FAST CHARGING TECHNOLOGIES FOR MODERN SMARTPHONES AND THEIR OPERATING PRINCIPLES

Xalikov.S.S
Associate Professor at the Department of "Radio Electronic Devices and Systems" Tashkent State Transport University, Candidate of Technical Sciences

Abstract: *This article analyzes the development of charging systems for modern smartphones, their technical capabilities, and operating principles. Unlike traditional chargers, modern smartphones consume more power due to the presence of operating systems with high resource demands and radio modules constantly connected to digital networks. As a result, the capacity of modern batteries has significantly increased, making the development of efficient and safe charging methods a relevant challenge.*

The article examines the fast charging principles based on Qualcomm's "Quick Charge" (QC) technology, as well as the universal "USB Power Delivery" (USB PD) standard, their versions, differences, and operational algorithms. Additionally, experimental methods were used to study the charging process of various smartphone models using the QC 2.0 standard; the results were analyzed, and a comparative table was provided.

The study investigates the relationships between smartphone battery capacity, charging current, and charging time, the role of internal electronic circuits in controlling charging speed, and the characteristics of modern high-power chargers used for next-generation batteries. It demonstrates the possibility of increasing charging power not by current strength but by raising the voltage according to the USB PD standard.

This article may be useful for students, engineers, and specialists studying modern approaches in smartphone charging technologies and battery systems.

1. INTRODUCTION

The power supply of modern smartphones has drastically transformed from a conventional charger into a smart device that manages voltage and/or current. Older mobile phones did not require adjustments to their volt-ampere characteristics. However, the operating system and hardware of smartphones consume significantly more energy than older mobile phones due to increased capabilities and the constant connection of radio modules to various digital networks such as the Internet. This has influenced the growth in battery capacities (measured in milliampere-hours). The challenge of efficiently charging such batteries remains a relevant issue for major smartphone manufacturers.

One technical solution to this problem is altering the volt-ampere characteristics of the electrical current supplied by the charger. This specification is known as "Quick Charge (QC)" or its counterpart "USB Power Delivery (USB PD)." QC technology was developed by Qualcomm and includes the following features:

- Transmission of increased power through USB cable infrastructure with connectors exceeding standard USB specifications. For maximum efficiency, both the charger and the device must support the Quick Charge specification.
- Technology for gentle and fast charging of batteries.
- A chipset package for battery management and mobile device power supply.

Some chargers support both QC and USB PD charging technologies, offering universal compatibility.

The most commonly used charging standards for smart devices include:

- **BC 1.2 (USB Battery Charging Revision 1.2)** – the first fast charging standard (5 V, 500 mA). The type of charger is identified by the voltage on the D+ and D– contacts of the USB port.
- **QC 1.0** – a fast charging technology (5 V, 2 A) compatible with the USB Battery Charging specification. The mechanism for identifying the charger became much smarter, allowing devices using QC 1.0 to select the appropriate charging current more accurately.
- **QC 2.0** – a key distinction of this technology compared to previous standards is the use of various voltage and current combinations within the ranges of 5 to 20 V and 1.5 to 2 A (power source voltages of 5, 9, 12, and 20 V for the device VBUS).
- **QC 3.0** – unlike QC 2.0, where voltage could only be selected from fixed values of 5, 9, 12, or 20 V, QC 3.0 allows voltage to vary incrementally in 0.2 V steps, expanding the voltage range to 3.6–20 V (with 5–12 V being the most commonly used). The maximum power remained at 18 W, the same as the previous version.
- **QC 4.0 and QC 5.0** – these technologies are currently under development. It has been revealed that QC 4.0 chargers support both QC and PD charging protocols, and this technology will enable charging a 2750 mAh battery for 5 hours of use in just 5 minutes, and charging the battery from zero to 50% in 15 minutes. QC 5.0 allows chargers with power exceeding 100 W and adds compatibility with USB Power Delivery 3.1. Compared to QC 4.0, the fifth version is four times faster, 70% more efficient, and reduces battery heating by 10°C.

2. RESEARCH METHODS

In the past, the charging time of mobile phones depended primarily on the capacity of their batteries. The charging time for older mobile phones was approximately 8–10 hours, and their battery capacities ranged up to about 1000 mAh (with actual capacities between 500 mAh and 750 mAh). Battery capacity was closely related to the multifunctionality and capabilities of the phone's operating system and electronic components.

Today, the difference in battery capacity between old phones and modern smartphones exceeds a factor of 10. This is due to several factors, such as increased performance and speed of smartphones, as well as power consumption by applications running in the background. The greater the power consumption, the faster the battery discharges. Consequently, manufacturers had to increase the battery capacity of smartphones.

To achieve faster charging, manufacturers increased the amount of energy delivered per unit time, i.e., charging batteries with higher current. Thus, the charging time of a battery is determined by the current strength. However, this charging method cannot be applied to all smartphone batteries indiscriminately, as battery operation requires adherence to several conditions. The most important condition concerns the maximum current with which the battery can be charged. In practice, this value is linked to the battery capacity for each specific model by a coefficient:

$$k = \frac{I}{C}$$

where: I - is the charging current; C - is the battery capacity.

For example, if a battery has a capacity of 3000 mAh and the documentation specifies a charging coefficient of 0.5, or it is indicated in the battery manual as 0.5 C (where *C* stands for *Capacity*), then the battery can be charged with a current of 1.5 A, that is:

$$0{,}5 = \frac{1500}{3000}$$

This charging current can be varied: lowering it extends the battery's service life but slows down the charging process, while increasing the current saves time but negatively affects both the battery's lifespan and its condition. Naturally, users consistently demand that device charging times become significantly faster. As a result, in recent years, the efforts of scientists and engineers have been focused on this issue, and over the past 20 years, significant work has been dedicated to increasing the aforementioned charging coefficient.

In the latest generations of smartphones, batteries are installed in a built-in, non-removable format. In classic smartphones or older mobile phones, users could easily replace the battery themselves without the need for a specialist. These lithium-ion batteries contained a liquid electrolyte and were housed in a metallic (usually aluminum) casing, which ensured safe operation even under mechanical impact.

Built-in batteries, however, are manufactured using more modern lithium-polymer (Li-Po) technology, which utilizes a gel-like electrolyte. Thanks to this, they do not require a sturdy metal casing. One of the key advantages is that the battery shell walls can be made thinner, allowing more electrolyte to be packed into the same volume – thereby increasing the battery's overall capacity.

Of course, this type of battery also has its disadvantages: it is more fragile and therefore more hazardous in use. Since it lacks a rigid outer shell, these batteries were designed to be non-removable and maintenance-free. Manufacturers typically install them within solid device enclosures to provide physical protection.

However, greater capacity is not the only advantage of lithium-polymer batteries. With the advancement of technology, developers have succeeded in raising the allowable charging coefficient. For instance, a modern battery with a capacity of **4000 mAh** can now be charged with a current of up to **8 A**, which is twice the nominal value:

$$2 = \frac{8000}{4000}$$

It is well known that the value indicated in milliampere-hours (mAh) represents the amount of current a battery can supply to a load over the course of one hour. For example, a battery with a capacity of **2000 mAh**, when discharging at a current of **2 A**, would ideally last exactly one hour. Likewise, if we ignore losses, charging this battery with a **2 A** current would also take exactly one hour (**I = 2 A, t = 3600 s**). It's easy to calculate that fully charging a battery with a charging coefficient of **2** — regardless of its capacity — would take only **0.5 hours**, which is a phenomenal improvement compared to what we saw just 10 years ago.

In practice, the charging current for smartphone batteries is not determined by the external charger but by the charging control circuitry integrated within the smartphone's internal electronics. If you connect a charger capable of providing a higher current to a smartphone, contrary to popular belief, the phone will neither malfunction nor charge any faster. The charging process will proceed at the rate dictated by the smartphone's built-in charging controller. An external charger cannot force the phone to draw a higher current than it is designed to accept. However, there is one drawback: if the external charger's output is lower than the phone's required charging current, it will become a limiting factor in the process.

Scientists and engineers have already developed batteries that can be charged with currents up to **8 A**. But this raises a question: how can smartphones support such high charging currents when a standard USB charger delivers only **1.5 A at 5 V**? Moreover, how can this **8 A** current be transferred through a standard USB cable, whose wiring isn't designed for such loads? This issue first arose for manufacturers around **15 years ago**, when the earliest smartphones appeared. One of the key features that set smartphones apart from simpler mobile phones was their ability to exchange data with computers over a USB connection. However, the **USB 2.0** specification, published in **2000**, allowed for a maximum current of only **500 mA**, which was already insufficient for efficient battery charging, even by the standards of that time.

As is well known, standard USB cables have four lines: two for power supply and two for data transmission. Manufacturers agreed on a solution: to use the data lines in the USB cable as a signal to indicate the connection of a higher-power charging device. In chargers supporting fast-charging modes, the data lines of the USB cable were shorted together. When a smartphone was connected to the USB port, the circuit responsible for USB communication would check for continuity between the two data pins. If this connection was detected, commands were sent to the internal charging controller to increase the current consumption up to **2 A**. If no such connection was detected, the smartphone would continue to draw only **500 mA** from the **+5 V** power line as usual.

3. RESEARCH RESULTS AND DISCUSSION

To examine the basic standard for fast charging, we conducted an experiment by assembling a circuit (Figure 1), which demonstrates a charging system based on the **QC 2.0** standard. In **Figure 1**, the following devices were selected for the experiment:

- **Laboratory power supply** – to provide **12 V** input to the **DC-DC converter;**
- **DC-DC converter –** to convert **12 V** to **5 V;**

- **USB-A connector** – serves as an adapter;
- **USB tester** – for monitoring the connected load parameters;
- **USB cable** – to connect smart devices;

Various smart devices were selected as the load for this experiment.

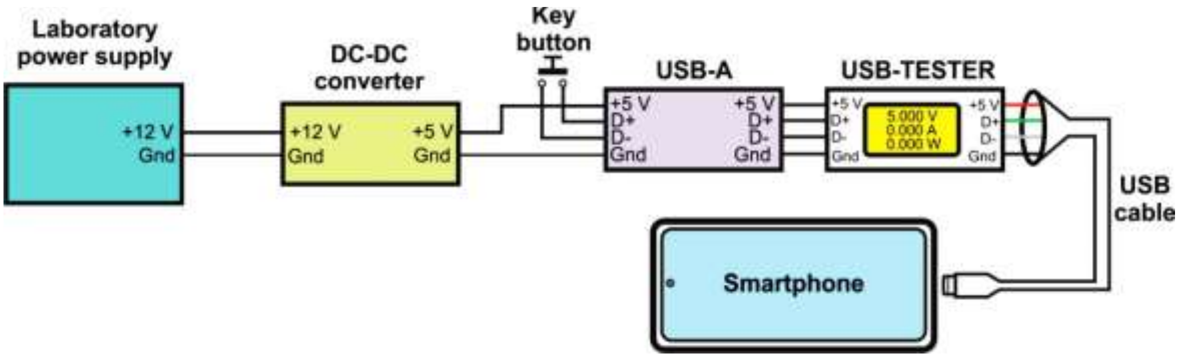

Figure 1. Experimental circuit for observing the operation of a QC 2.0 standard charging device

At the initial stage, a **ZTE Obsidian** smartphone was connected to the simple test stand. The device identified a regular charging connection, and the tester displayed the following values: **5.204 V**, **0.405 A**, and a power consumption of **2.107 W**.

After pressing the **key button** and closing the circuit between the **USB D+ and D- data lines**, it was observed that the device responded to the command – the charging current increased, with the tester showing **5.180 V, 0.888 A**, and **4.599 W**. However, the device did not utilize the available **2 A** in this mode. The explanation is simple: the battery capacity is only **1800 mAh**, and its lithium-ion design limits the charging rate to **0.5 C**, which equates to **900 mA** for this capacity.

Next, an **iPhone 7** was connected to the stand. Initially, no significant changes were observed. However, after closing the signal circuit with the **key button**, the device recognized the modified state of the USB data lines and switched to the charging mode. The tester then showed **5.155 V, 1.461 A,** and **7.532 W**.

Finally, a **Samsung Galaxy S8** was connected to the stand. This device, upon first connection to the USB cable, immediately switched to standard charging mode, with the tester displaying **5.196 V, 0.493 A**, and **2.562 W**. After activating the **key button**, the smartphone increased the charging current to **1.7 A**, continuing the charging process, while the tester recorded **5.147 V**, **1.639 A**, and **8.438 W**.

Thus, the **QC 2.0 protocol**, based on switching the **D+ and D- USB data lines**, is part of the **USB BC 1.2 (Battery Charging)** specification. Charging devices operating under this standard are classified as **DCP (Dedicated Charger Port)** – ports not used for data transfer.

The summarized results of the experiment are shown in **Table 1**.

Table 1

Experimental results of observing the operation of the charging test stand for smart devices

№	Type of smart devices	Battery capacity	Device response without key connection			Device response in key-connected mode		
			Voltage, V	Current, A	Power, W	Voltage, V	Current, A	Power, W
1.	Smartphone ZTE OBSIDIAN	1800 mAh	5,204	0,405	2,107	5,180	0,888	4,599
2.	Smartphone iPhone 7	1960 mAh	0	0	0	5,155	1,461	7,532
3.	Tablet Nextbook BRT81	2900 mAh	5,196	0,457	2,385	5,172	1,210	6,260
4.	Smartphone Samsung Galaxy S8	3750 mAh	5,196	0,493	2,562	5,147	1,639	8,438

In addition, continuing the ideology of fast charging, some manufacturers have developed additional protocols that are activated by setting specific voltage levels on the signal lines using resistor dividers. These voltages are read by the smartphone's USB controller and used to identify the charging device. According to this scheme, most devices switch to the regular charging mode.

From Figure 2, it can be seen that different chargers, when connected not through the standard smartphone port, do not switch the device to fast charging mode. To achieve fast charging, it is possible to experiment with changing resistor values so that the smartphone switches to fast charging mode.

Thus, achieving a charging current of 8 A by simply shorting the USB signal lines is not possible, as the USB cable wiring is not designed for such current capacity. Nevertheless, modern smartphones have found a solution to this problem. In fact, smart devices require power rather than just current. Therefore, by increasing the voltage periodically rather than the current, the required power for charging smart devices can be achieved. To solve this problem, a new standard called USB PD (Power Delivery) was developed.

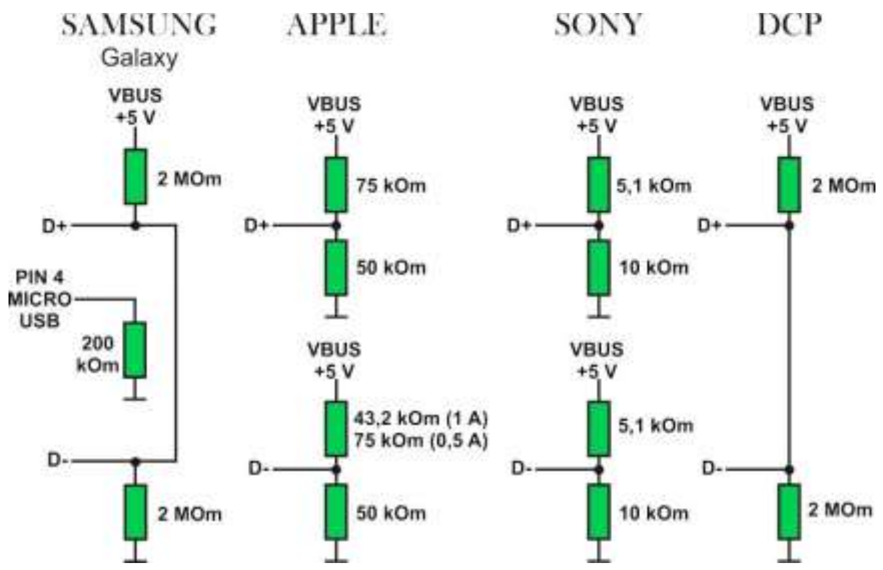

Figure 2. Setting resistor dividers to establish specific voltage levels on the signal lines of charging devices from leading manufacturers

To continue the charging experiment with smart devices, tests were conducted according to the Power Delivery standard using a Samsung Galaxy S8 smartphone and a MacBook laptop. For this purpose, the "Super-Fast Charging" and "Apple A1540 USB Type-C" chargers from Samsung and Apple were selected (Figure 3).

According to the specifications, the Super-Fast Charging charger supports the USB Power Delivery Programmable Power Supply (USB PD PPS) third generation standard, i.e., PD3.0, with a maximum power output of 25 W. Output voltage: according to the Power Data Objects (PDO) standard – 9 V; according to the PPS standard – 3.3–5.9 V or 3.3–11.0 V. Output current according to PDO – 2.77 A (9 V); according to PPS – 3.0 A (3.3–5.9 V) or 2.25 A (3.3–11.0 V). The Apple A1540 USB Type-C charger specifications are: output voltage – 14.5 V; output current – 2 A; maximum power – 29 W. To monitor voltage-current characteristics, a digital voltmeter and ammeter were connected in the circuit. The connection to the smartphone and laptop test bench differs in Type-C signal lines: the laptop initiates fast charging through the CC port (Figure 3.a), while the smartphone uses the TX and RX ports (Figure 3.b).

When connecting the charger to the laptop, it was found that the charger sets 14.4 V and gradually increases the current to 1.9 A, with a maximum power of 27.4 W.

The programmable controller in the "Super-Fast Charging" charger, compliant with the USB PD standard, can read the voltage and transmit its value over the signal lines to the smartphone processor. The smartphone processor compares this voltage at the USB connector and determines the current voltage drop in the USB cable (during the experiment $\Delta U = 5.217 - 4.927 = 0.29$ V). This method helps prevent cable overheating and monitors its condition and manufacturing quality. During the experiment, the "Super-Fast Charging" charger performed standard switching according to the PD protocol.

There is another interesting protocol called Direct Charge (DC). This standard differs from others by the method of connecting the charger to smartphones. Here, the connection between the charger and the smartphone is also made through data transmission via the signal lines. After message exchange, the smartphone's charge control circuit activates a bypass MOSFET switch (an internal circuit in the smartphone) and connects the USB cable's power line directly to the positive terminal of the battery. This connection method primarily reduces heat generation inside the smartphone.

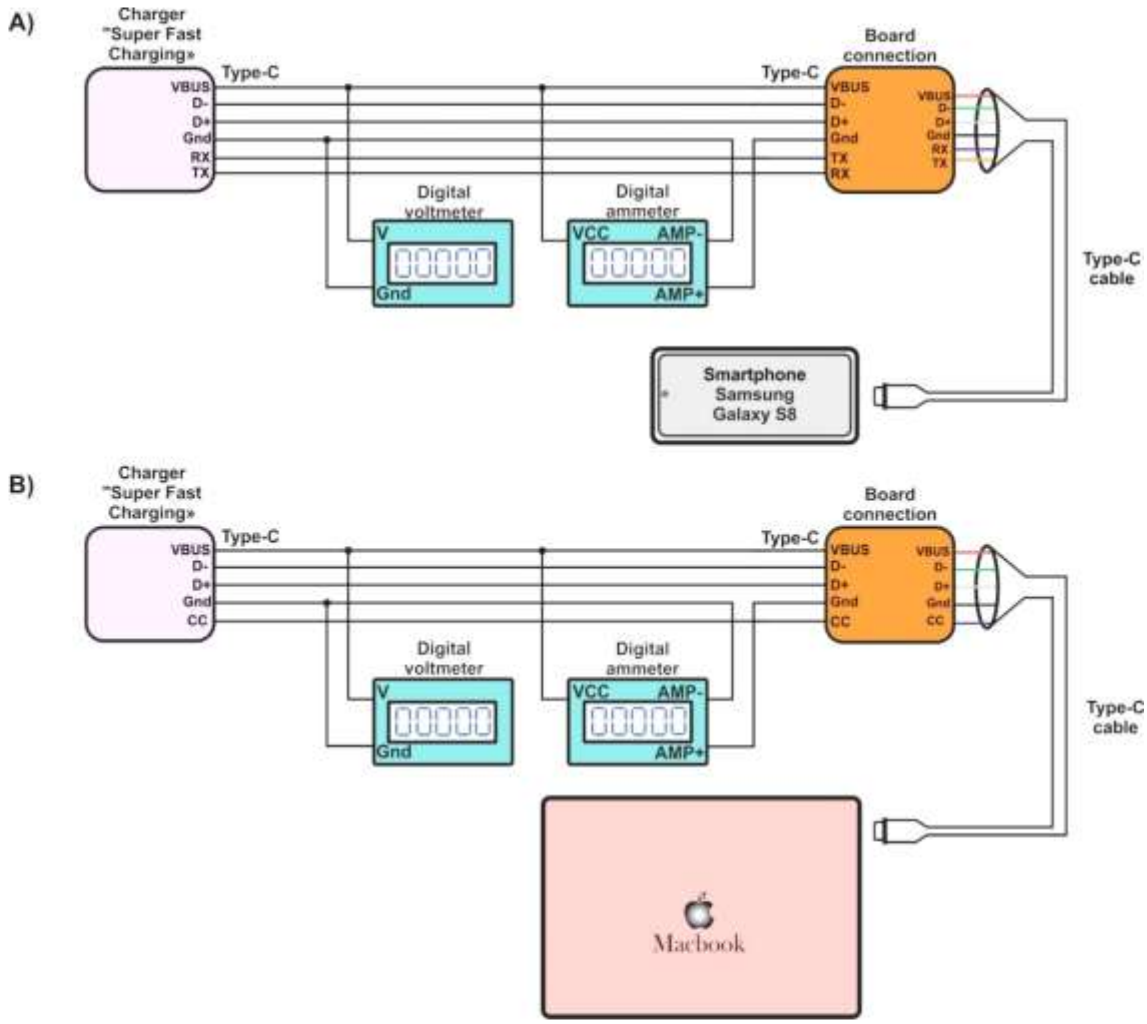

Figure 3. Investigation of smart devices using the Power Delivery connection standard

Of course, compared to USB PD, the DC standard has drawbacks in terms of energy capacity, as the charging current cannot exceed 2 A. Therefore, the developers of the DC standard created interactive USB cables. These cables differ from ordinary USB cables by containing a chip with identification information about the maximum current supported by the cable. This makes it possible to produce cables with thicker conductors and a current rating of up to 5 A, while when using a standard cable, the charger will automatically reduce the current to 5 A.

CONCLUSIONS

The development of modern smartphones and their functional capabilities has led to a significant increase in battery capacities, which in turn required improvements in charging technologies. Older mobile phones could be charged using standard chargers with fixed voltage and current parameters, whereas modern devices demand intelligent management of the charging process.

To address this challenge, fast charging technologies such as Quick Charge (QC) and USB Power Delivery (USB PD) were developed. These technologies allow dynamic adjustment of voltage and current parameters depending on the battery's condition and the smartphone's capabilities. QC technologies, from version 1.0 to the current 4.0 and 5.0, have progressively increased the allowable charging power, voltage ranges, and implemented intelligent control mechanisms, ensuring both reduced charging time and improved safety.

Experiments have shown that different devices respond differently to the activation of fast charging mode by shorting the USB signal lines (D+ and D-), which is the basis of the QC2.0 protocol. It was also demonstrated that even when using powerful chargers, the charging current is limited by the smartphone's internal controller according to the allowable charge rate (C-rate).

The transition to new types of batteries, such as lithium-polymer, has enabled increased capacity and higher allowable charging currents but also required the development of new energy transfer standards, since classic USB cables and connectors are physically not designed to handle currents above 2 A.

Therefore, the development of the USB PD standard was a logical step forward – by increasing the voltage of transmitted power, the required charging capacity can be achieved without exceeding critical current levels. This made it possible to implement ultra-fast and safe charging for modern smartphones, laptops, and other mobile devices.

Thus, modern charging systems represent a combination of advanced charging parameter control technologies, new connection standards, and batteries with enhanced capacity and allowable charging currents.

REFERENCES

1. **Qualcomm Technologies, Inc.** Quick Charge Technology Overview. Qualcomm official documentation and whitepapers. Available at: https://www.qualcomm.com/products/quick-charge
2. Huang, J., & Wang, S. (2020). Review on Fast Charging Technologies for Lithium-ion Batteries in Smartphones. Journal of Power Sources, 451, 227765. https://doi.org/10.1016/j.jpowsour.2019.227765
3. USB Implementers Forum (USB-IF). (2020). USB Power Delivery Specification Revision 3.0. Available at: https://usb.org/document-library/power-delivery
4. Zhang, L., Li, H., & Chen, Z. (2018). Battery Management and Fast Charging Control for Lithium-Polymer Batteries. IEEE Transactions on Industrial Electronics, 65(7), 5706–5715. https://doi.org/10.1109/TIE.2017.2789640
5. Ma, C., & Sun, J. (2019). A Comparative Study of USB Battery Charging Specifications: BC 1.2, QC 2.0, and USB PD. Electronics, 8(6), 668. https://doi.org/10.3390/electronics8060668

6. Choi, S., & Lee, Y. (2017). Development of Smart Charging Circuits with Integrated Battery Management Systems for Smartphones. Journal of Energy Storage, 11, 36–44. https://doi.org/10.1016/j.est.2017.03.001

7. Kim, D., & Park, J. (2016). Design and Implementation of High-Power Fast Charging Protocols for Portable Devices. IEEE Transactions on Consumer Electronics, 62(3), 253–259. https://doi.org/10.1109/TCE.2016.7578937

8. Liu, H., & Zheng, L. (2018). A Study on the Effect of Charging Current and Voltage on Lithium-Polymer Battery Lifespan.Energy Reports, 4, 227–235. https://doi.org/10.1016/j.egyr.2018.02.001

9. Battery University. How to Prolong Lithium-based Batteries.Available at: https://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries

10. Samsung Electronics Co., Ltd. (2021). Super-Fast Charging Technology and Specifications. Technical white paper. Available on Samsung developer resources.

11. Apple Inc. (2021). USB-C Power Adapter Specifications for Apple Devices. Apple Developer documentation. Available at: https://developer.apple.com