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# USB Charging

## A New Challenge in Testing

## Introduction

The USB – Universal Serial Bus – is an industry standard for cables, connections and protocols that debuted in the 1990s and was aimed at replacing all the different cables and connectors used (principally) in computer systems and deliver an enhanced data rate.

The specification for USB was expanded beyond data transfer to include power supply interfacing between computers and peripheral devices. Vendors were quick to see the opportunity here and USB became increasingly popular not only for data exchange but also to charge devices. Regulatory bodies (such as those in the EU and China) made USB mandatory for mobile phones to improved interoperability and reduce waste. And from an initial power supply of 2.5W per port, we are now seeing 100W delivered.

In this White Paper we will look at charging techniques, and how these are tested, including interoperability testing. We will also look at the problems that can be expected with USB and how we address them.

## USB Versions and Types

To date there have been four generations of USB specifications, from the original USB (USB 1), through USB 2, USB 3 and USB 4. Each of these has had several iterations and specification updates. Multiple connectors are also offered. It is worth summarising these here.

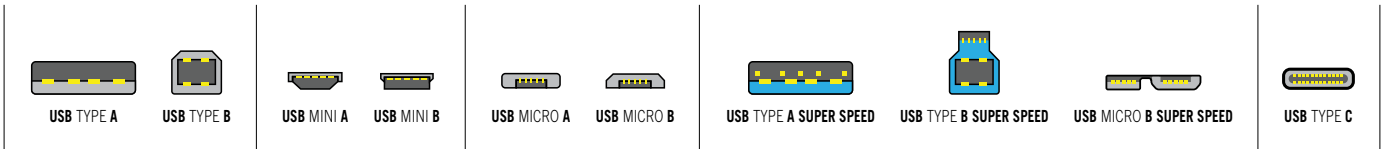
The original USB connector, termed USB A, has a flat rectangular form factor and is possibly the most recognisable. USB A is supported in USB 3.0, USB 2.0 and USB 1.1. This is sometimes called the 'host' connector, as it is that which connects to computers.

USB Type B is the connector found at the opposing end of a cable to the Type A connector, and is that plugged into peripherals. It is near-square with two flattened corners to help with orientation. Note that there are smaller, mini and micro versions of the connectors.

Starting with a clean sheet, USB-C™ connectors are smaller, much like a micro USB Type A, and reversible – the same connector can be used on both ends of the cable (see figure 1).

FIGURE 1: Connector profiles

Note that all products implementing USB 3.x Micro-B will no longer be eligible for certification after February 28th, 2021




| USB | | | | | | | |
|---|---|---|---|---|---|---|---|
| Legacy | | | | USB Type-C™ | | USB Type-C™ | |
| 2.0 | | 3.2 | | 2.0 | | USB 3.2 / USB4 | |
| 4 Pins<br>4 Wires | | 9 Pins<br>8 Wires | | 24 Pins<br>7-10 Wires | | 24 Pins<br>15-18 Wires | |
| Std | Micro | Std | Micro | Passive | E-mark | Passive | E-mark |
| 500mA | 1500mA | 900mA | 900mA | 3A | 5A | 3A | 5A |
| 5m | 2m | 3m > Gen.1<br>1m > Gen.2 | 1m > Gen.1<br>1m > Gen.2 | 4m | Dependencies<br>Active of Passive | 2m@USB3.2 > Gen.1<br>1m@USB3.2 > Gen.2<br>2m@USB4 > Gen.2<br>0.8m@USB4 > Gen.3 | Dependencies<br>Active of Passive |

TABLE 1: USB Revisions

The table describes the pin and wire configurations for legacy and USB Type-C™ connectors.

## Charging Options

### USB Legacy charging with USB A

As shown above, within the USB 2.0 specification, the maximum current passed is limited to 500mA @5V. With USB 3.0 the maximum current allowed has increased to 900mA. The release of the USB.ORG Battery Charging Specification (detailed on www.usb.org) allows power drawing at the rate of 1.5A @ 5V (7.5W).

One of the reasons for the 7.5W limitation is because the long cable and connector is not able to handle high currents due to the voltage drop. The 7.5W limit is, however, not enough for many vendors and they will override these restrictions, making their vendor-specific charging mechanisms. We have seen instances of currents as great as 3A, even over USB A.

### USB Type-C™ charging without PD

Besides the many advantages USB Type-C™ has, like reversible connectors, robustness, higher data rate, more protocols, EMI and RFI mitigation, the power delivery (PD) capabilities over the cable and connector also drastically improved, with the capability to deliver up to 100W (20V@5A).

Looking into the product receptacle:

| A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | A12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GND | TX1+ | TX1- | Vsus | CC1 | D+ | D- | SBU1 | Vsus | RX2- | RX2+ | GND |
| GND | RX1+ | RX1- | Vsus | SBU2 | D- | D+ | CC2 | Vsus | TX2- | TX2+ | GND |

Looking into the cable or product plug:

| A12 | A11 | A10 | A9 | A8 | A7 | A6 | A5 | A4 | A3 | A2 | A1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GND | RX2+ | RX2- | Vsus | SBU1 | D- | D+ | CC | Vsus | TX1- | TX1+ | GND |
| GND | TX2+ | TX2- | Vsus | Vconn | | | SBU2 | Vsus | RX1- | RX1+ | GND |

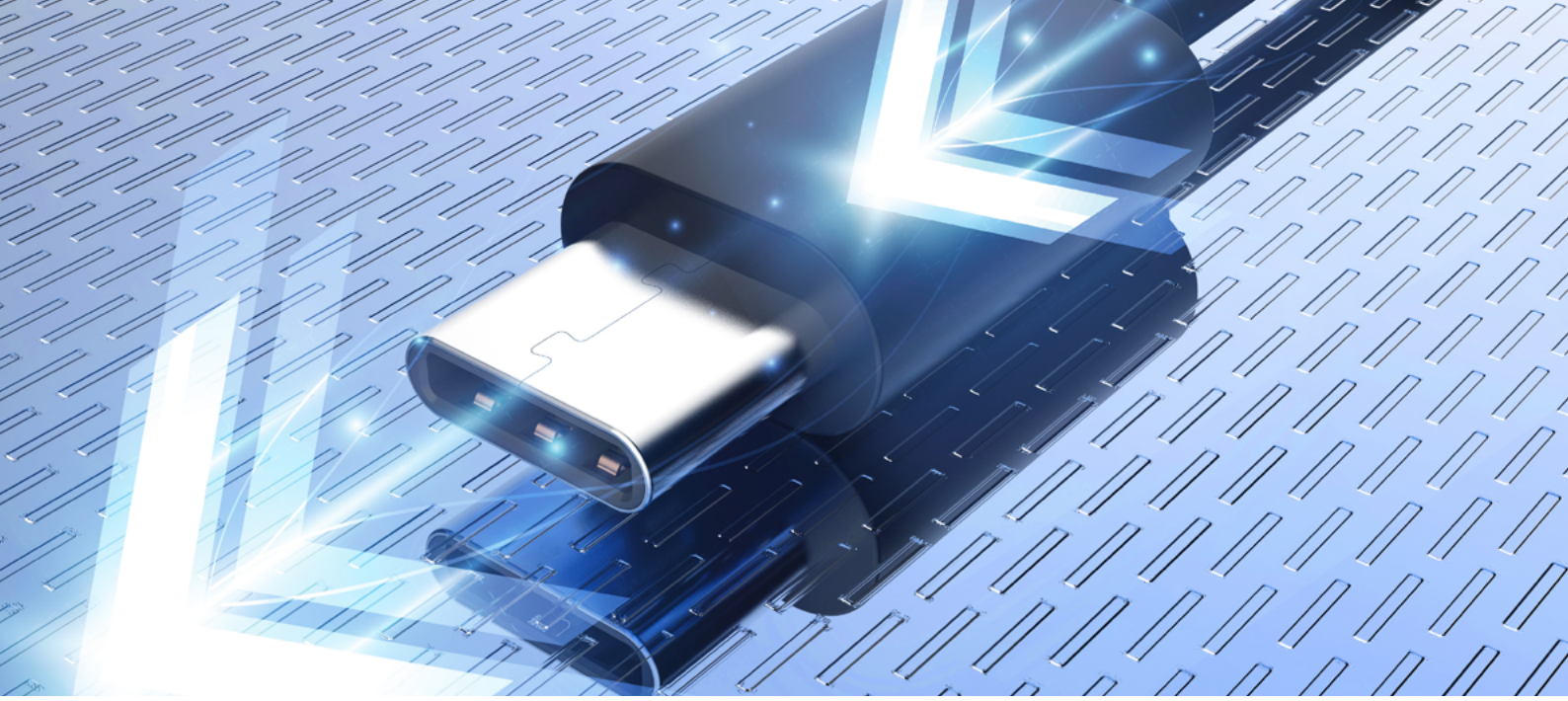
Without supporting Power Delivery protocol, it is possible to support up to 15W (5V@3A). A USB Type-C™ power source has the option to support three different maximum current defaults including 1.5A and 3A. The current default for USB2.0 source is 500mA and for USB3.x 900mA. This differentiation between these three currents is made with a pull-up resistor (at the source) on the configuration channel (CC) line.

With a simple voltage divider calculation, it is easy to determine the voltage on one of the CC lines to see what the USB Type-C™ source supports:

$$Vcc\_out = \frac{Rd}{Rd + Rp} \times Vbus$$

Rd = 5.1K
Rp can be 56K (legacy USB), 22k (1.5A) or 10K (3A)

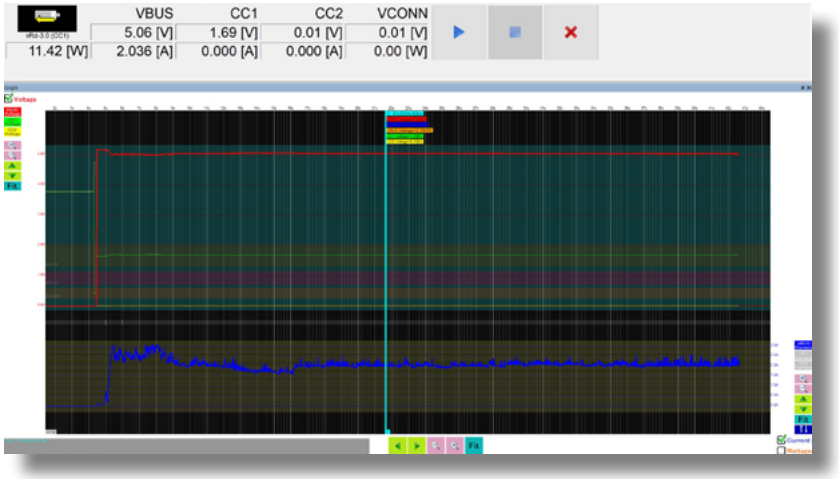
This will result in a Vcc out voltage on one of the CC lines ~0.4V = Legacy USB; ~0.94V = 1.5A; ~1.6V = 3A. Note that there is tolerance allowed on the resistors and the Vbus voltage is often not exactly 5V and therefore this value can vary.



## USB Type-C™ charging with PD

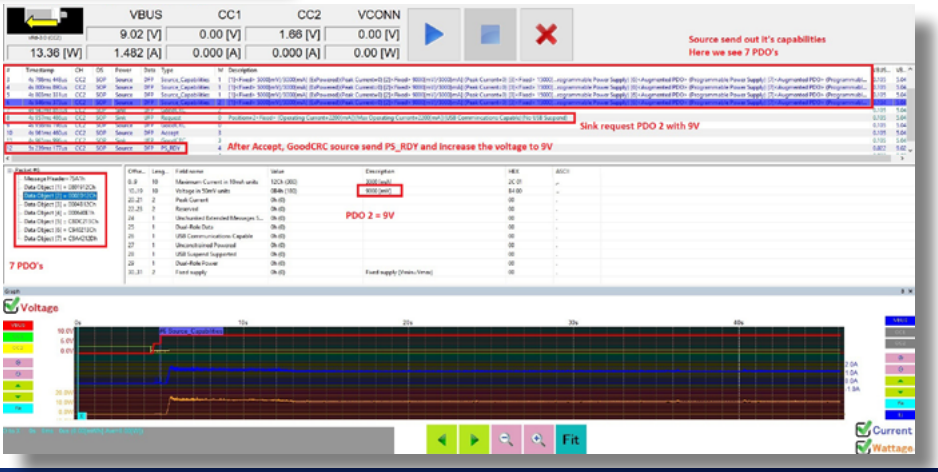
Power delivery is a separate specification (defined by USB.ORG) that allows power up to 100W. USB power delivery is always over USB Type-C™ and uses separate communication over the CC lines using an additional pin and wire in USB Type-C™ cables.
Power delivery, then, is a distinct feature, and as such has a complete and distinct communication protocol over the USB Type-C™ CC lines. In order to achieve higher power, the voltage can increase up to 20V at 5A. The power negotiating is simple and robust over the CC lines:

- source sends its capabilities
- sink makes a Request
- source accepts and sends PS Ready




The figure here illustrates voltage and current log over time where:
Red line = Voltage on Vbus (5V)
Blue line = Current on Vbus (2.036A)
Green line = Voltage on CC1 (1.69V)

Here an example trace where the mobile charge is at 9V@1.5A:
The voltage on CC1 indicates that the source is capable in handling 3A. When flipping the USB Type-C™ cable the voltage on CC2 (yellow line) will get the 1.69V and CC1 will be 0V.

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The source and sink capabilities are defined in the so-called PDO (Power Data Object). A source (or sink) may support multiple capabilities. During the negotiation, the sink will request the best match of the source PDO and source will deliver its request and the PD contract is established. On the final PD source products on the market the supported PDOs are often printed on the housing.

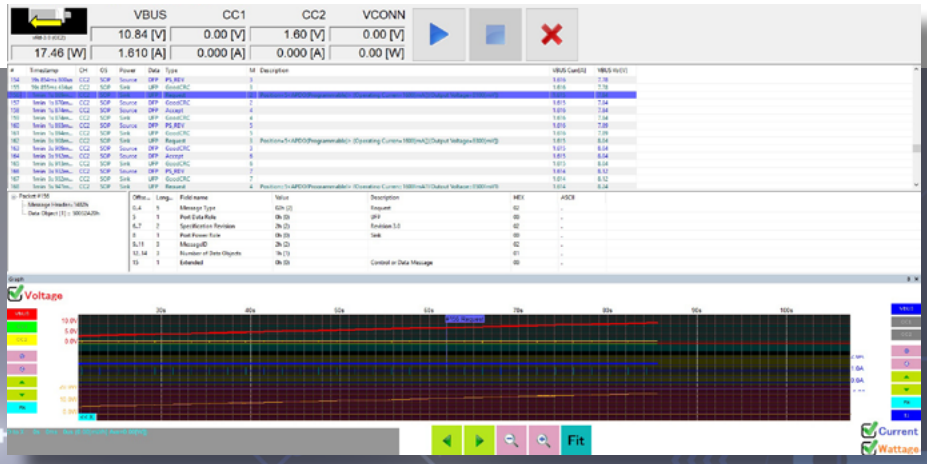
Besides the static PDO, there is also an APDO (Augmented Power Data Object). An APDO supports a Programmable Power Supply (PPS) and both source and sink need to support the PPS in order to achieve a PPS contract.

Programmable power supply (PPS) is a feature of USB Power Delivery for battery charging. A mobile device with a battery requests a VBUS voltage and current directly between a range to charge the battery. This feature achieves the reduction of voltage transformation loss and heat for devices having a battery. In order for this feature to work, a USB PD source device should provide VBUS voltage and current limit in small steps. The VBUS voltage rises until either the target voltage is reached or the specified maximum VBUS current is reached.

Illustrated below is an example where the mobile device requests to increase the voltage 200mV every 2 seconds.

When the current within a PD contact is more than 3A there is a risk the cable assembly or connectors are not able to handle this if the Vbus wire is too thin or the USB Type-C™ plug cannot handle currents above 3A. Therefore if the current exceeds 3A it is important that the cable assembly is clearly identified as being able to handle a current > 3A. This identification can be achieved by placing an e-marker chip that gives the details of its capabilities within the cable. When no e-marker cable is used, the current between source and sink will not exceed 3A.

With legacy USB, the power always comes from the host or A-port and goes to the device. With USB Type-C™ and power delivery this changed and the power now can come device to host or dynamically change direction.
For example, the USB Type-C™ port on your laptop can be used for charging the laptop but is also able to provide the required power to a connected device. On the CC lines Rp and Rd will be used to differentiate the product is source (Rp) or sink (Rd).



## What can go wrong?

- Wrong legacy to USB Type-C™ cables that report 3A: An A plug to C plug cable must have a Rp 56kΩ so the sink is informed that the current is limited to Legacy USB. However, we see often that these cables have a Rp of 10K which implies a load of 3A. So a device is informed that it can take 3A from the host but the host might only be able to handle 0.5A. This may work for some combinations, but is a risk for some hosts or hubs where the power can cause damage or failure.

- At the maximum 100W power, high levels of heat dissipation are possible:
  If there is a bad connection in the USB Vbus/GND chain this will result in higher resistance and produce a temperature increase. The higher the current the higher the heat dissipation, according to P = $I^2$ x R. Especially with cables that have detachable USB plugs for connecting multiple types of devices, we often see there is more resistance and the temperature will increase drastically with high current. For monitoring purposes, the heat dissipation can be detected with an infrared heat camera, prior to a potential fire situation.

- If the PD negotiation goes wrong it is possible a higher voltage or current passes than allowed: this will have inevitable damaging effects on the product.

- Slow charging due to the negotiation between source and sink not selecting the best PDO or vendor specific mechanism: Since there are many charging techniques it's important to select that with the best performance.

- Increased complexity: With USB Type-C™ and Power delivery there is an increase in complexity what will increase risk on things that can go wrong.

- Connection shorting: USB Type-C™ is a small connector where VBUS, data lines and GND are very near to each other - short circuits can easily occur.


In the heat scan, a temperature of 150.4°C is measured with a current draw of 3A what cause the plastic of the connector to melt!


## Testing

### Performing Tests

The USB-IF Compliance Programme provides a solid and detailed basis for testing. In particular, the programme covers a number of the protocols and electrical tests. These include:

- USB Type-C™ Functional tests
- USB Power Delivery protocol and electrical tests
- USB QuadraMax load tests
- Interoperability testing against a few products
- If data communication is supported, all these tests need to be performed.

To increase the USB charging quality and safety aspects even further the following should be tested or addressed:

- Interoperability (against an extended set of certified products is considered sufficient).
- Compliance testing undertaken under ideal or favourable conditions e.g. ambient conditions where an issue may only occur at high temperatures.
- Vendor specific charging or protection mechanisms are not covered in the basic specification
- Situations where one run is sufficient to pass compliance but where an issue may occur only after multiple runs or at certain sequence.

In regard to the final point, it is of high importance to thoroughly test the compliance aspects of the USB charging implementation and monitor the behaviour over long charging periods and varying environmental conditions.

There are some other areas of 'real world' operation that the compliance programme does not cover. These areas should be considered when a testing programme is designed, as they will be important (or at least desirable) for the client who is intent on delivering a high-quality product to the customer. These include:

- Safety and safe operation
- Performance: slow charging, for example would not produce a compliance failure but such lack of performance would not be acceptable to end users
- Performance and operation against non-compliant products
- Performance at different (or required) temperature ranges, or consideration of other environmental conditions.
- User experience and ease of use
- Power efficiency
- Cosmetic factors (such as the placing of the connector)

### What Testing Involves

A vendor may choose to send the device for testing, or attend in person. Prior to committing to the testing we will have agreed with the vendor a test plan that meets the need of the vendor. This could be part of a standard plan or, should it be required, something customised to their requirements. The scale of testing may also be determined by the budget: a quality assurance test plan (and the subsequent execution) can be adapted to meet a budget and on how many test cases need to be covered.

### The Importance of Interoperability Testing

Inevitably there are many non-compliant devices – of all kinds – on the market and they are often priced attractively for consumers, well below the prices charged for those from 'official' sources and authorised manufacturers. In terms of quality, these products can range from good to poor and, in some cases, downright dangerous.

When such devices are freely available in the marketplace there is a chance that even a careful consumer might sometime encounter one when, for example, looking for a new phone charger. In fact, there are many very popular products in the marketplace that are actually non-compliant and have a high chance of being connected to client devices.

It is unfortunate that USB Compliance testing does not cover all possible scenarios and is restricted to limited interoperability testing. Vendors often incorporate specific protection techniques, but this is not always the case, so often many issues affecting devices can only be triggered by undertaking an intense programme of interoperability testing.

It is therefore crucial when ascertaining the robustness of a product to test it against as many USB Type-C™ products as possible.

To provide the most extensive interoperability testing, Eurofins maintains a large testbed of sink, source and dual role devices to deliver comprehensive real-world interoperability tests. If, or when, we encounter an issue with any device, we maintain a log so we can investigate the issue and provide the log to the customer.

Our laboratories are also equipped to perform to in-depth testing and analysis. Further testing can be conducted under different temperature conditions and by using IR cameras we can make sure the product meets all requirements under a wide range of operating conditions.

### References

All specifications are publicly available at www.usb.org

## Conclusion: How Eurofins can help

Eurofins Digital Testing is an official accredited USB-IF Compliance lab and we can certify your product, or products. Please get in touch to discuss your product and we can then advise more fully the steps needed to achieve certification.

As noted above, we also have a comprehensive test facility equipped with a wide range of chargers and mobile devices from different manufacturers and of different vintages. This can be used for interoperability testing during which the performance of your device against each device will be monitored and logged to assist in debugging. This is all conducted under the guidance of our expert engineers. Our testing is scaled to precisely meet the needs of the vendor and we can perform simple testing through detailed analyses, matched to the product, to the requirements of the vendor and to meet the vendor's expectation of the customer.

Click here to get in touch with our USB Experts

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## About Eurofins Digital Testing

Eurofins Digital Testing, and its division Eurofins Cyber Security, is a global leader in independent Quality Assurance, (QA), testing and cyber security for software systems, content and devices with operations in Belgium, Hong Kong, the Netherlands, Sweden, the UK and the USA. We help businesses in media, fintech, energy, governmental and other industries assure quality in their digital transformations towards Industry 4.0.

We are a trusted provider in a broad spectrum of quality solutions covering: managed test services & augmented test resourcing, industry recognized advisory & training, including Eurofins Academy, lab-based testing services & infrastructure, test automation & conformance testing services & tools, comprehensive cyber security services & tools.

Eurofins Digital Testing is part of Eurofins Scientific, a Life Science testing group which has more than 800 laboratories in over 50 countries and over 48,000 employees worldwide. Founded in 1987, Eurofins is the global leader in bio-analysis, with a level of expertise that makes it the first call for businesses around the world.

"Eurofins Digital Testing: Your trusted partner in quality"

## Why work with us?

- Eurofins Digital Testing was the first test lab to be approved by USB-IF and is the only laboratory authorized to carry out such testing in the EMEA region
- Custom testing: in addition to full testing we also offer pre-certification or selective testing
- Debugging: we can help you identify and correct problems
- Our large pool of devices available for interoperability testing
- Flexible scheduling and testing: you may attend the test or ship the product to us for testing
- Extensive range of additional testing and consulting services

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