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Reflow oven with Wi-Fi connectivity

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Abstract

This paper will address a theme that highlights the role of an electrical equipment in the electrical industry, focusing on the process of soldering components onto the surface of printed circuit boards.

The choice of the theme "Reflow Oven with Wi-Fi Connectivity" was driven by the desire to create a system with practical and applicative outcomes. The aim is to develop equipment that facilitates the soldering process of Surface Mounted Device (SMD) components. Such an automated system is valuable in the production of small batches of equipment, such as electronic modules for prototypes or various applications.

The equipment or electronic module aims to depict a Printed Circuit Board (PCB) on which both Surface Mounted Devices (SMD) and Through Hole Technology (THT) components are mounted. Throughout the paper, the implementation of an automated system capable of carrying out the soldering process for SMD components will be discussed.

Keywords: IoT, reflow oven, Wi-Fi, soldering, PCB

1 Introduction

Humanity has been experiencing a powerful technological innovation in the development of electrical and electronic components and equipment, aimed at assisting people by integrating them into daily life. The automation and intelligent control aspect seems to increasingly take over both simple and complex operations, replacing human personnel, with a focus on complete automation of industrial processes and beyond.

One of the most important categories of electronic devices consists of circuit elements that provide connectivity between devices or, specifically, to the internet. Connected devices are becoming more prevalent in people's purchasing desires because of their intuitive, simple, and user-friendly interaction and usage.

From this perspective, Internet of Things (IoT) devices are increasingly present in people's homes and in the industrial environment due to their convenient interaction and numerous benefits. Through such connected devices, the user experience becomes much friendlier, as they can be controlled from devices users already own, such as mobile phones.

In terms of construction, simplicity is the key, as IoT devices are largely uncomplicated, with few control or display elements. The entire interaction with these devices takes place through the internet using mobile phones, web pages, or other interconnecting devices.

For electrical devices to achieve remarkable performance, it is necessary for the components used to be energetically efficient. Therefore, the continuous search for new devices that propose energy improvements is essential, as electrical energy, the "raw material" of this industry, is crucial and cannot be wasted carelessly. Simultaneously, the improvement of current devices is pursued to approach the ideal characteristics, including minimal energy dissipation, low current consumption, fault-free operation over time, or the ability to withstand increasing command or data processing speeds.

In the case of producing small series of equipment, industrial reflow ovens cannot be used efficiently due to factors such as the low number of printed circuit boards passed through the oven or the small number of components that need to be soldered onto the printed circuit board. Industrial reflow processes are most efficient when applied to the production of large batches of similar equipment. Therefore, acquiring an industrial reflow oven for small-scale needs is often impractical. Hence, the concept of designing a smaller device for such purposes is considered. This involves creating a compact reflow oven that closely approximates the characteristics of an industrial reflow oven.

To benefit from this technology in small equipment series, the design of a much smaller system, compared to an industrial device, is proposed to carry out the reflow process in an easy and automated manner. Therefore, the chosen theme proposes the implementation of an automated system that serves as a reflow oven, which can be wirelessly controlled from various mobile or fixed devices by connecting them directly to the designed system.

The designed system is intended for the production of prototypes, small or medium series of electronic equipment concerning soldering components onto the surface of the printed circuit board for interconnection purposes.

Thus, the oven is defined as a well-insulated enclosure where the temperature will be controlled according to a certain characteristic initially set. The main idea is to create a system that monitors a temperature characteristic to solder Surface Mounted Device (SMD) components onto the printed circuit board using solder paste intended for this process.

In this regard, a food preparation oven will be used, which will be entirely adapted from an electrical and mechanical point of view to meet the thematic requirements. Essentially, the significance of the theme lies in creating equipment that can monitor a temperature characteristic established according to the requirements of the components and solder paste.

It is imperative that the communication with the entire device be wireless, functioning as an Access Point (AP). Devices with wireless connectivity can connect to it to establish communication following the Transmission Control Protocol/Internet Protocol (TCP/IP) model. The need for communication with the system arises from the desire for the reflow process to be monitored and controlled through a web page accessible from any device's browser, initiating the connection and communication with the terminal. From this perspective, the implementation method should not involve additional components to control the terminal; instead, they should be replaced by a web page interface, significantly reducing the use of electronic components. The advantage of software implementation is that any command button or display can easily be transposed into a graphical interface by replacing them with virtual ones. The interaction with these virtual components can be done using devices that are already part of our technology era.

Constraints related to implementation are accentuated by the fact that, from the beginning, a small-sized oven is desired for use in small equipment series. Thus, for the production of multiple electronic modules exceeding the oven's capacity, multiple soldering cycles will be required, repeated until the desired number of boards with soldered components is achieved.

Another technical challenge would be the rapid cooling process inside the oven to meet the imposed reflow characteristic. In this regard, various methods for implementing the cooling system will be analyzed.

The imposed objectives are related to the implementation of an IoT system, which is ultimately intended to be functional and productive. Requirements can be outlined starting from the main idea of implementing the described system based on a microcontroller with the greatest possible integration of peripherals required for the design, followed by the need to implement a temperature regulator and a web interface for oven control and monitoring.

The device should be safe in terms of handling during operation and electromagnetic compatibility with other devices. It should also be environmentally friendly in relation to the surrounding environment or the power grid from which it will be powered. Among the requirements, the possibility of selecting the reflow curve through the graphical interface, as well as monitoring the process through real-time data monitoring, can be mentioned.

2 Stages of Soldering through Reflow Procedure

Soldering through reflow involves a series of well-defined individual stages in the process. The following presentation provides an overview of these stages as they constitute an important topic within the scope of the work.

The stages through which the assembly requiring soldering must pass are described by the temperature variation curve of the reflow process, as depicted in Figure 1.

The necessity for such a procedure arises from the fact that temperature represents the greatest adversary to electronic components. As soldering involves a thermal process on these components, it is crucial to control the thermal exposure.

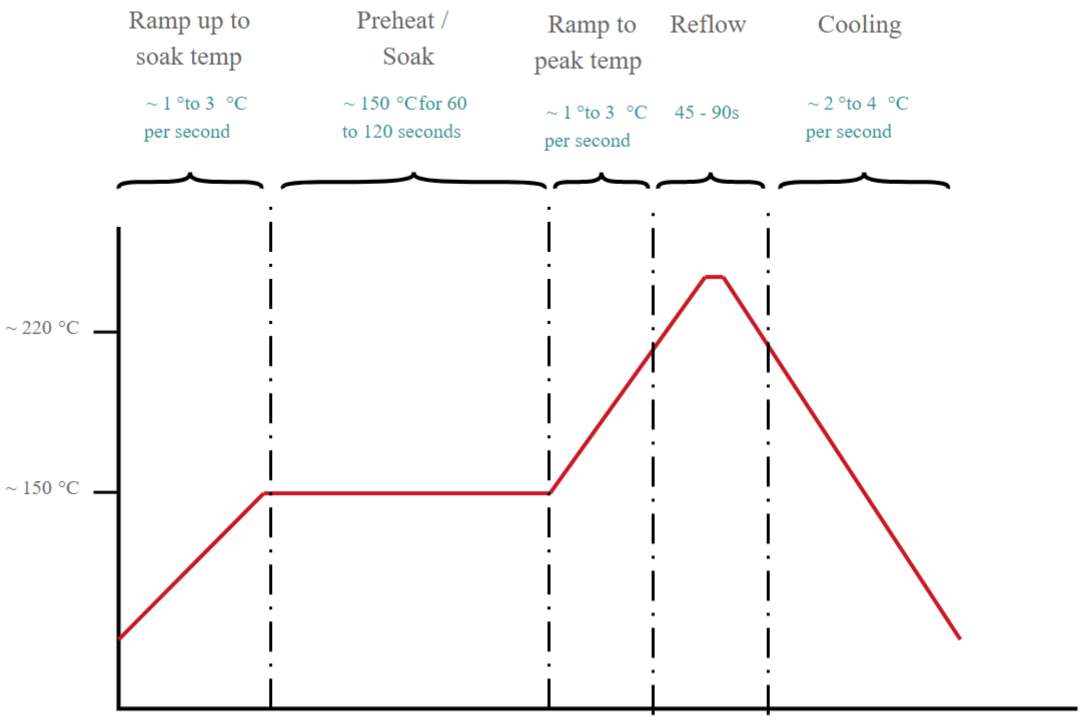

Figure 1: Reflow Process Temperature Profile

Achieving the correct temperature profile during the process ensures the quality of the resulting solder joints and is crucial for preventing component damage.

The following are brief descriptions of the stages that must be followed for the assembly of electronic equipment, with reference to the aforementioned diagram:

Preheating (Ramp up to soak temperature): This stage initiates when the assembly, consisting of the printed circuit board with pre-applied paste and components, is introduced into the oven. The goal of the first segment in the diagram is to gradually bring the assembly to a constant temperature. The gradual temperature increase avoids thermal shocks to the components, preventing potential damage. A sudden temperature increase could cause certain areas not to reach the required temperature due to their thermal mass. The temperature ramp-up rate typically ranges between approximately 1 and 3°C.

Soaking (Soak): After reaching the preheating temperature, the assembly enters the "soak" segment, where it is maintained at a constant temperature for an extended period. This stage ensures that the PCB and components reach the required temperature uniformly, considering possible thermal shadowing areas caused by larger components. Additionally, it allows for the removal of volatile substances from the solder paste and provides time for the activation of the flux.

Ramp to Peak Temperature (Ramp to peak temperature): This segment involves a continuous temperature increase of the assembly to prepare it for the next stage.

Reflow: This is the stage where the soldering process takes place. It reaches the highest temperature in the entire process. Soldering occurs as the solder paste melts, creating the necessary electrical connection. Microscopically, this stage is analysed from the perspective of the solder paste. The flux in the solder paste reduces surface tensions at the meeting point of the two metals (component pad and PCB pad), facilitating the formation of a metallurgical bond by allowing individual solder balls to combine through melting.

Cooling: The temperature decreases for already soldered assemblies is carried out in a way that avoids potential mechanical or thermal stress on the components. Proper cooling inhibits the formation of excess intermetallic compounds (cold solder) or thermal shock. Cooling temperatures typically range between 30 and 100°C. The cooling rate is relatively fast, chosen to create a solder joint with a fine structure and a solid bond, ensuring mechanical strength through the solidification of the liquid metal. The described stages of the reflow process will serve as a foundation for designing the oven within the project.

In the industry, large-sized ovens are used, and the entire mentioned process takes place horizontally. The structure of such an oven can be observed in Figure 2.

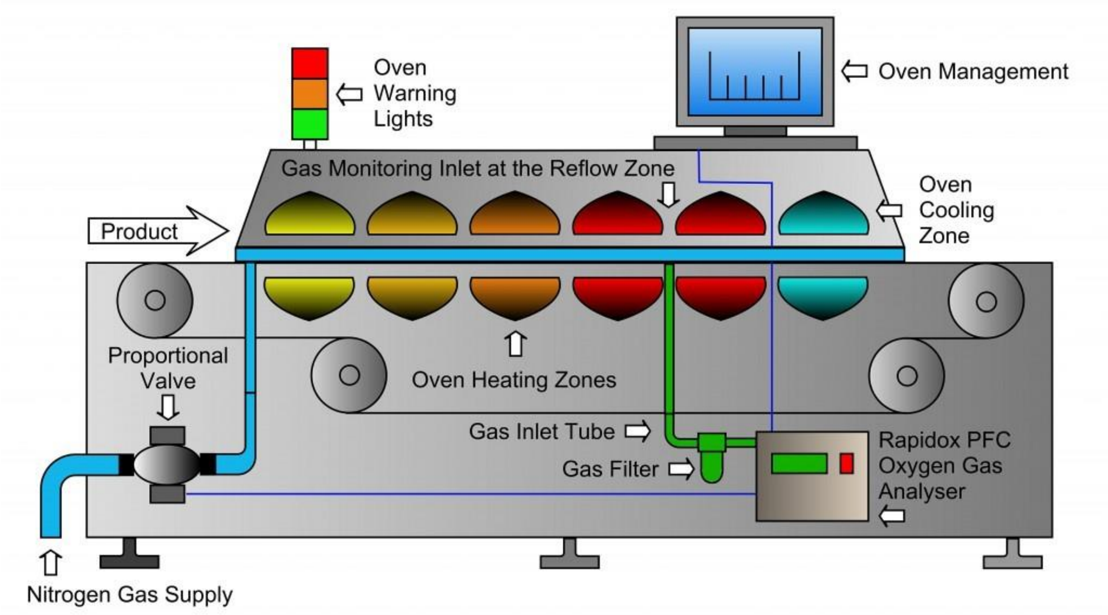

Figure 2. Internal Structure of an Industrial Reflow Oven

In addition to the previously described stages, it should be mentioned that an industrial oven will perform the entire soldering process in a gas environment, with nitrogen, which contributes to the quality of the solder joints. The absence of oxygen in the environment halts the oxidative process, positively impacting the quality of the solder joints.
The oven is composed of several horizontally arranged segments, defining the temperature zones within the reflow curve.

3 Approach

For the design of the entire system, requirements and ways in which they could be implemented will be specified by finding a theoretical solution that can be realized practically with the necessary materials. The final assembly needs to impose a safe operating regimen, considering the integrability of multiple components into the same system.

The technical design of the system will be done in stages, dividing the entire assembly into subsystems that will eventually create the whole system. It is crucial that each block element to be implemented in the end constitutes a whole by combining all the blocks and imposing the condition of coexistence between them. In other words, each implemented block must take into account the other components of the system so that, when combined, the final system can be functional, stable, and safe.

The main idea of a reflow oven is to have a controlled, insulated, and heated chamber where the reflow or "reflow soldering" process of SMD components takes place. Such ovens are used in the industry for mass production of electronic equipment. Before reaching the soldering process, one or more individual PCBs go through the process where solder paste is applied using a stencil, and then automated or semi-automated component placement takes place. Once the PCB reaches the equipped stage, soldering of the components is necessary.

The reflow oven comes into play at this stage, making the soldering of components possible. It is important that soldering is done in a controlled manner, adhering to the data-sheet of the components, as well as the soldering details imposed by the solder paste in terms of soldering phases and temperatures.

This paper aims to address this topic with the purpose of implementing such equipment following the stages of analysis and design. In the end, the goal is to obtain equipment that can produce small and medium-sized batches, enabling the soldering of multiple SMD components simultaneously while adhering to the stages of the reflow process. The oven is intended to be controlled and monitored wirelessly from a device.

4 Implementation

The starting point for designing the system involves traversing the reflow curve and establishing the necessary elements to enable temperature variations using the raw material described earlier.

In the first stage of the reflow process, a gradual temperature increase occurs, involving the two heating elements and the fan for temperature homogenization within the chamber. Solid State Relay (SSR) modules will be used to control these three elements, connecting the DC control part to the AC power part.

The decision to use SSR modules is influenced by their galvanic isolation between circuits and their ability to provide faster command execution compared to traditional relays with coils and moving armature.

Another important factor in choosing SSR command modules is their capability to switch at regular and well-defined intervals, ensuring a smoother current absorption from the power grid while respecting its sinusoidal shape as much as possible. Another element that requires power from the mains is the light bulb for illuminating the oven chamber, and a classic relay can be used for its control since it operates in only two states.

For temperature monitoring, a 100Ω RTD sensor will be used along with a conversion element to be interpreted by the microcontroller.

Regarding the cooling stage of the chamber, a fan will be used to introduce air into the oven, facilitating the cooling process. This stage involves the use of two elements to open and close the ventilation openings.

Safety elements include the addition of a fuse across the entire oven structure to prevent unforeseen incidents, as well as a sensor to determine the state of the door during operation.

Since audible warnings are among the most easily perceived, such an element will be added to emit sounds at certain stages of the process or in case of warnings.

All these elements, of course, require a central control module to execute the entire soldering process.

Finally, it is worth mentioning that the power supply needs of all modules within the equipment are another important consideration in its design.

To provide a clear overview of the equipment's needs, a block diagram has been created, as shown in Figure 3.

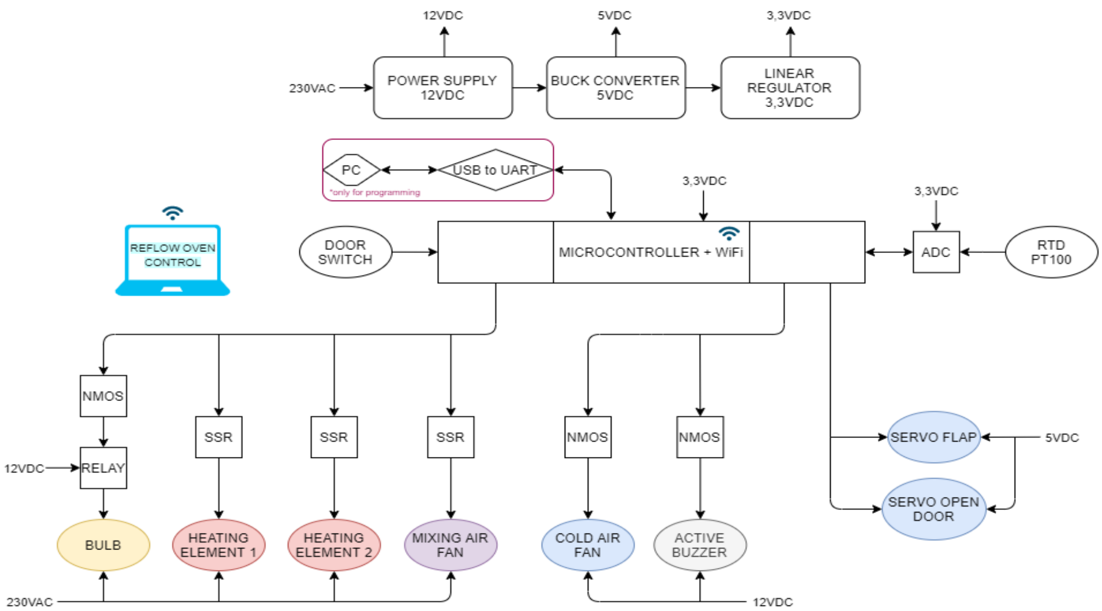

Figure 3: Block Diagram of the System
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5 Technical solution

To enable the interconnection of all modules designed throughout the work, the design of the printed circuit board (PCB – Figure 4) was necessary. Thus, based on the schematic that was created, each functional group of the schematic was translated into the PCB layout.

Several essential considerations were taken into account for the PCB design, especially in this case when dealing with mains voltage, which will be present on the same PCB along with low voltages for supply and control, which are direct current.

The PCB component layout aimed to create an imaginary line of separation between the section working with mains voltage and the section handling low voltages.

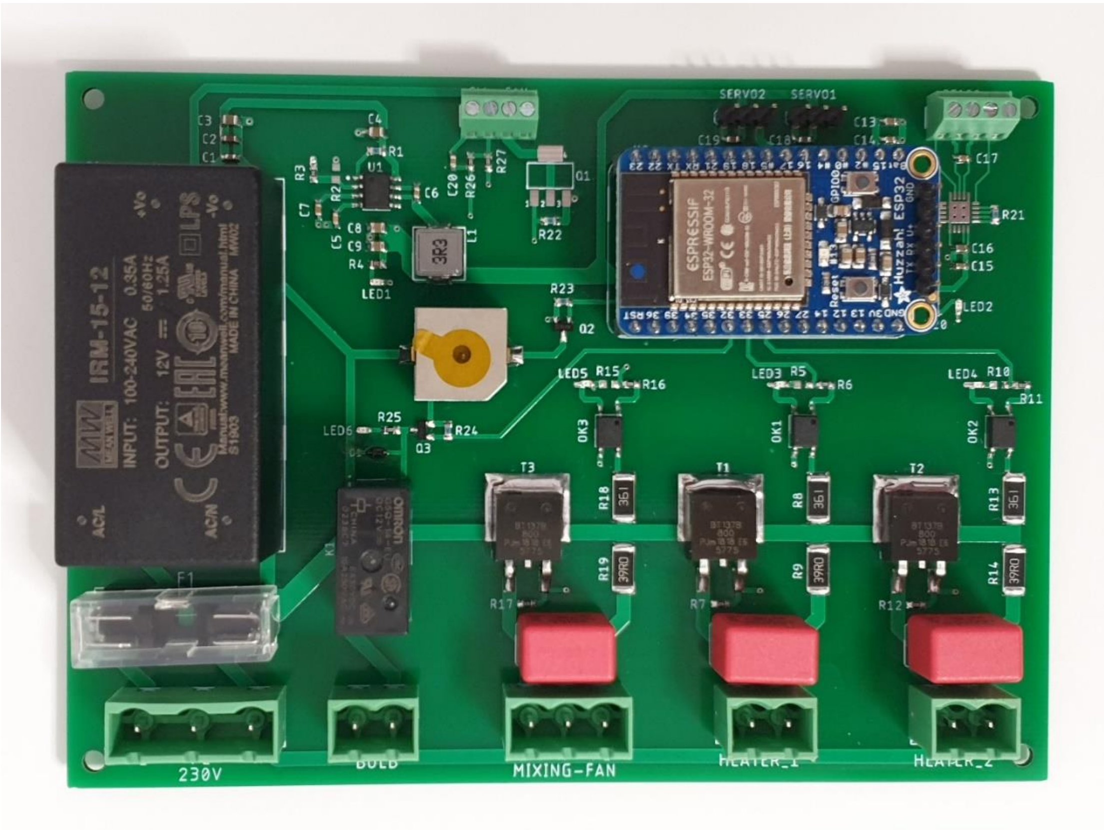

Figure 4: Assembled PCB (Motherboard of reflow oven)

6 Conclusion

The entire conceptual mobilization discussed throughout the work originated from the desire to create equipment through which the soldering procedure of SMD components could be carried out as efficiently as possible. The adoption of this concept was derived from the industrial environment, where such equipment is capable of producing electronic modules on a large scale. However, these devices are intended for mass production of electronic modules, and the process for producing prototypes or small series of equipment is costly and cumbersome.

In this regard, studies were conducted on the soldering process and methods through which it could be performed on a much smaller scale. The objective of the study involved seeking solutions for implementing a reflow oven with functionalities as close as possible to those of an industrial oven. To achieve this goal, a small electric oven was used as the starting point for the research.

It should be noted that heat is the greatest enemy of electronic components, and soldering SMD components onto the printed circuit board must be done in accordance with the manufacturer's specifications in terms of the reflow characteristic for specific components and solder paste. Although this process requires time, it is compensated by the correct operation of the components, preventing damage due to the heat involved in the soldering process.

The constructive elements of the oven were analysed from both electrical and mechanical perspectives. Measurements were taken to determine the electrical parameters of the components, which was necessary for the implementation of control modules. Among the most important parameters were the supply voltage and current consumption.

The next step involved the step-by-step creation of electronic modules, starting from elements that perform input functions to those that perform output functions. Input elements included temperature sensors and micro-switch sensors for door state detection. An industrial implementation method, using an integrated circuit, was employed to interpret the temperature sensor readings.

Output elements included heating resistors, the light bulb, and the fan for air circulation. Control modules using Solid State Relays (SSRs) directly on the circuit board were created for these elements. Component choices were made within all functional blocks following detailed calculations and considering the objectives they were expected to achieve. Various simulations were conducted, along with practical tests, to ensure the implementation was both safe and functional.

In the design process, an initiative was taken to consider the cooling process of the soldered module to fully comply with the reflow process characteristic. Additional elements were added to create an airflow to assist in cooling the oven enclosure.

The project's scope is oriented towards the production of electronic modules, particularly rapid prototyping or creating small series of electronic equipment. In this context, the oven benefits the user by reducing the practical soldering time.

Future development of the project will focus more on user interaction and functionality, aspects that form the basis of the software structure. There is a desire to enhance how the oven operates, closely following the reflow process.

Another idea for further development is to create an Android application for easy user interaction with the equipment. The emphasis of the work has been more on hardware design.

In conclusion, such equipment is useful due to the advantages it offers users in terms of aiding the soldering of SMD components, which is not always easy to accomplish manually and is a time-consuming and energy-consuming process.

Additionally, the advantage of such an IoT device lies in the fact that control can be done from devices we already possess. The reflow oven does not have peripheral elements that allow physical interaction with the user, such as buttons or various types of displays, resulting in material savings. Control is achieved solely through wireless means.

It is worth mentioning that throughout the system's design, significant attention was given to the area of electrical safety, ensuring that the user is not exposed to potential hazards during the operation of the equipment.

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