power demand of the internal system, 1.653 W, providing a substantial safety margin for reliable, continuous operation.

Table 4. Power budget analysis for the wireless-powered vacuum oven

Internal System Power Consumption (Load)	Operating Voltage (V)	Max. Current (mA)	Power (mW or W)
AM2301	5	1.5	7.5 mW
BMP085	5	0.1	0.5 mW
nRF24L01	5	115	575 mW
Arduino Micro (Controller)	6.92	800	794 mW
Subtotal (Components)	-	-	1377 mW
LM2596 (Regulator Overhead)	-	-	276 mW
Total Estimated Power Demand	-	-	1.653 W
Wireless Power Transfer System (Supply)			(W)
Input to WPT System	24V DC	2.5 A	60 W
Effective Power at Primary Coil	24V AC (Peak)	-	30 W
Available Power at Secondary Coil	18V AC (Peak)	-	22.5 W

To evaluate the economic feasibility of the proposed wireless-powered system, a cost analysis was performed based on the main electronic and power components required for a functional prototype. Table 5 provides a detailed bill of materials, itemizing each component, its function, quantity, and approximate unit cost in US dollars. The analysis reveals that the total cost for all essential electronic components-including the microcontrollers, sensors, power supply, and wireless power/data modules-is approximately $157.69 USD. This figure demonstrates that a sophisticated, fully wireless control and power system for a vacuum oven can be implemented at a remarkably low cost.

Table 5. Bill of Materials (BOM) and cost analysis for the electronic system

Item	Component	Description	Qty.	Unit Price (USD)	Total Price (USD)
1	AM2301	Temperature sensor	1	10 USD	10 USD
2	BMP085	Pressure Sensor	1	20 USD	20USD
3	nRF24L01	2.4 GHz Wireless Transceiver Module	2	4 USD	8 USD
4	XKT-801-48	Wireless Power Transmitter Module	1	32 USD	32 USD
5	LM2596	DC-DC Buck Converter Module	2	3 USD	6 USD
6	NDR-120-24	24V DC Power Supply	1	32.39 USD	32.39 USD
7	Arduino Uno R3	Microcontroller Development Board	1	28.60 USD	28.60 USD
8	Arduino Micro	Microcontroller Development Board	1	20.70 USD	20.70 USD
TOTAL					157.69 USD

5. Conclusion

This study successfully presented the systematic design of a low-cost, wireless-powered vacuum oven, addressing the significant challenges of high cost and complex sealing associated with conventional systems. By employing the VDI 2221 design guideline, a comprehensive process was followed, moving from task definition and conceptualization to the detailed embodiment of the final design. The core innovation of the proposed system lies in the complete elimination of physical wire feedthroughs into the vacuum chamber by integrating both WPT for internal electronics and wireless data communication for real-time monitoring. A technical value assessment demonstrated the superiority of the fully wireless concept over alternative hardwired and battery-powered designs. Furthermore, a power budget analysis confirmed that the WPT system can deliver 22.5 W to the secondary coil, substantially exceeding the estimated 1.65 W maximum power demand of the internal sensor and control suite, thus ensuring a robust operational safety margin. The cost analysis highlighted the economic feasibility of the prototype, with the total cost of the essential electronic components estimated at approximately $158 USD, positioning it as a highly accessible alternative to expensive commercial equipment. For future work, the next logical phase should focus on the physical prototyping and experimental validation of the design. A critical area for investigation is the performance and integration of the proposed sensors within the operational environment. While these sensors are cost-effective, their accuracy, reliability, and long-term stability under vacuum conditions and varying temperatures must be empirically evaluated. Additionally, future research should explore the optimal methods for mechanically coupling these sensors inside the chamber to ensure they provide accurate readings of the food product's environment without interfering with the process or compromising the vacuum integrity. Successfully addressing these aspects will be crucial for transitioning this validated design into a fully functional and tested laboratory instrument.

References

[1] Dayuan Wang et al., "Novel Drying Techniques for Controlling Microbial Contamination in Fresh Food: A Review," *Drying Technology*, vol. 41, no. 2, pp. 172-189, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[2] Nupur Nandan Nagwekar, Vaibhav Baburao Tidke, and Bhaskar Narayan Thorat, "Seasonal Nutritional Food Security to Indian Women through Community-Level Implementation of Domestic Solar Conduction Dryer," *Ecology of Food and Nutrition*, vol. 59, no. 5, pp. 525-551, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[3] S. Madhankumar et al., "Design and Modelling of Automated Hot Oven Food Dehydrator," *2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS)*, Coimbatore, India, pp. 1130-1134, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[4] Abdullah Wagiman et al., "Design and Performance Evaluation of Hybrid Photovoltaic Thermal Solar Dehydrator," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 28, no. 2, pp. 181-189, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[5] Pedro Quiñones-Reyes et al., "Networked Control System for a Hybrid Dehydrator from the Design of Experiments," *2019 IEEE International Fall Meeting on Communications and Computing (ROC&C)*, Acapulco, Mexico, pp. 34-39, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[6] Mohammad Zarein, Seyed Hashem Samadi, and Barat Ghobadian, "Investigation of Microwave Dryer Effect on Energy Efficiency During Drying of Apple Slices," *Journal of the Saudi Society of Agricultural Sciences*, vol. 14, no. 1, pp. 41-47, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[7] Arif Rahman Hakim, Wahyu Tri Handoyo, and Adrianto Widi Prasetya, "Design and Performance of Scaled-Up Microwave Dryer for Seaweed Drying," *Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology*, vol. 15, no. 3, pp. 141-152, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[8] Lukas Kano Mangalla et al., "Experimental Study on the Performance Characteristics of a Microwave-Solar Heating Dryer," *IOP Conference Series: Materials Science and Engineering*, vol. 797, no. 1, pp. 1-6, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[9] Amin Hazervazifeh, Ali M. Nikbakht, and Shahriar Nazari, "Industrial Microwave Dryer an Effective Design to Reduce Non-Uniform Heating," *Engineering in Agriculture, Environment and Food*, vol. 14, no. 4, pp. 110-121, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] Mukda Bowornprasittikun et al., "Induction Food Dehydrator with Temperature Control," *2019 7th International Electrical Engineering Congress (iEECON)*, Hua Hin, Thailand, pp. 1-4, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[11] Sagar Bhatta, Tatjana Stevanovic Janezic, and Cristina Ratti, "Freeze-Drying of Plant-Based Foods," *Foods*, vol. 9, no. 1, pp. 1-22, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Thayla B. Roratto et al., "An Innovative Hybrid-Solar-Vacuum Dryer to Produce High-Quality Dried Fruits and Vegetables," *LWT*, vol. 140, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] Linh Thuy Khanh Do et al., "Mathematical Modeling and Optimization of Low-Temperature Vacuum Drying for Banana," *Carpathian Journal of Food Science and Technology*, vol. 13, no. 4, pp. 47-61, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[14] Benjamin R. Hubbard et al., "Open Source Vacuum Oven Design for Low-Temperature Drying: Performance Evaluation for Recycled PET and Biomass," *Journal of Manufacturing and Materials Processing*, vol. 5, no. 2, pp. 1-35, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] Oscar Lucía et al., "Induction Heating Technology and its Applications: Past Developments, Current Technology, and Future Challenges," *IEEE Transactions on Industrial Electronics*, vol. 61, no. 5, pp. 2509-2520, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[16] J. Jänsch, and H. Birkhofer, "The Development of the Guideline VDI 2221-the Change of Direction," *DS 36: Proceedings DESIGN 2006, the 9th International Design Conference*, Dubrovnik, Croatia, pp. 45-52, 2006. [Google Scholar] [Publisher Link]

[17] Wolfgang Ernst Eder, "Theory of Technical Systems-Educational Tool for Engineering," *Universal Journal of Educational Research*, vol. 4, no. 6, pp. 1395-1405, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[18] Consistent Performance, at a High Degree: Thermo Scientific Vacuum Ovens, Thermo Fisher Scientific Inc, pp. 1-16, 2017. [Online]. Available: https://assets.thermofisher.com/TFS-Assets/LED/brochures/Vacuum%20Ovens%20Portfolio%20Brochure_FINAL_Aug2017.pdf