XDPL8220 Output Control Schemes

XDP™ Digital Power

White Paper
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About this document

Scope and Purpose

This White Paper explains the different control schemes of XDPL8220 : ***Constant Voltage (CV)***, ***Constant Current (CC)*** and ***Limited Power (LP)***. Example applications are described for each scheme. Non valid combinations of power supply and load are listed. The startup of the system until steady state is explained.

Intended audience

The intended audience are engineers who design power supplies for different loads using XDPL8220.

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1 Introduction

An introduction to output control schemes of XDPL8220 is provided.

XDPL8220 converts power from an input source (typically the ***Alternating Current (AC)*** grid) to an output sink. The sink is referred to as the load of XDPL8220. The amount of power transferred can be regulated according to different schemes. Two examples are:

- A typical power supply for e.g. a ***Universal Serial Bus (USB)*** device or a notebook ensures a ***CV*** to the load. The amount of power transferred is continuously adapted to maintain the output voltage within a certain range. Some ***Light Emitting Diode (LED)*** loads include a linear regulator and are also supplied by ***CV***.
- A typical power supply for simple ***LED*** strings (without regulator) ensures a ***CC*** to the load. The amount of power transferred is constantly adapted to maintain the output current within a certain range.

To avoid an overload of the power converter, but still continue the power transfer, a power converter can also enter a third scheme in which it ensures a ***LP*** to the load, regardless of voltage or current.

Depending on its application, a power converter typically is working in one of the three schemes under the condition that the current/voltage does not reach any limit which triggers a protection. XDPL8220 implements ***CV***, ***CC*** and ***LP*** into one product.

This document first provides example applications for each of the output control schemes separately. Furthermore, the usage of XDPL8220 with its multiple schemes is explained. At the end of this document, the startup of the multischeme driver is explained.

2 Output of a Power Converter

The output of XDPL8220 consists of three different parts as shown in ***Figure 1*** :

1. The Driver which delivers power to the output.
2. An output capacitor.
3. The Load which draws power from the output.

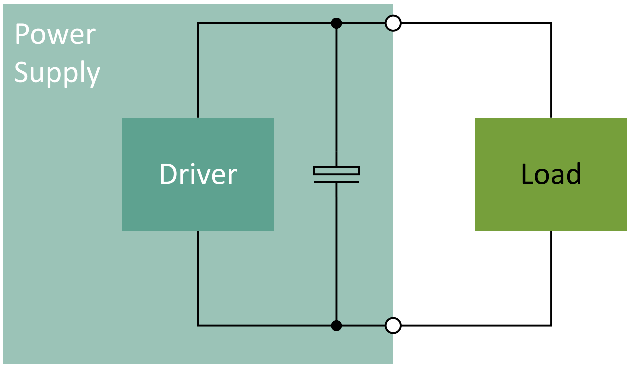

Figure 1 Output of XDPL8220

Operation at steady state (assuming a quasi-constant energy in the capacitor) is only possible if the power delivered to the output capacitor within a time is exactly matching the power drawn by the load within the same time (law of conservation of energy).

In case of a difference in power, the voltage of the capacitor will change:

- Whenever the driver delivers more power than drawn by the load, the voltage of the output capacitance will increase.
- Whenever the load draws more power than delivered by the driver, the voltage of the output capacitance will decrease.

The output capacitor is an energy storage which integrates the difference in power between driver and load:

3 Output I/V Characteristics

The concept of I/V characteristic curves for the output of XDPL8220 is described including examples.

To understand possible steady-state operating conditions, both driver and load have to be considered together. The operation characteristics of both driver and load can be depicted in I/V characteristic curves. Any point on any curve is a possible operation point for either driver or load. Only points which are available on both curves (intersections) are possible steady state conditions for the combination of driver and load.

Example: ***Figure 2*** shows the characteristic curve of a ***USB*** power supply. Independent of the load, the power supply provides a ***CV*** of 5 V at the output. The maximum power of this ***USB*** power supply is assumed to be 5 W, thus limiting the operation to a maximum output current of 1 A. Also shown are two characteristic curves of resistors of 6.25 ohm and 10 ohm. The figure immediately shows the stable points of operation for the combination of driver and each load which are:

- For a resistance of 10 ohm, the stable point is at (0.5 A ; 5 V).
- For a resistance of 6.25 ohm, the stable point is at (0.8 A ; 5 V).

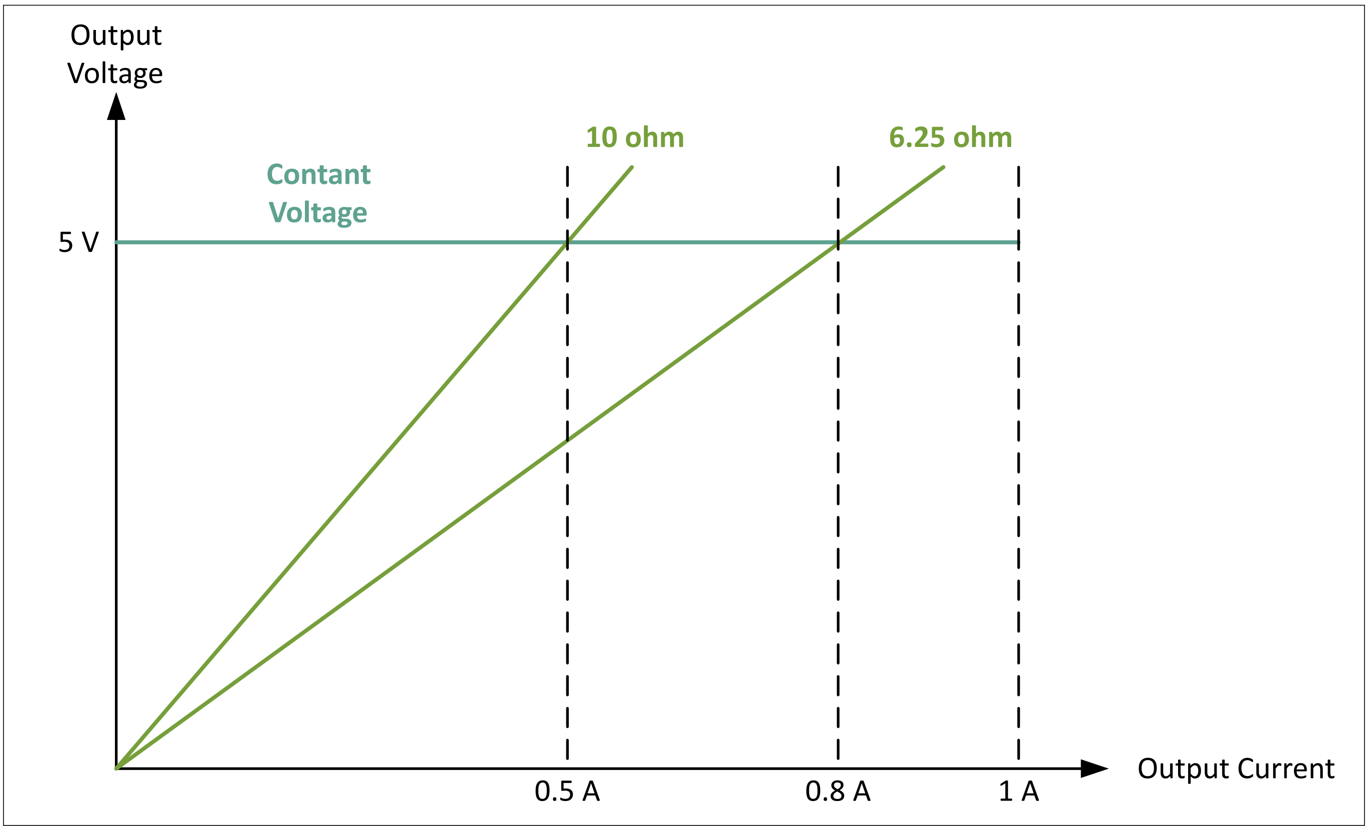

Figure 2 **Characteristic I/V curves of a USB constant voltage power converter and two different resistive loads**

3.1 Constant Voltage Output with a Constant Current Load

Most ***Switched Mode Power Supply (SMPS)*** power supplies provide ***CV*** at their output. A load for a ***CV*** driver is typically a ***CC*** load.

Examples for this application are:

- An ***SMPS*** example is a power supply for a ***USB*** connection which delivers a ***CV*** of 5V at its output.
- In lighting, a ***CV*** output is typically used if the connected ***LED*** string includes a linear regulator. The linear regulator will ensure a constant current while it adapts the ***LED*** voltage to the ***CV*** output of the driver (e.g. 12 V or 24 V).

In general, a ***CC*** load draws a constant current independent of the output voltage. Typically, the load turns on at a certain turn-on voltage V_{on} and stops drawing power at a turn-off voltage $V_{off} < V_{on}$. For example, ***LED*** strings with linear regulator will turn-on and turn-off typically near to the forward voltage of the ***LED*** string.

The example in ***Figure 3*** shows a stable point of operation at an output voltage of 5 V and an output current of 0.5 A.

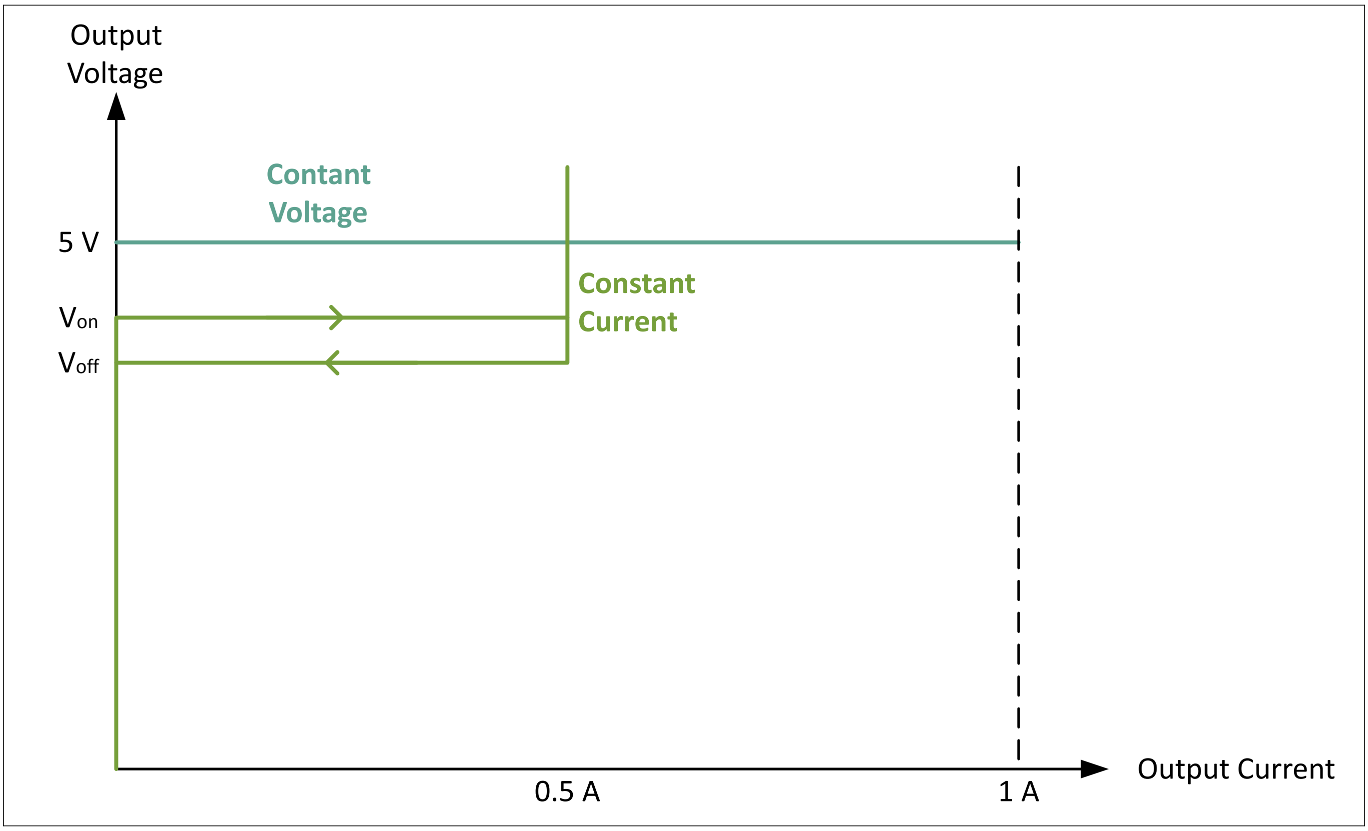

Figure 3 Characteristic I/V Curves of a CV Driver and a CC Load

3.2 Constant Current Output with a Constant Voltage Load

A power supply delivering a ***CC*** at its output is typically operated with an ***CV*** load.

Examples for this applicaitons are:

- Battery chargers which are charged with a ***CC*** power supply while the battery voltage stays rather constant.
- ***LED***s can be approximated as a ***CV*** load, especially in case of a low differential resistance of the ***LED***s.

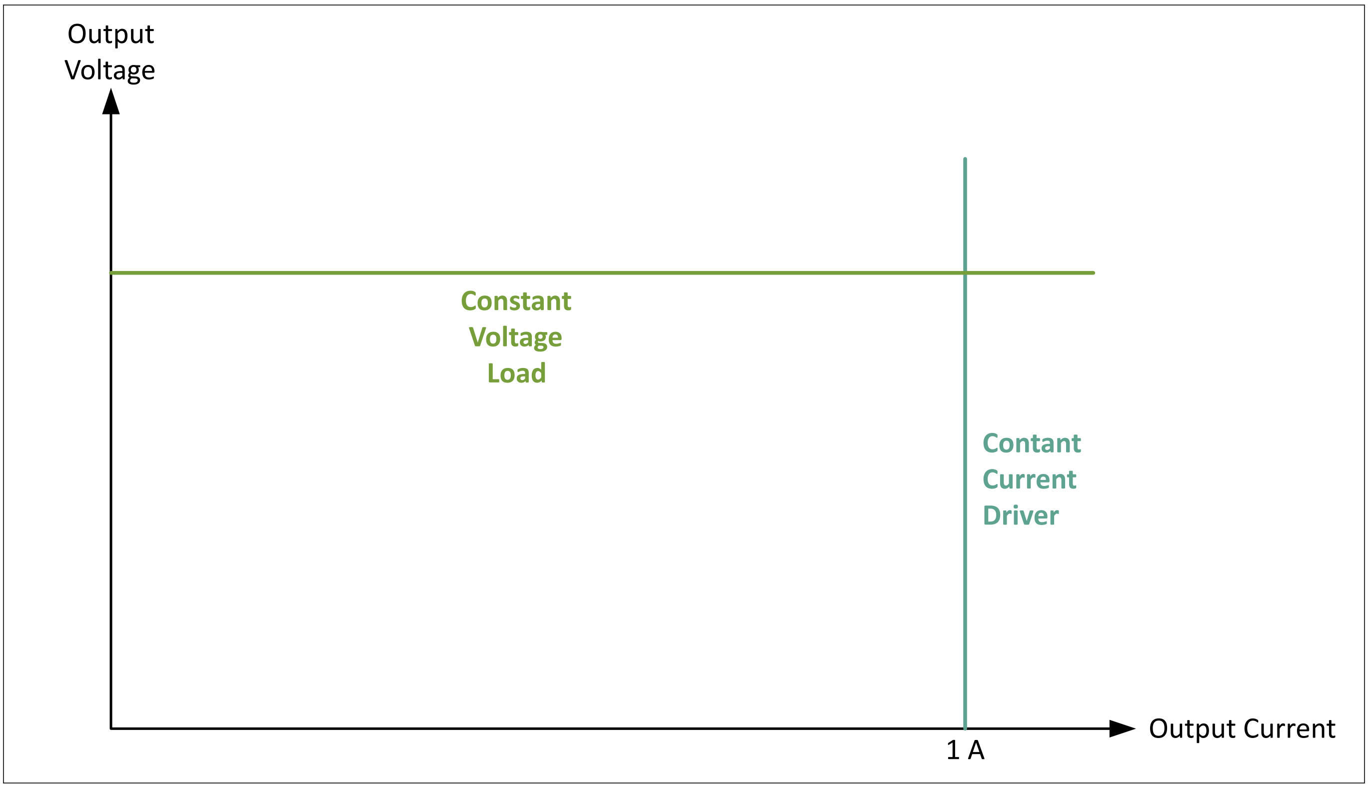

Figure 4 Characteristic I/V Curves for a CC Driver and a CV Load

3.3 Constant Current Output with an LED Load

LED loads are typically operated with a driver using a ***CC*** scheme.

Figure 5 shows an example of three ***LED*** strings with different forward voltages V_f and differential resistance r_d. Regardless of the forward voltage of the ***LED*** strings, all are operated with a constant current of 1 A.

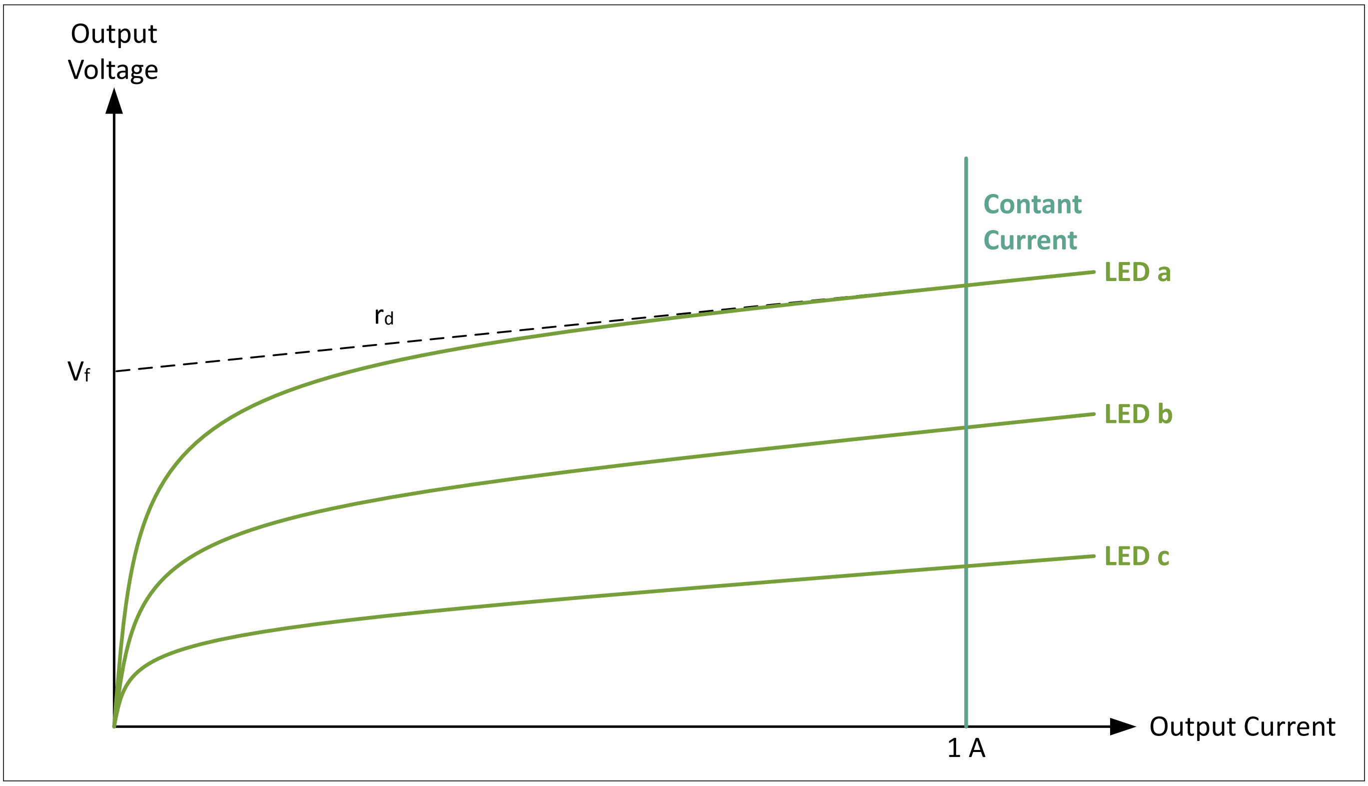

Figure 5 Characteristic I/V Curves of an CC Driver and an LED Load

3.4 Operation with a Constant Power Load

The operation with a ***Constant Power (CP)*** load is described using an example.

The load draws a constant power independent of the output voltage. Typically, the load turns on at a certain turn-on voltage V_{on} and stops drawing power at a turn-off voltage $V_{off} < V_{on}$. A typical example of a ***CP*** load is a subsequent power stage, e.g. a DC-DC buck converter which is drawing a ***CP*** from its previous stage.

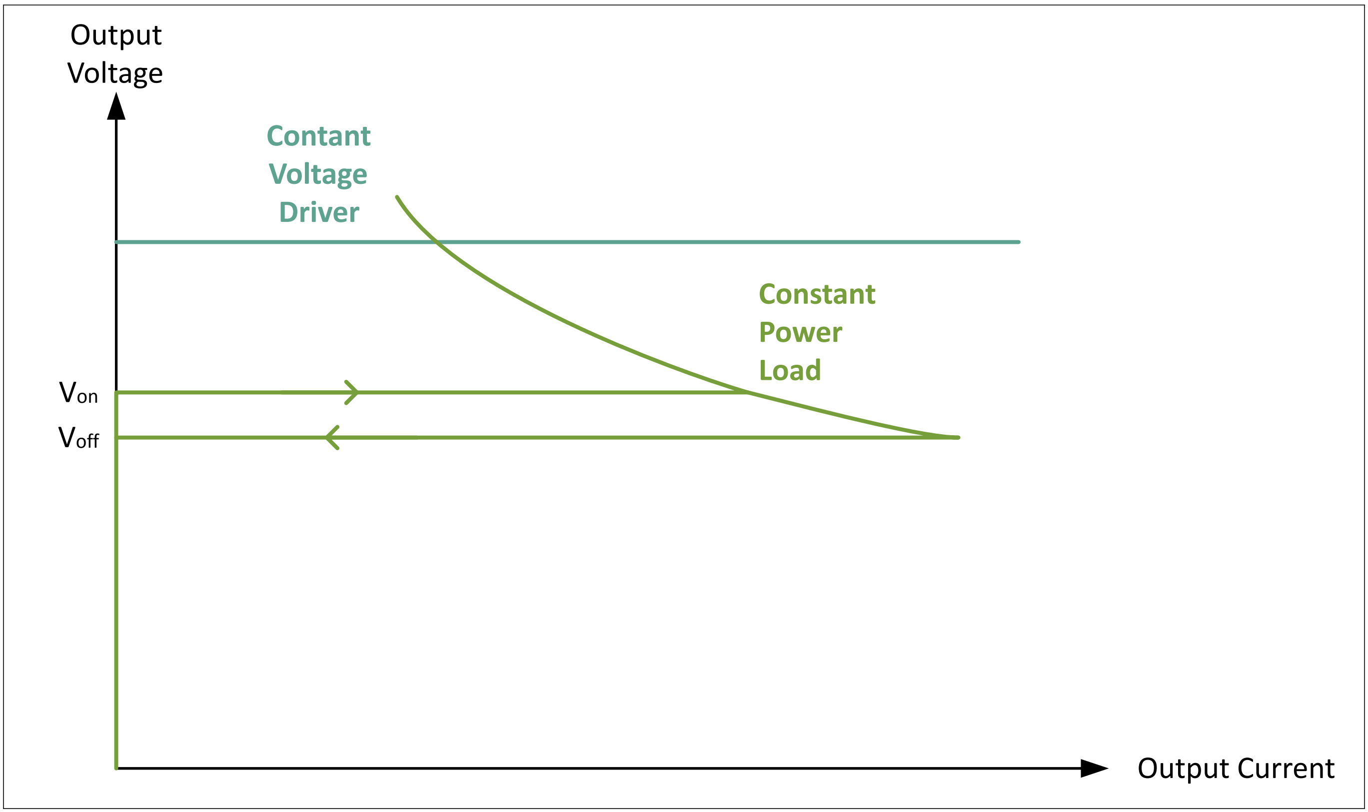

Figure 6 Characteristic I/V curves of a CV driver with a CP load

3.5 Unstable Combinations of Driver and Load

Not all combinations of driver and load result in stable operation. Examples are listed below.

The following combinations lead to no stable operation, because there is either no single stable point of operation or many ambiguous adjacent points of operation:

- ***CV*** driver with ***CV*** load:
  - In case driver and load would have exactly the same voltage, there will be unlimited points of operation. The output current can basically be anything between minimum and maximum. On a real measurement bench, a system typically settles in a random point of operation which is determined by remaining parasitic resistive parts of the load (e.g. cables) and the tolerances of driver and load.
  - In case the driver voltage is smaller than the load voltage, the load will never draw any current. If the driver cannot operate under no-load conditions, it will not be able to operate stable at the desired output voltage. As a consequence, the output will overshoot until the load turns on. The system will most likely settle at a point of operation which is determined by the load voltage set-point and the minimum power that the driver can provide. Parasitic resistances (e.g. cables) may shift the point of operation.
  - In case the driver voltage is higher than the load voltage, the load will turn on before the driver has reached its set-point. As a consequence, the system will settle at a point of operation which is determined by the load voltage and the maximum power which the driver can deliver. Parasitic resistances (e.g. cables) may shift the point of operation.
- ***CC*** driver with ***CC*** load:
  - If the current delivered by the driver is higher than the current drawn by the load, the output capacitor will continuously be charged, typically until the output overvoltage protections is triggered.
  - If the current delivered by the driver is smaller than the current drawn by the load, the system will enter a hysteretic operation between turn-on and turn-off thresholds of the load: Once the load turns on, it discharges the output to the turn-off threshold. Then the load will turn off and the driver will charge the output voltage up to the turn-on voltage of the load. Depending on the settings of the load and driver, different protections might get triggered and stop the operation.
- ***CP*** driver with ***CP*** load:
  - If the driver has a constant (or limited) power, the power set-point has to be substantially higher than the power drawn by the load. The smaller the difference in power is, the longer the time to the voltage set-point will be (as the output capacitance is charged with the difference of power only).
  - If the power drawn by the load is higher than the maximum power which the driver is allowed to deliver, the output capacitor will be discharged until the load turns off. A hysteretic on/off switching is likely.

3.6 Multiple Output Schemes

The setup of a XDPL8220 with its multiple output schemes is described. XDPL8220 does not only regulate its power transfer according to one output scheme, but to one of multiple schemes. To achieve this, the XDPL8220 dynamically selects the scheme which to use for regulation of power transfer. This behavior can be compared with a universal lab power supply which can be limited to a voltage set-point and a current set-point, for example 25 V and 1 A: As long as the power drawn from the source is lower than the power according to the set-points (25 V * 1 A = 25 W), the current set-point is not reached (e.g. I < 1 A) and the voltage is regulated to the voltage set-point (25 V). If a load draws all available power, the current is regulated (or limited) to the current set-point (1 A) and the voltage will reduce depending on power drawn by the load and on power delivered by the source.

This example can easily be extended to include also a limited power scheme: The power supply will deliver increasing power to regulate to either a voltage set-point, a power set-point or a current set-point. While one or more of the set-points are exceeded, the power transfer is reduced. This ensures that the power supply will settle only on one of the set-points.

Figure 7 shows the characteristic curve of a multi-scheme driver (***CV***/***CP***/***CC***) connected to an ***LED*** load. The same driver can also be used for a ***CC*** load as shown in ***Figure 8*** . The driver will regulate its power to achieve an operation point of its characteristic I/V curve. The characteristic I/V curve of the load will determine this point of operation. If the curves do not intersect or intersect at multiple points, no stable operation or no unique point of operation is available. The system might not find a stable point of operation and a protection might be triggered.

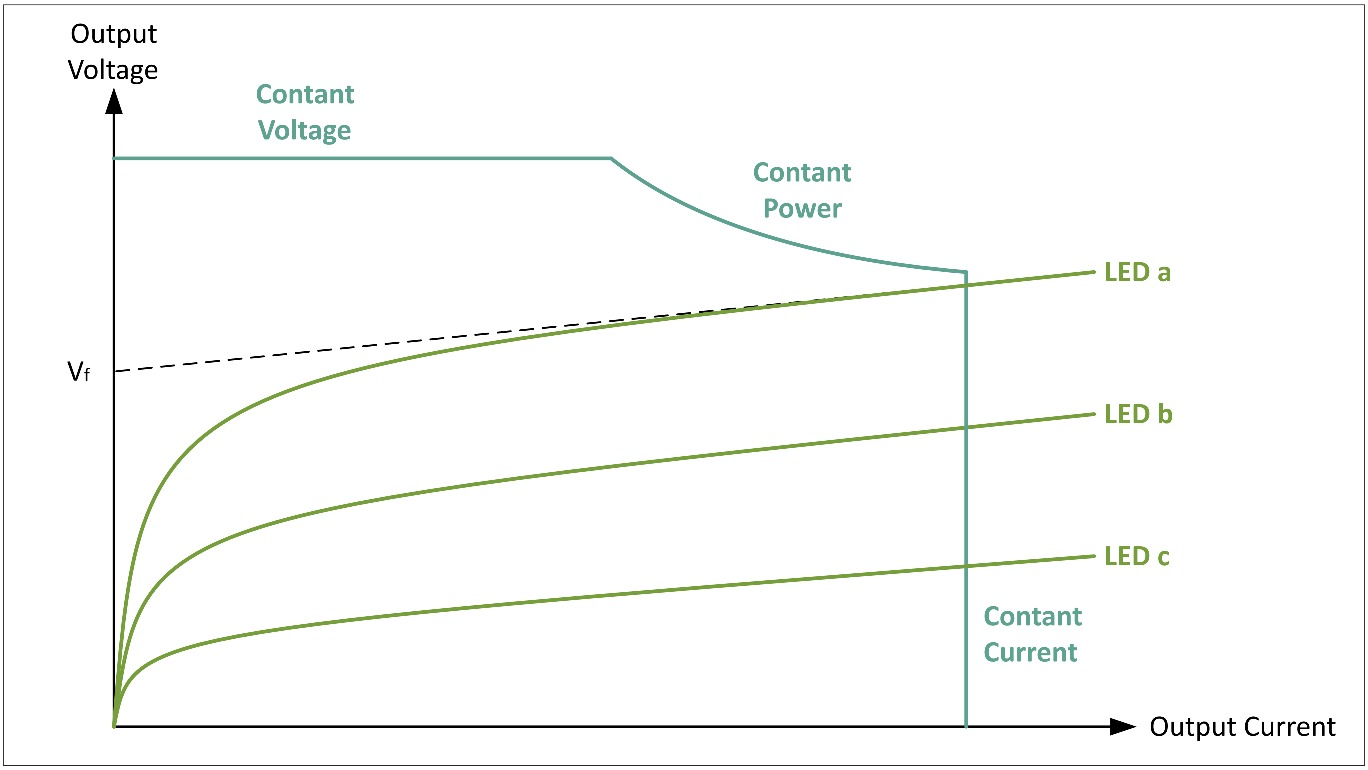

Figure 7 Characteristic I/V curves for a Multi-Scheme Driver and LED load

Output I/V Characteristics

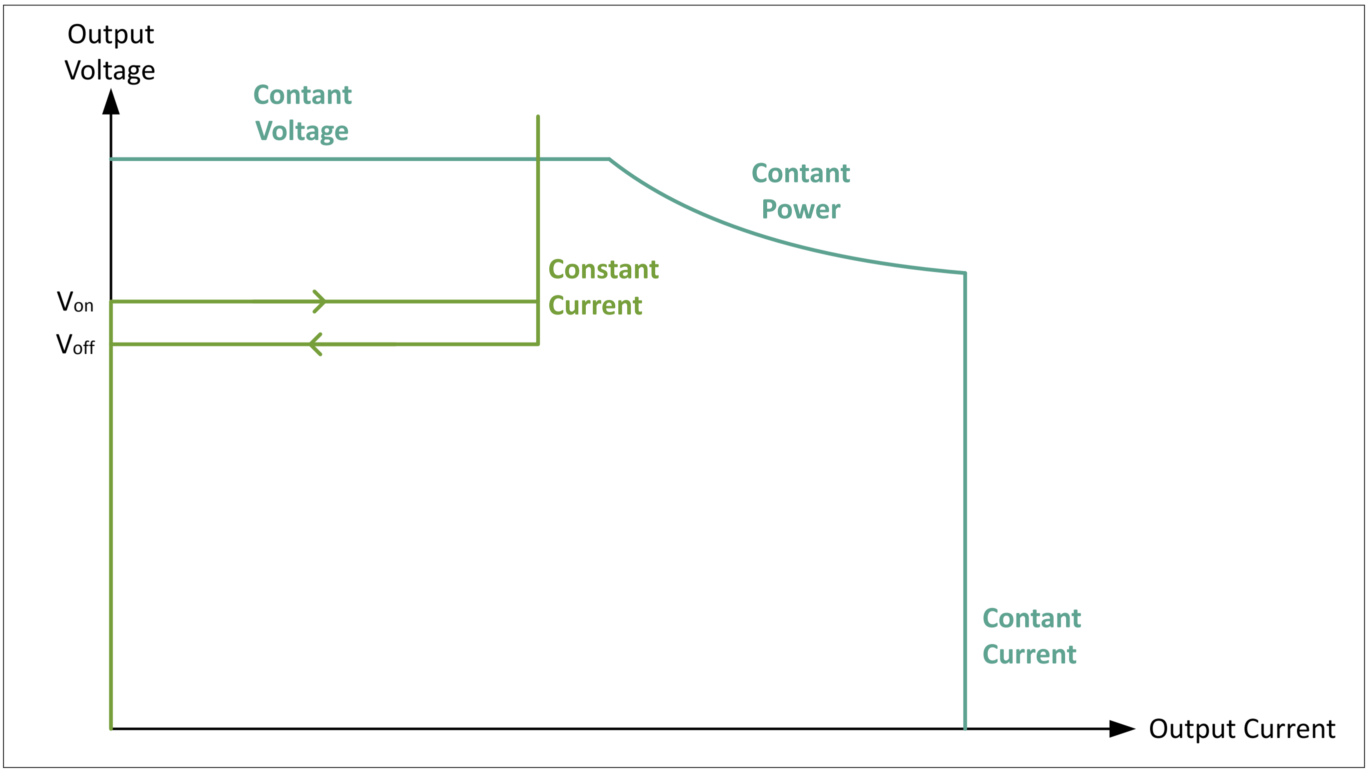

Figure 8 Characteristic I/V curves for a Multi-Scheme Driver and CC load

3.7 Startup

The startup of the system into steady-state is described.

The steady state is never entered immediately. Typically, the output capacitor is discharged, thus the output voltage is zero at startup.

As most loads only turn-on at higher output voltages, the output can be considered open at startup. Therefore, all energy which is delivered by the driver charges the voltage of the capacitor until the load turns on. ***Figure 9*** shows the characteristic curves for the steady state of driver (Cyan) and load (Green). Additionally, also the path for the startup is shown (Purple): At the initial condition (V_{out} = 0 V), the driver will provide a current. As the load is drawing no current, the difference between green and purple curve is used to charge the output capacitor. The driver has to foldback its power transfer before hitting the ***CV*** set-point to avoid an overshoot.

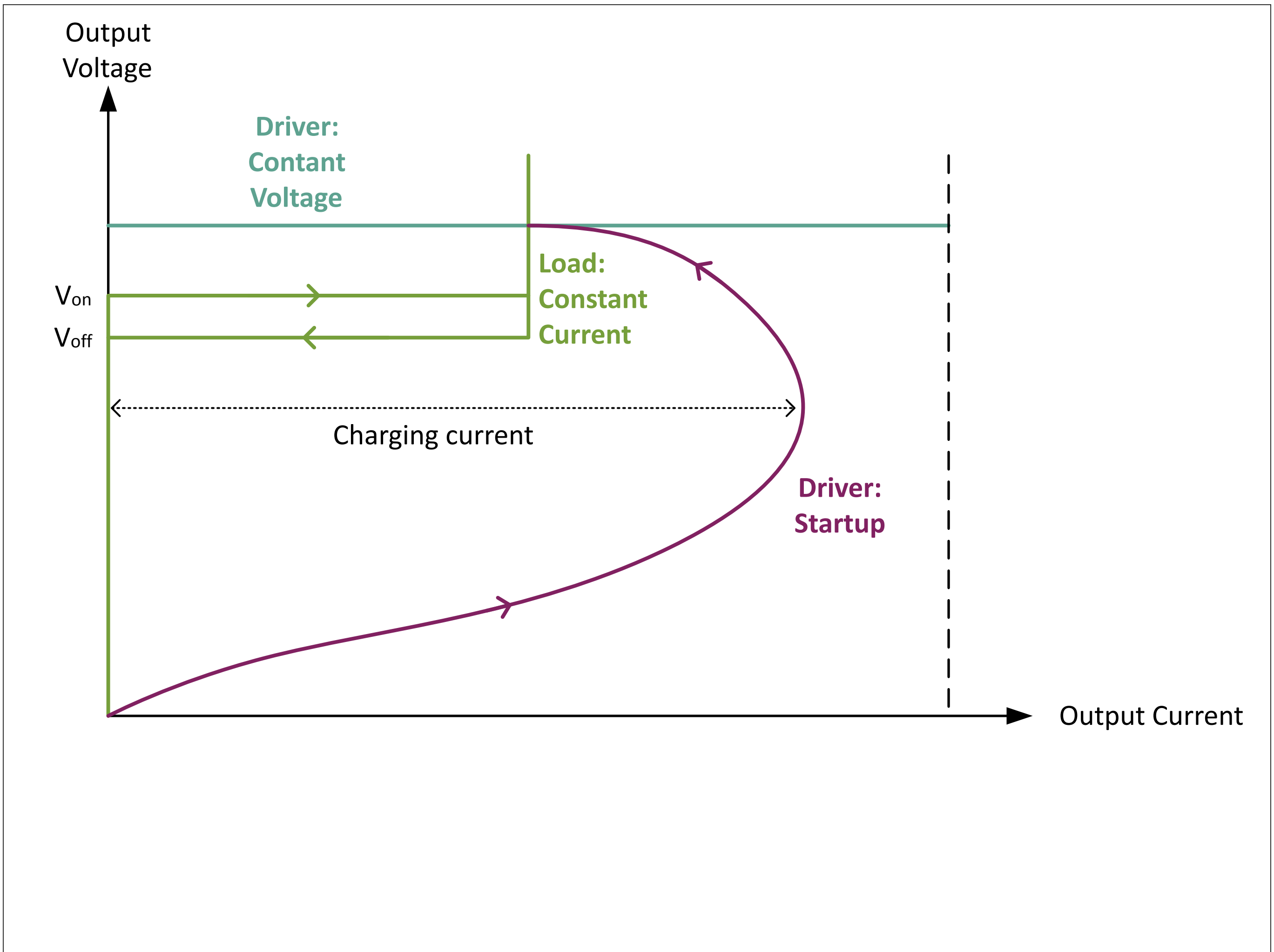

Figure 9 Characteristic Curves for a CV driver and a CC load including startup

The startup can typically be accelerated if the power during startup is increased and/or the gain of the control loop is increased. ***Figure 10*** shows a startup of a multi-scheme driver which ramps quite fast to the ***CC*** set-point. As the charging current is higher in this case, the driver will proceed faster along the path compared to the previous figure. However, if the control loop cannot settle directly into the steady-state, an overshoot of output voltage is likely. Slowly the system may oscillate around the steady-state condition until finally converging to the steady state. A too high control loop gain might even block the driver from achieving the steady-state.

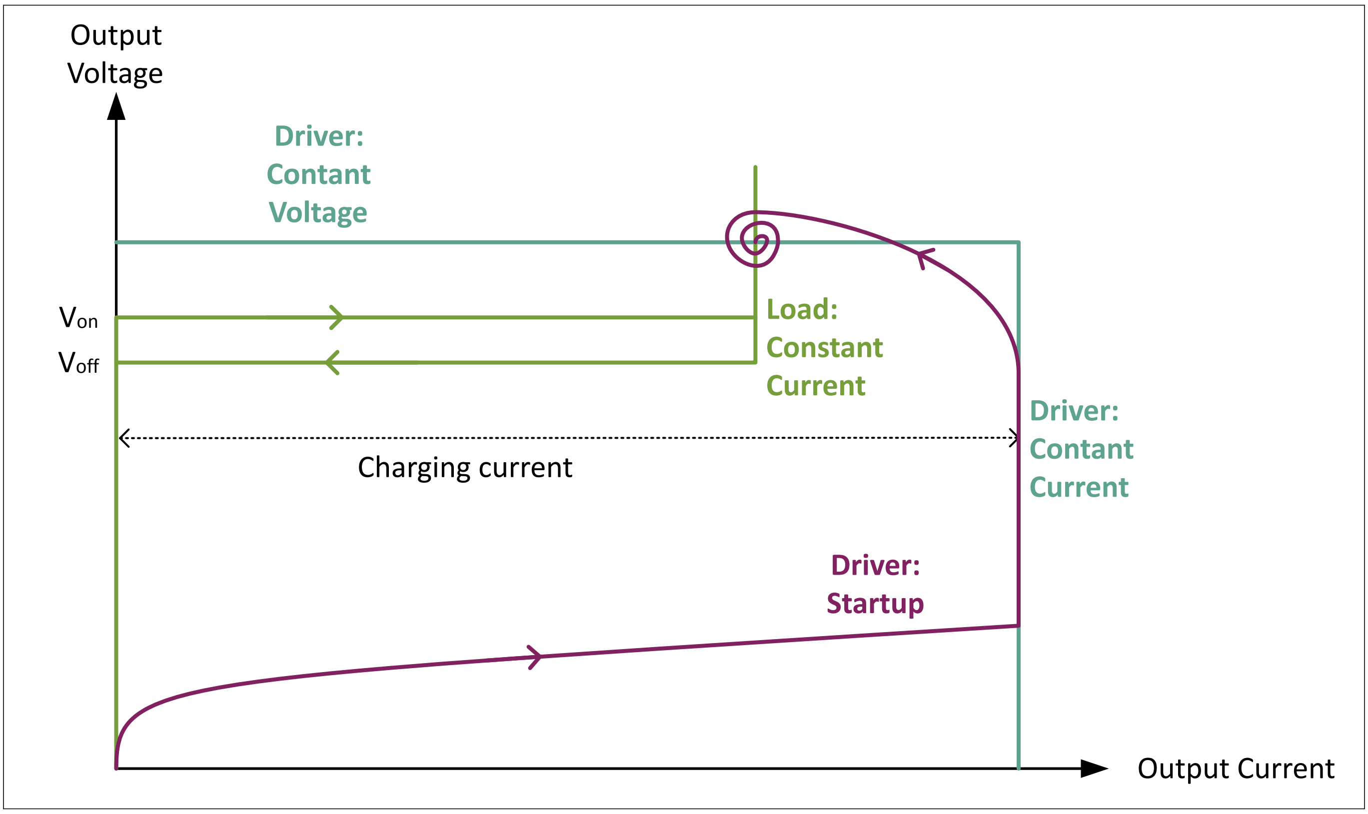

Figure 10 Characteristic Curves for a Multi-scheme Driver and a CC load including startup with overshoot

Limitations

During startup, the power drawn by the load must always be lower than the power delivered by the driver. If this requirement is not met, the output capacitor will never charge and the system will never reach steady state. A special case is shown in ***Figure 11*** : When the ***CP*** load starts up, it will draw more current than the driver can deliver (the driver is limited by the ***CC*** regulation in this case). As a consequence, the output capacitance will discharge, causing the load to draw even more current. This will even accelerate the discharge of the output capacitance. Depending on the turn-off threshold V_{off} of the load, the system may enter an on/off oscillation or even trigger a protection. To avoid this issue, options are:

1. Increase the current set-point to be higher than the maximum current drawn by the ***CP*** load during startup.
2. Increase the turn-on voltage V_{on} of the load to reduce the current of the ***CP*** load during startup.
3. If the ***CP*** load is configurable, limit the current or power drawn during startup.

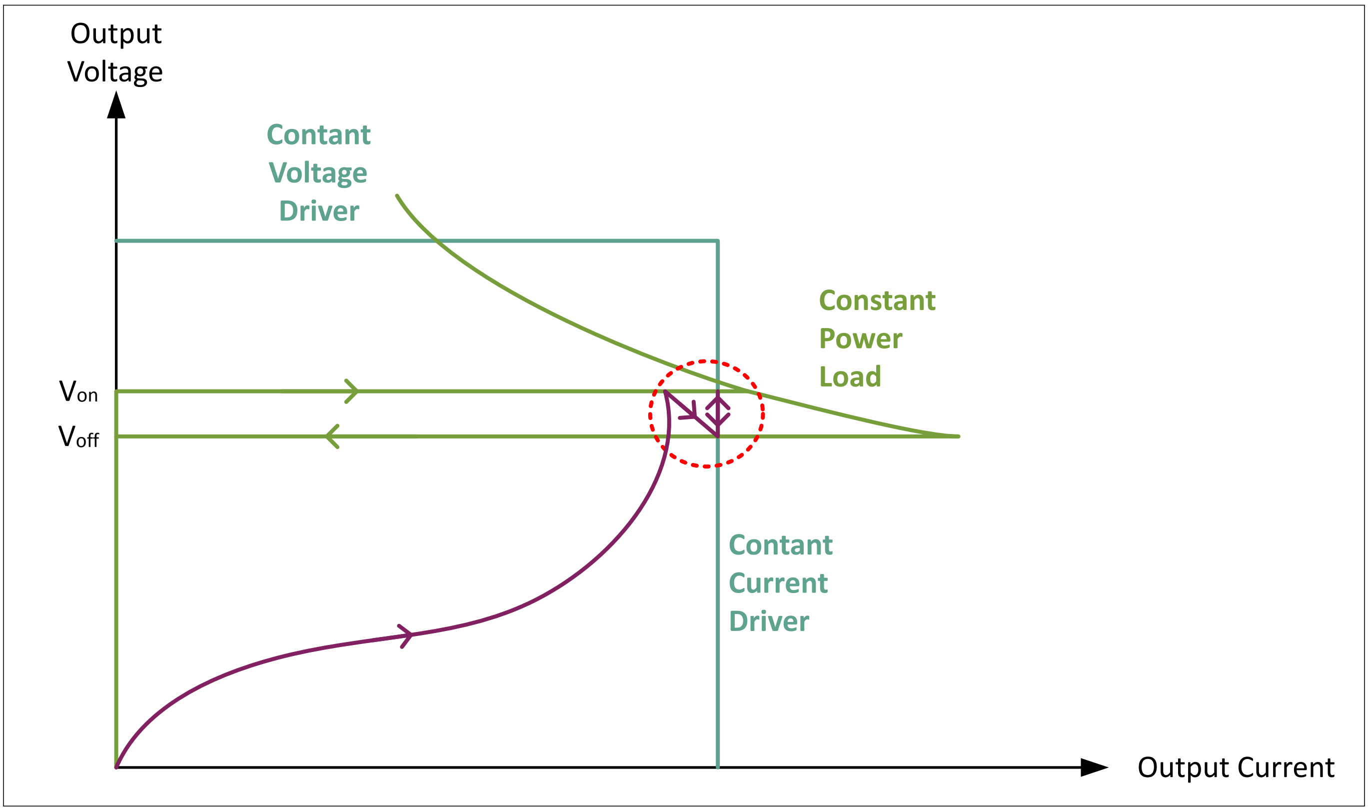

Figure 11 Characteristic I/V Curves of a Multi-scheme Driver with a CP load (blocked startup)

Abbreviations

AC

Alternating Current (AC)

An Alternating Current is a form of power supply in which the flow of electric charge periodically reverses direction.

CC

Constant Current (CC)

Constant Current is a mode of a power supply in which the output current is kept constant regardless of the load.

CP

Constant Power (CP)

Constant Power is a mode of a power supply in which the output power is kept constant regardless of the load.

CV

Constant Voltage (CV)

Constant Voltage is a mode of a power supply in which the output voltage is kept constant regardless of the load.

LED

Light Emitting Diode (LED)

A light-emitting diode is a two-lead semiconductor light source which emits light when activated.

LP

Limited Power (LP)

Limited Power is a mode of a power supply in which the output power is limited regardless of the load.

SMPS

Switched Mode Power Supply (SMPS)

A Switched Mode Power Supply is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently. Like other power supplies, an SMPS transfers power from a source, like mains power, to a load, such as a personal computer, while converting voltage and current characteristics.

USB

Universal Serial Bus (USB)

Universal Serial Bus is an industry standard that defines cables, connectors and communications protocols used in a bus for connection, communication, and power supply between computers and electronic devices.

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