



Design and Development of a Thermal Management System for Tablets: A Smart Cover Approach to Enhance Safety and Performance

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ABSTRACT

The ubiquity of smartphones and tablets in our daily lives has led to an increased demand for high-performance batteries. However, these batteries are susceptible to explosions due to negligent usage, atypical charging conditions, and overheating caused by battery-intensive applications. In response to this predicament, a novel study proposes the utilization of a "Smart Cover", which functions as a tablet cover capable of assessing and detecting the tablet's temperature. Furthermore, it incorporates a built-in temperature sensor that triggers an alarm when necessary. Additionally, the Smart Cover activates fans integrated within the tablet's cover to facilitate cooling. The design of the cover was achieved through the use of 3D design software in AutoCAD, while an electrical circuit was employed to safeguard tablets against ignition and battery explosions. The research methodology employed in this article is classified as "Modeling and Simulation." From an operational research perspective, ensuring device safety while maintaining performance efficiency is a critical challenge. This study examines the design and effectiveness of smart tablet covers in terms of heat dissipation and explosion prevention, aligning with industrial engineering applications that prioritize product safety and reliability.

1. Introduction and Background

The increasing use of mobile devices and tablets has raised concerns about the safety of lithium-ion batteries. Overheating is a significant risk associated with these batteries, which can lead to battery expansion and potentially explosive situations [1-3]. To address this problem, researchers have designed and developed smart tablet covers that not only dissipate heat but also prevent battery explosions [4].

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The article emphasizes the importance of protecting tablets from overheating and how smart tablet covers with cooling technology can help prevent device explosions and extend battery life. These covers are designed to regulate the temperature of the tablet, featuring air vents and heat-dissipating materials to maintain an ideal temperature [5]. Investing in a smart tablet cover is recommended for any tablet owner to ensure optimal performance and longevity. Tablets have become increasingly popular due to their ease of use and the popularity of Android and Windows operating systems. As more people rely on tablets and smartphones for their daily activities, including education, the need for protection against breakdowns and malfunctions has become more critical [6,7].

Unfortunately, many cases of fires and explosions in tablet and mobile phone batteries are reported annually, highlighting the need for alarm and safety mechanisms in electronic devices [1,5]. As children and teenagers use tablets for educational and even entertainment purposes, an explosion of a tablet can have fatal consequences. Even individuals with physical disabilities use tablets and smartphones. The detonation of a tablet or smartphone battery while in use can be highly perilous and result in harm to various parts of the body [8-11]. Incidents involving lithium-ion batteries that lead to explosions are often caused by factors such as physical damage or exposure to elevated temperatures, which ultimately inflict harm upon the batteries. The primary catalyst for battery destruction is excessive heat, which can trigger chemical reactions or short circuits, thereby increasing the likelihood of an explosion. Batteries serve as an indispensable technology in contemporary society, particularly for powering portable electronic devices like tablets and smartphones [12]. Consequently, it becomes paramount to shield these devices from overheating and other potential hazards to ensure their optimal performance and safety.

The problem under study is defined in Section 2. Section 3 analyzes the thermal behavior of mobile phones. Section 4 presents the study's sketch and methodology. Finally, concluding remarks are presented in Section 5.

2. Problem definition

Lithium-ion batteries offer the highest energy density, providing more power and longer life than other battery types. Therefore, it is necessary to take preventive measures to reduce the possibility of an explosion and fire in the battery. Emergency measures should also be considered. Lithium-ion batteries are commonly used to power portable electronic devices. The principles of chemistry, performance, cost, and safety of different lithium-ion batteries differ. Handheld electronics mostly use lithium-polymer batteries (with polymer gel as the electrolyte). Lithium cobalt oxide (LiCoO_2) serves as the cathode, while graphite functions as the anode, resulting in a high overall energy density. Since lithium-ion batteries have high power, they can be used in devices that require high electrical power; however, this high power can also be a factor in

frequent explosions [13]. In this study, we will design and simulate a tablet cover, known as a "Smart Cover," according to the facilities and needs we expect it to provide. The goals of designing this cover include:

1. The cover should provide physical protection for the tablet, preventing damage caused by possible shocks to the battery and other device components. Additionally, it should have the ability to charge as a mobile power bank, supplying energy when needed.
2. The cover should detect temperature rises in the tablet that are generated in the battery and other parts in a closed environment due to high density. Upon detection, it should alert the user.

3. Scrutinizing the thermal behavior in Mobile Phones

Smartphone Heat Generation and Transfer: Within a conventional mobile phone, the major sources of heat are the electronic chips mounted on the printed circuit boards. These include transistors, integrated circuits, resistors, and the phone's battery. Each of these internal components possesses its unique thermal conductivity, electrical resistivity, and specific heat capacity, among other properties. When a smartphone is in use, the electric current flowing through its components encounters resistance, resulting in the generation of basic heat [14].

When a smartphone is in use, its components meet with resistance, which results in the most basic form of smartphone heat generation, as given by equation (1):

$$P = I^2 R \quad (1)$$

Where P is the heat generated, I is the electric current, and R is the resistance to the flow of current. As equation (2) shows, this generated heat is proportional to the temperature increase in the components:

$$P = mc \Delta t \quad (2)$$

$$P = hA(T_s - T_f)$$

Where m is the mass of the component, c is the specific heat capacity, and Δt is the magnitude of temperature increase [15].

Furthermore, the battery itself emits heat as it discharges during use. In reference, experiments conducted on lithium-ion batteries found that they generate heat due to battery resistance, known as "ohmic heat", as well as due to entropy change. Mathematically, this heat generation is represented by equation (3):

$$P_{bat} = P_{bat.r} + P_{bat.s} \rightarrow I_{bat}(t)^2 \cdot r_{int} - T_{bat} I_{bat}(t) \frac{\partial V^{oc}}{\partial T} \quad (3)$$

Where P_{bat} is the total heat generated by the battery, $P_{bat,r}$ is the ohmic heat, $P_{bat,s}$ is the heat due to entropy change, $I_{bat}(t)$ is the battery discharge current at time t , r_{int} is the internal resistance of the battery, T_{bat} is the battery temperature at time t , and V^{oc} is the battery open-circuit voltage [15].

Additionally, it can be generally stated that the thermal behavior of a mobile phone is influenced by factors such as heat production rate, thermal conductivity, and heat loss rate. Equations such as $P = mc\Delta t$ and $P = hA(T_s - T_f)$ can be used to model the heat transfer between the phone and its environment based on factors such as specific heat capacity, surface area, and temperature difference. By understanding the thermal behavior of mobile phones, we can develop effective strategies to mitigate overheating and ensure optimal performance.

Excess heat generated by smartphones (above 45°C) can damage internal components and cause discomfort for users. When considering the mode of heat transfer from the internal components of the phone, a model was developed based on the electrical analogy of heat transfer. This model specifies a bidirectional pattern of heat transfer, one through the back cover of the smartphone to the surroundings and another through the smartphone's display. Heat travels via conduction within the smartphone and by natural convection from the smartphone surface to the surroundings [16].

Typically, a mobile phone is constructed with multiple layers, including the keyboard, PCB, chips, bottom case, and battery. The front case and keypad are usually considered as one layer, known as the screen. Chips, responsible for generating heat, are soldered onto the PCB (printed circuit board). Aside from serving as an enclosure wall, the bottom case also holds the battery in place. For analysis, a schematic diagram of a typical five-layer mobile phone, without an additional shielding layer, is depicted in Figure 1. Although some mobile phones may have a different structure, the system analysis method utilized in this paper can still serve as a reference for mobile phones with varying layers [14].

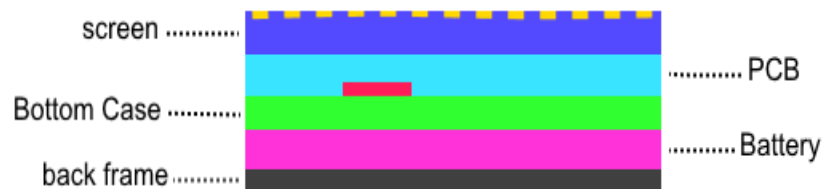


Figure 1. Layers of mobile phones and tablets.

Thermal management is a critical design challenge for smartphone devices as it impacts both device reliability and energy consumption. Traditional dynamic thermal management techniques are effective for computer systems; however, physical space constraints in smartphones result in a significant thermal coupling effect between major heat-generating components, such as the application processor and the battery. As a result, the temperature of one part is influenced by the temperature of other parts, making thermal behavior interdependent. Ideally, thermal management studies involve precise and rapid physical

modeling that aids in making informed decisions about materials, components, and layout, alongside power control feedback, to achieve optimal performance and target lifetime while minimizing testing requirements.

4. Methodology and sketching

4.1. Experimental

During a straightforward test, two phones from different brands were monitored for 60 minutes using a CPU monitoring program. The test included offline music streaming, social media usage, video calls, internet browsing, and video streaming. The purpose of this test was to measure the heat levels generated by mobile phones during use. We use Android CPU Monitor, one of the most advanced programs for monitoring CPU consumption, developed specifically for the Android operating system. With this tool, you can monitor the temperature and frequency of your processor in real-time and view a graph of your information over time.

Additionally, the software displays battery information. Android CPU Monitor collects data from your system's sensors with high accuracy and presents it with a user-friendly interface. The CPU Monitor Android software, developed by System Monitor Tools Lab, is publicly available on the Google Play Store. In this test, we used three Tablet phones from different brands (the names of the brands are omitted) with the same RAM and CPU specifications as in Table 1. Temperature changes are presented in Table 2.

Table 1. Technical specifications of the tablet

Tablet phone model	Tablet phone ROM GB	Tablet phone CPU core
Tablet phone 1	8	8
Tablet phone 2	8	8
Tablet phone 3	8	8

Table 2. Temperatures obtained during 1 hour

Tablet phone model	0-30min	0-60min
Tablet phone 1	30-36°C	30-53°C
Tablet phone 2	30-37°C	30-52°C
Tablet phone 3	30-37°C	30-55°C

4.2. Expression of circuit design based on sensor

The LM35 sensor is a highly accurate temperature-measuring device. It is an integrated temperature sensor with three pins that act as an integrated circuit. Pin 1 serves as the source, while pin 2 (the middle pin) is used as the output voltage or V_{out} . The operating range of the LM35 sensor voltage is between 4V and

30V, and the output voltage range is 0V to 1.5V. Pin 3 acts as the ground, as shown in Figure 2. Additionally, this sensor has a coefficient of 10 mV/°C, which means that for every 1°C increase in temperature, there is a corresponding increase in voltage of 10 mV [17]. Working voltage: DC 4~30V;

- Working current: less than 130 uA;
- Output voltage: + 6V —1.0V;
- Output impedance: 1mA load 0.1^2;
- Measuring precision: 0.5 °C (in + 25 °C);
- Leak current: less than 60 uA;
- Scale factor: linear + 10.0 mV / °C;
- Nonlinear value: ±1/4 °C;
- Calibration means: using direct Celsius temperature calibration;
- Measuring temperature range:- 55 °C to 150 °C.

In the Altium Designer software, the circuit of Figure 2 is designed, and the parts used in this circuit are based on the LM35 sensor.

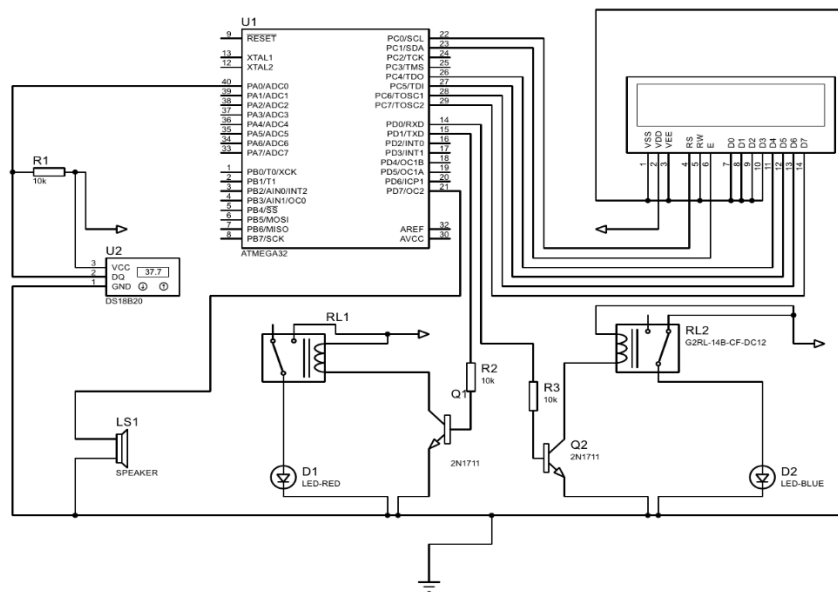


Figure 2. Electric circuit designed

After designing the circuit in Altium Designer software, we assembled it piece by piece on a breadboard for testing. We were pleased to find that the device worked properly. However, creating a circuit small enough to fit inside a tablet or mobile cover requires advanced technology capable of using very small parts and layering them within the cover.

As depicted in Figure 2, this circuit is composed of parts that take into account all relevant aspects. It's possible that certain parts may not be required for specific designs. Nevertheless, we made a concerted effort to consider all aspects and potential use cases, resulting in a comprehensive circuit design.

4.3. Modeling Smart Cover

In the first step, the cover is modeled using AutoCAD software, and then the circuit is placed within the body of the cover, as per previous research conducted. The temperature sensor is then placed flat on the back of the cover to sense (measure) the temperature on the back of the tablet when the tablet starts working. Figure 3 shows an image of a cover in which the temperature alarm system of the tablet can be placed to warn when the temperature rises, as explained in the previous section in detail. In continuation of the discussion, Figure 3 depicts a schematic showing the placement of the tablet or phone within the cooling cover, along with a fan, battery, and circuit.

The cover is made of Silicone, and an electrical temperature-measuring circuit (PCB) is installed and embedded in it. The sensor is placed inside the cover to sense the tablet's temperature accurately. To enhance heat absorption, a piece of aluminum is placed on the cover and connected to it, which quickens the conduction of heat from the tablet to the sensor. This multifunctional cover serves as both a protector and an alarm system, alerting the user when the device overheats. Additionally, a cooling fan may be installed to cool the device, and it can also serve as a power bank. However, these capabilities are dependent on the design and molding of the Smart Cover.

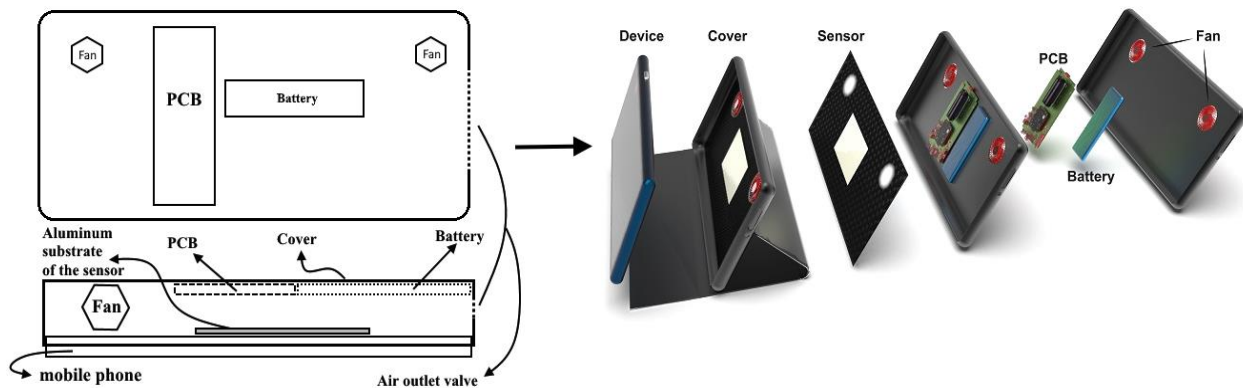


Figure 3. cover design:(a) 3D cover design(b)

A concern may still exist that if the temperature rises too high and the system warns, but the user does not notice, there is a probability that our device will explode. For this issue, we have designed the circuit so that its outputs are located within the fan cover, allowing it to turn on the fans for cooling. Besides that, they can warn the user.

As shown in Figure 3, the system operates on a micro level, and according to the program designed for it, settings can be changed as needed. Indeed, it is designed in a way that it can receive output, and at the same

time, the output can be connected to the cooling mini-fans. Fans are used to cool the system during periods when the tablet is experiencing a temperature rise. Currently, the circuit includes two LEDs and a speaker as its alarm output. The core of the circuit and its processor is an At-mega IC. The system's overall output is such that it displays the necessary warning if the tablet's temperature rises. It can be easily placed in the body of the tablet cover. When the sensor detects a high temperature, it sends a signal to the IC, instructing the transistor to switch on. However, a relay is included in the circuit so that when the transistor is connected to the cooling fan, it causes the transistor to burn out. Since the transistor is unable to handle the fan's flow, it activates the relay, which turns on the cooling fan, as well as the alarm and lights.

5. Conclusion

In this article, we have explored the primary cause behind the occurrence of explosions in smart devices. Additionally, a proposed solution is discussed to mitigate the risk of explosions in phones and smart devices. The design demonstrates the potential to achieve desired objectives by incorporating fundamental principles of safety and energy, along with simple controls. By enhancing user security, this design introduces a new type of tablet cover called the "Smart Cover," which utilizes 3D design technology from AutoCAD. The Smart Cover not only serves as a protective case for the tablet but also incorporates temperature measurement and detection capabilities. In the event of excessive heat, the built-in temperature sensor triggers an alarm and activates the fans integrated into the tablet's cover to cool it down. This innovative instrument employs an electrical circuit to safeguard tablets from fires and battery explosions. While the practical implementation of this concept has not yet been executed on tablets, it holds significant potential based on scientific data and design methodologies. A business model detailing the accessibility of this solution to the public will be forthcoming in the near future.

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