ON Semiconductor®

Universal Offline 200W 4-Port Type-C USB-PD Source & 200W AC/DC LLC with PFC

Test Report

Strata Developer Studio

USB-PD System | AC–DC Power | DC–DC Power | Discrete Devices | Sensors

February, 2019 – Rev. 0

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4-Port USB-PD Type-C Source - Introduction

USB-PD is the latest and most advanced fast charging protocol to date. The enclosed design is a Four Port 100W-per-port design targeted for consumer and computing applications to enable all future devices, from ultra-low power wearables to power hungry notebook computers and monitors. This design supports a total system power of 200W and uses ON Semiconductor's NCP81231 buck controller with ON's FUSB307 USB Type-C Port Controller. Each port is capable of providing the full 100W (20V at 5A) while providing additional protection logic to allow for robust design and safe charging. There is a power foldback feature implemented based on temperature, to ensure that the device is protected in the case of high on-board temperatures. A similar dual port design is available in an automotive grade version and is suitable for in-dash and infotainment systems, industrial and commercial transportation, and marine applications.

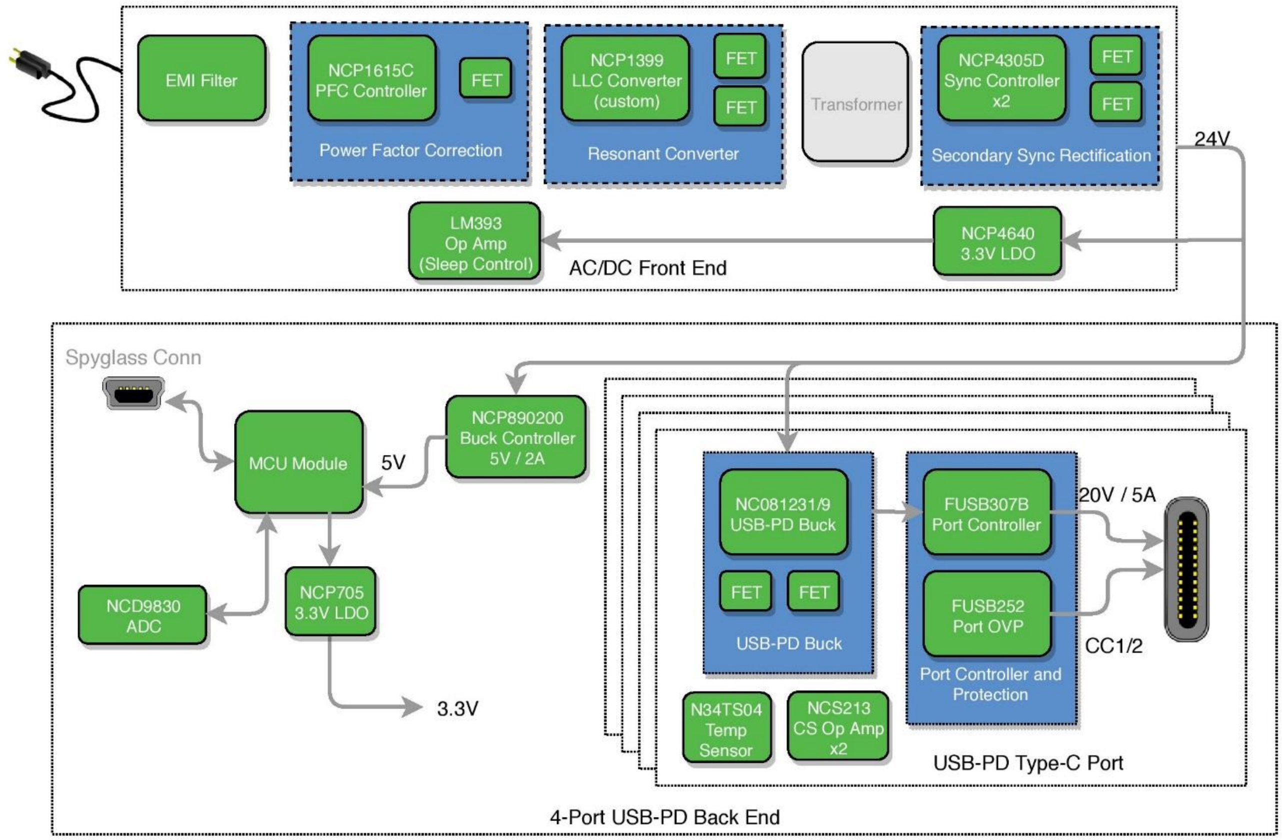
Features

- Four USB Type-C Outputs
- Supports USB Power Delivery up to 100W per port
- Power Management Algorithm to intelligently deliver 200W across four ports
- Default PDO's = 5V, 7V, 8V, 9V, 12V, 15V, 20V at 5A
- Input and Output Power Monitoring
- Thermal Protection, Overcurrent Protection,
- NCV81231 Buck + FUSB307 Port Controller

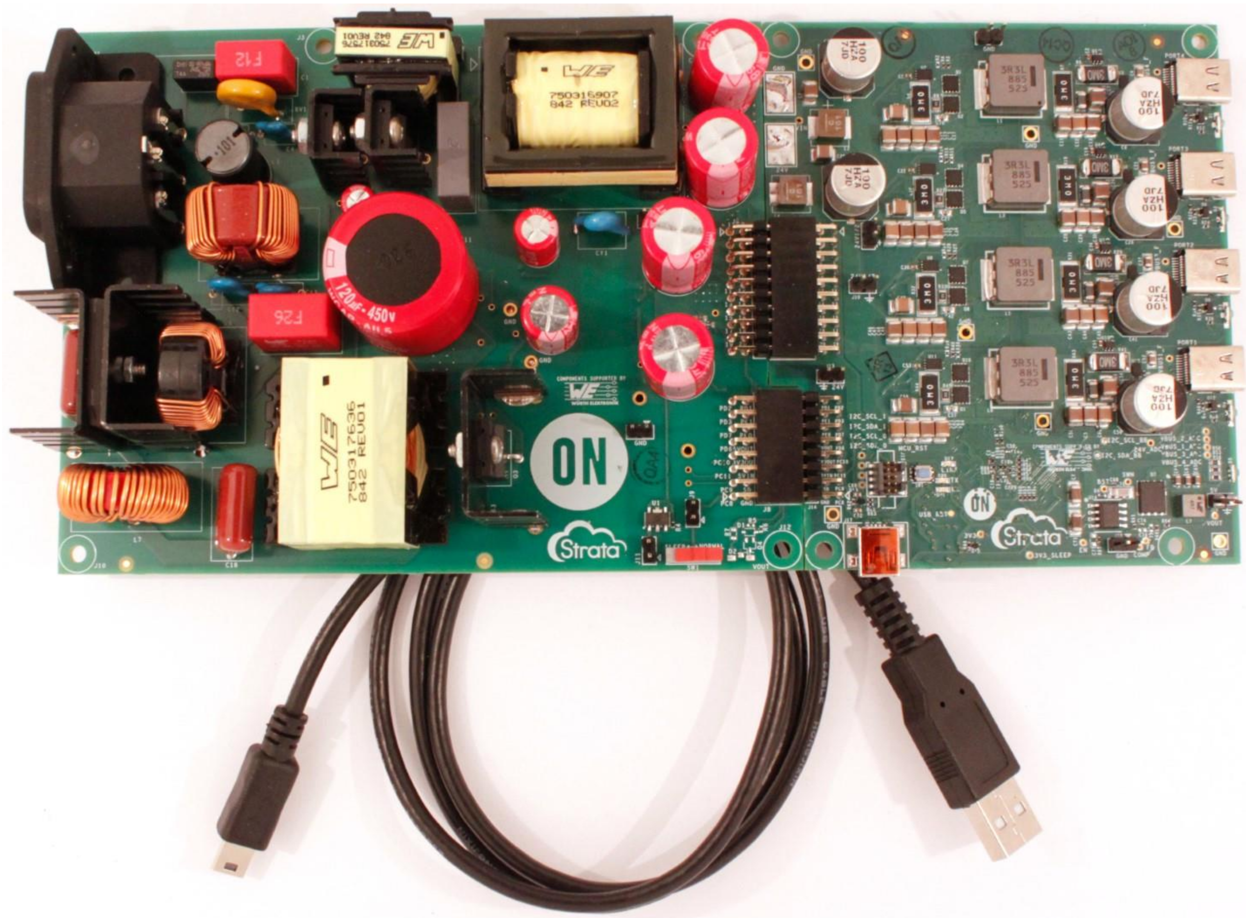
Applications

- Consumer Electronics
- Computing
- Point of Sale
- USB Type-PD Systems

Block Diagram



Board Picture



System Performance

Cable Attach / Detach

In USB Type-C systems there is no power in the cable while a device is not attached (0V on VBUS). When a device is attached, VBUS will transition to 5V.

The figures below show an attach and detach event occurring.

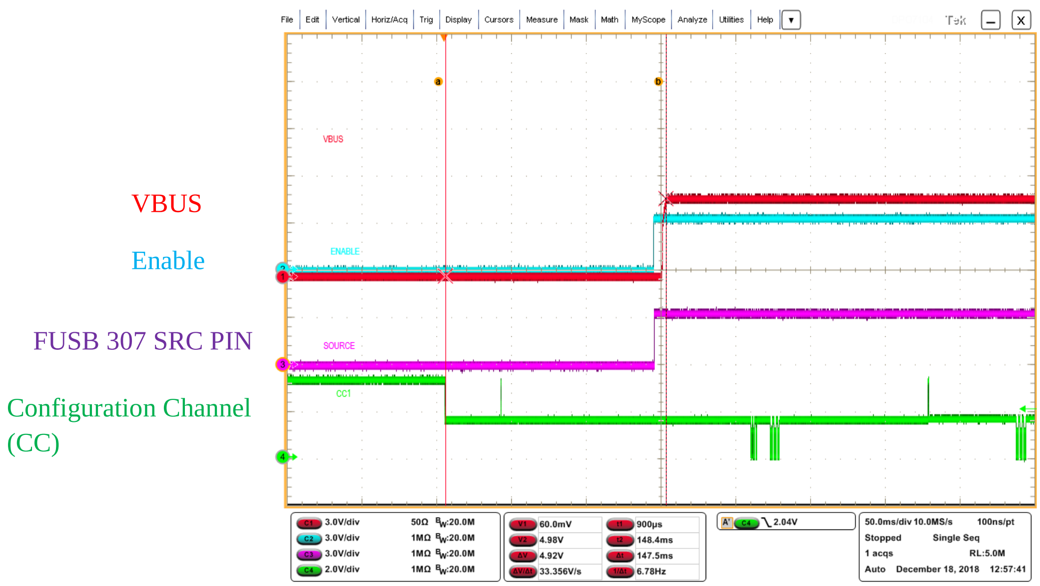


Figure 1 - Startup Waveform on Type-C Attach

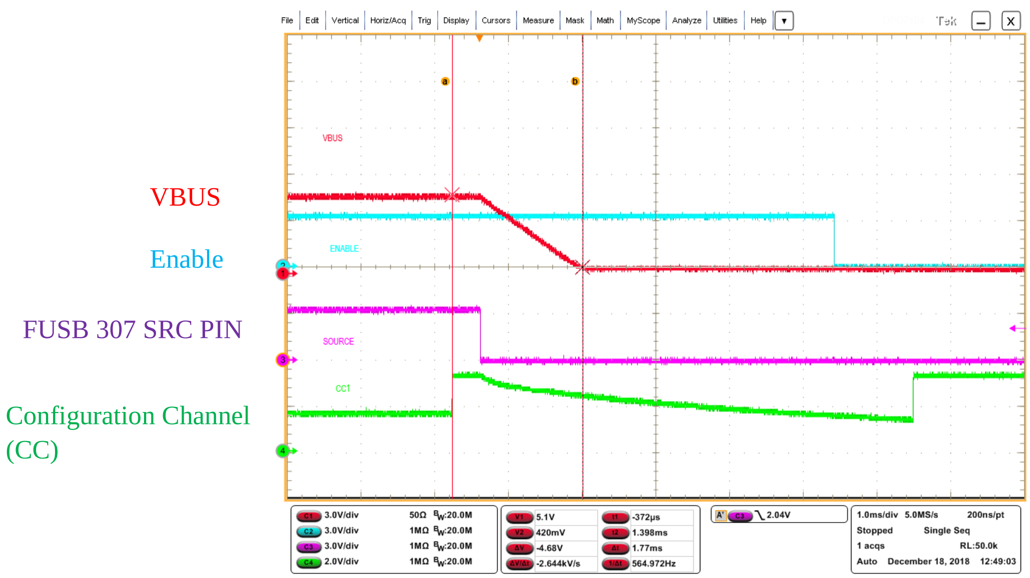


Figure 2 - Shutdown Waveform on Type-C Detach

USB-PD PDO Voltage Transitions

After a USB Type-C attach, if USB Power Delivery is implemented, the Sink device is able to negotiate with the Source to get a higher voltage on VBUS to enable fast charging. All PD communications is done on the Configuration Channel (CC) in the Type-C cable.

Below are images of VBUS voltage transitions from 5V to 20V and 20V to 5V.

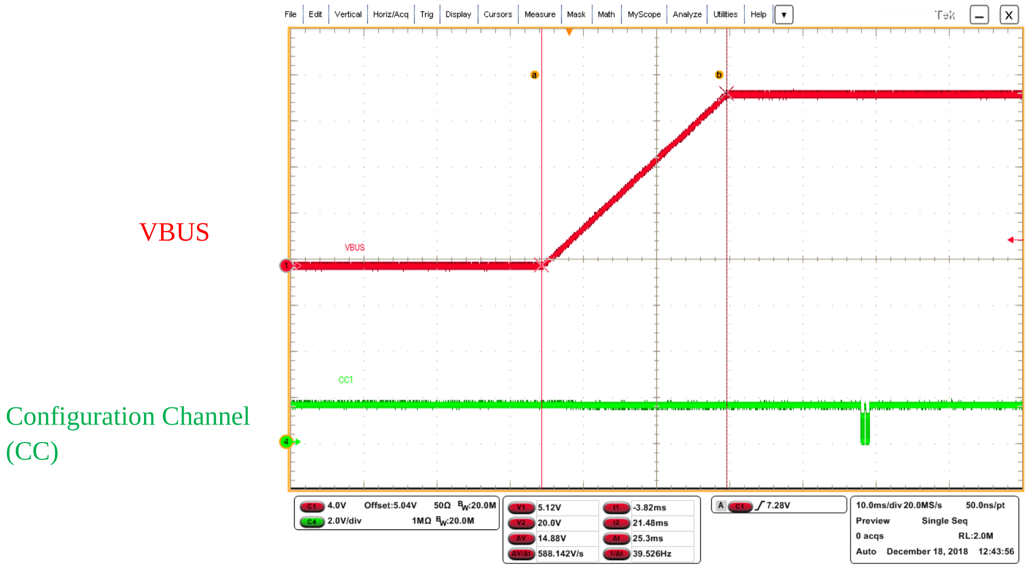


Figure 4 - 5V to 20V VBUS Transition

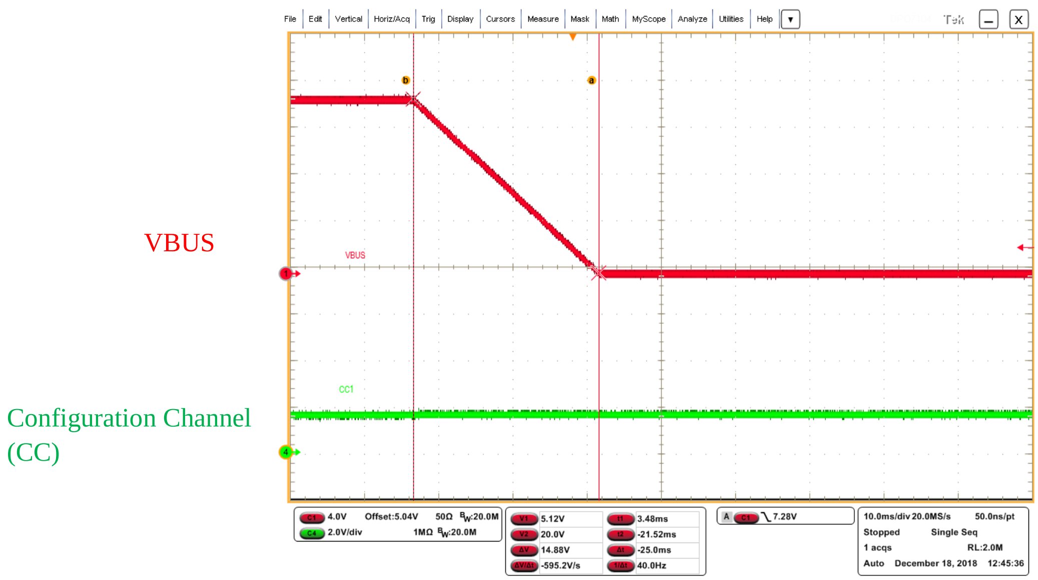


Figure 3 - 20V to 5V VBUS Transition

Cable Compensation

Due to higher current charging than legacy USB devices, there is a significant voltage drop in USB-PD systems. To combat this problem this system has implemented an active algorithm that monitors the output current and biases the VBUS voltage to account for the voltage drop seen by the sink device.

Below is an oscilloscope shot of voltage @ connector and load with the corresponding current step showing cable compensation adjusting to the new current.

Cable Compensation default setting = 100mV/A.

Figure 4 – 1.5A to 2A load step to induce 100mV/A VBUS increase

Figure 5 - 1.5A to 2A load step to induce 200mV/A VBUS increase

System Efficiency

System efficiency is measured by applying 24V to the input of the board with all power rails enabled and a single Type-C port outputting the voltages in the legend below. The figure shown below reflects total system efficiency including sense elements as opposed to the efficiency of a single buck stage supplying a port.

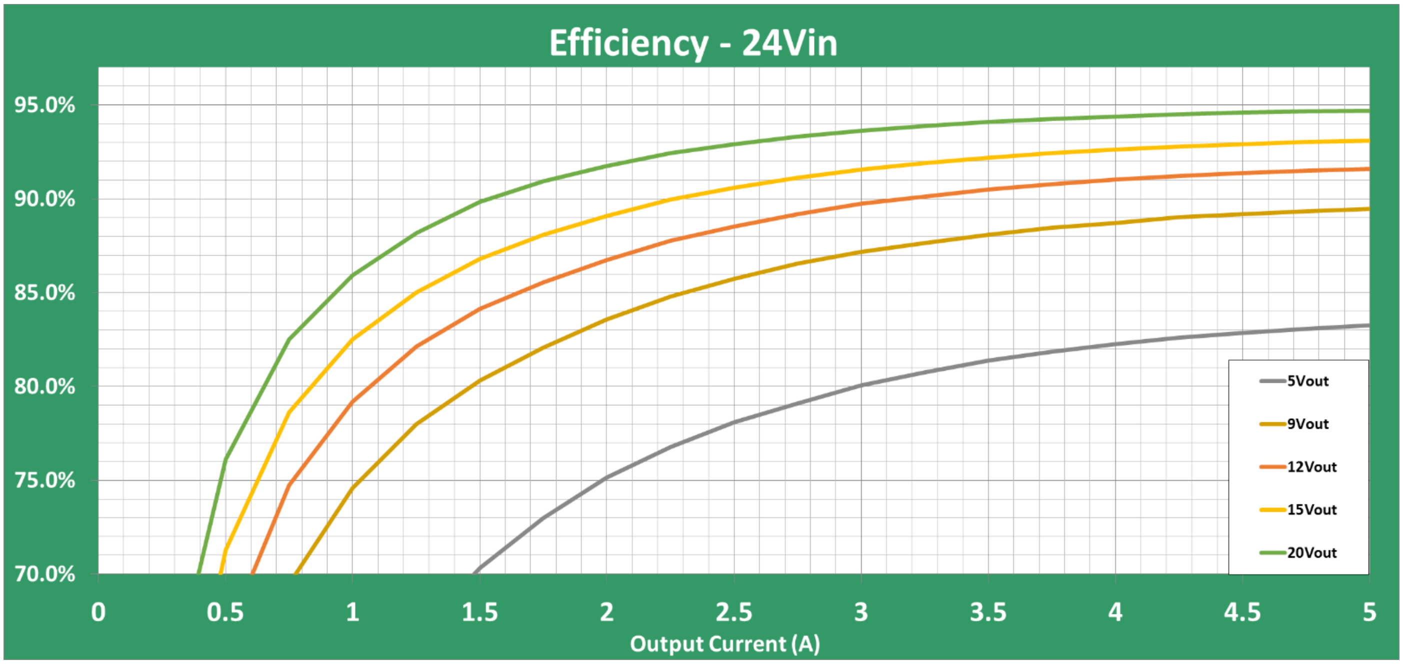


Figure 9 – System Efficiency from 0A to 5A at 5V, 9V, 12V, 15V, and 20V

Current Limit

Multiple current limit protection features are implemented in this system. The first is the software current limit settable in the Strata UI anywhere from 1A to 6A – operation shown in Figure 10. This feature could be implemented to restrict power to a sink device so that it does not consume more current than it has allocated from the source.

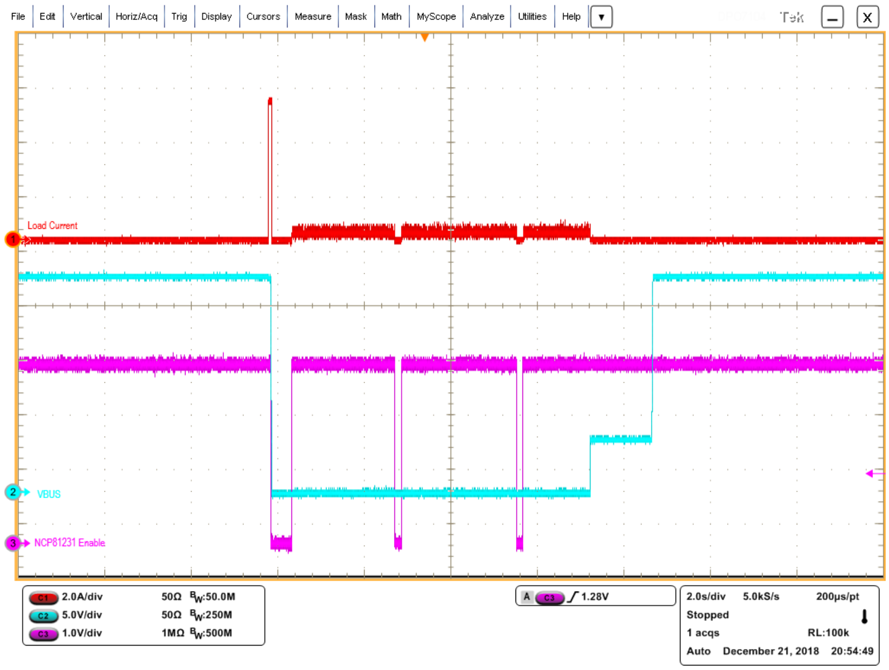


Figure 10 – Software current limit with retry. OCP event removed and VBUS returns to 20V

A short circuit current limit exists within the FPF2895 load switch present at the output of each type-c port which is set to 6A – operation shown in Figure 11. This part will protect the device in case of a faulty sink device or a short within the connector.

Figure 11 – FPF2895 OCP event w/ load step of 0A to 7A and VBUS at 20V

Thermal Performance

All data taken with no cooling and Tsoak time of 10min.

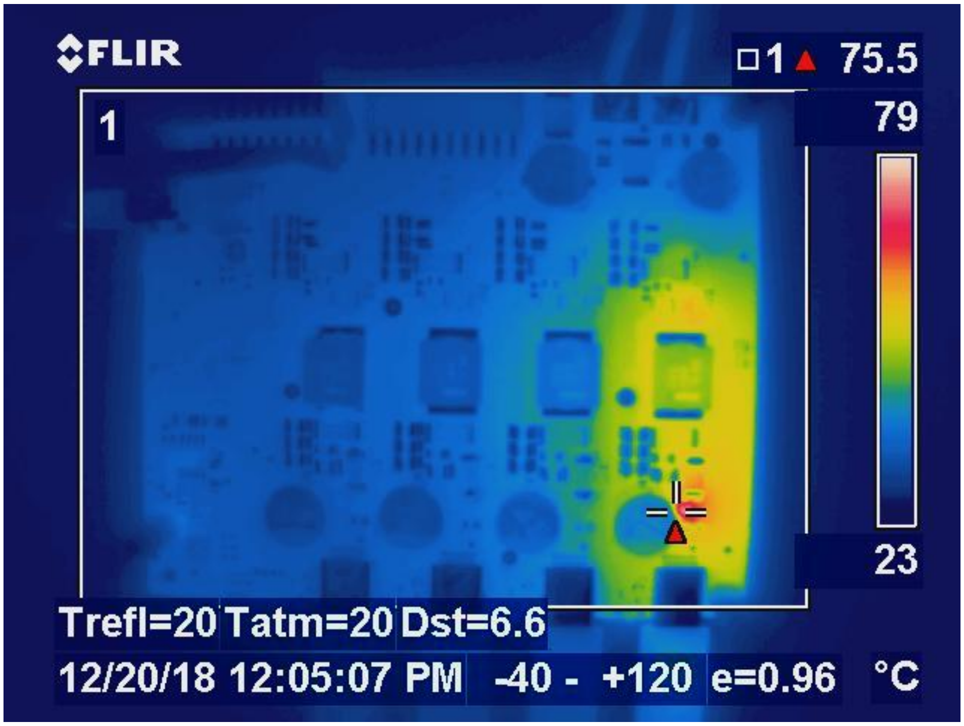


Figure 12 - One Port: 100W

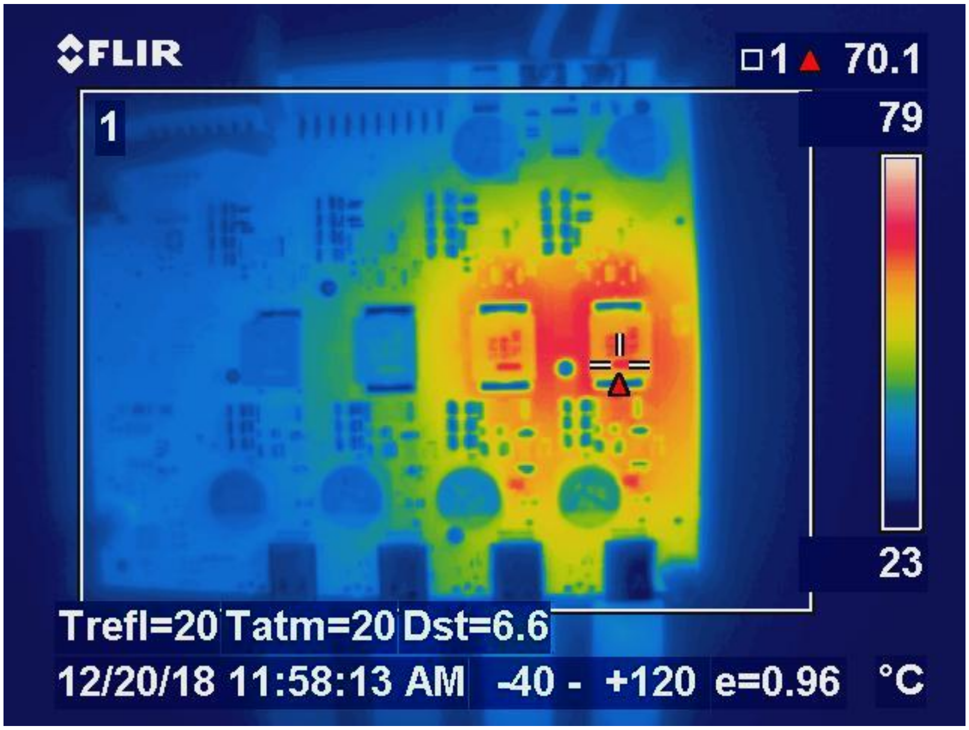


Figure 13 - Two Port: 50W each

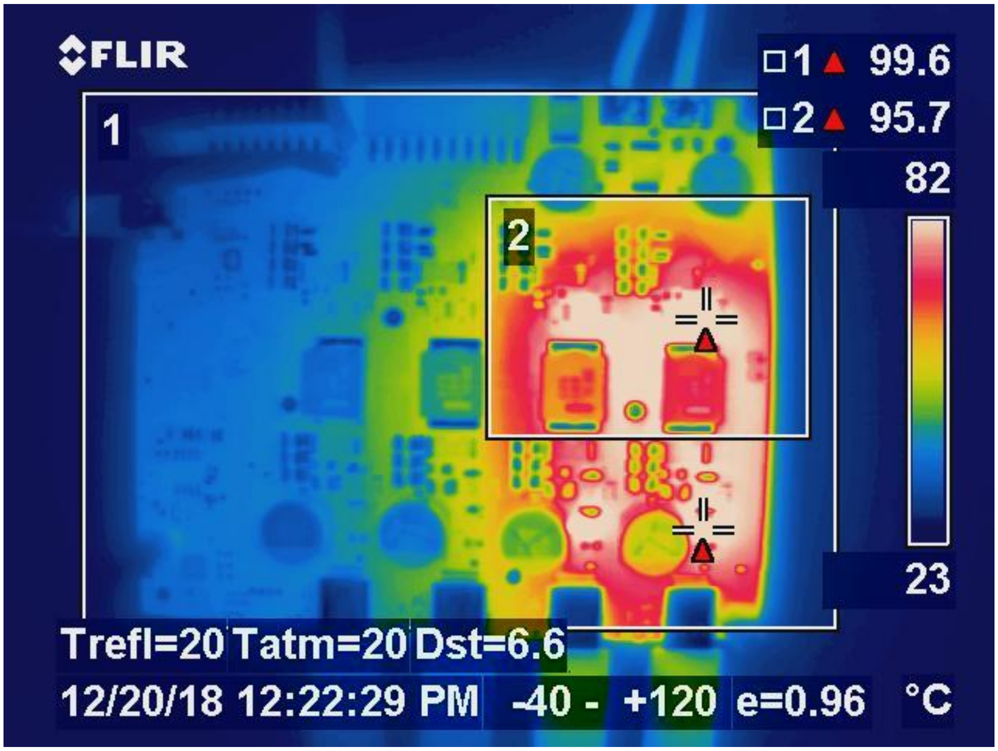


Figure 14 – Two Port: 100W each

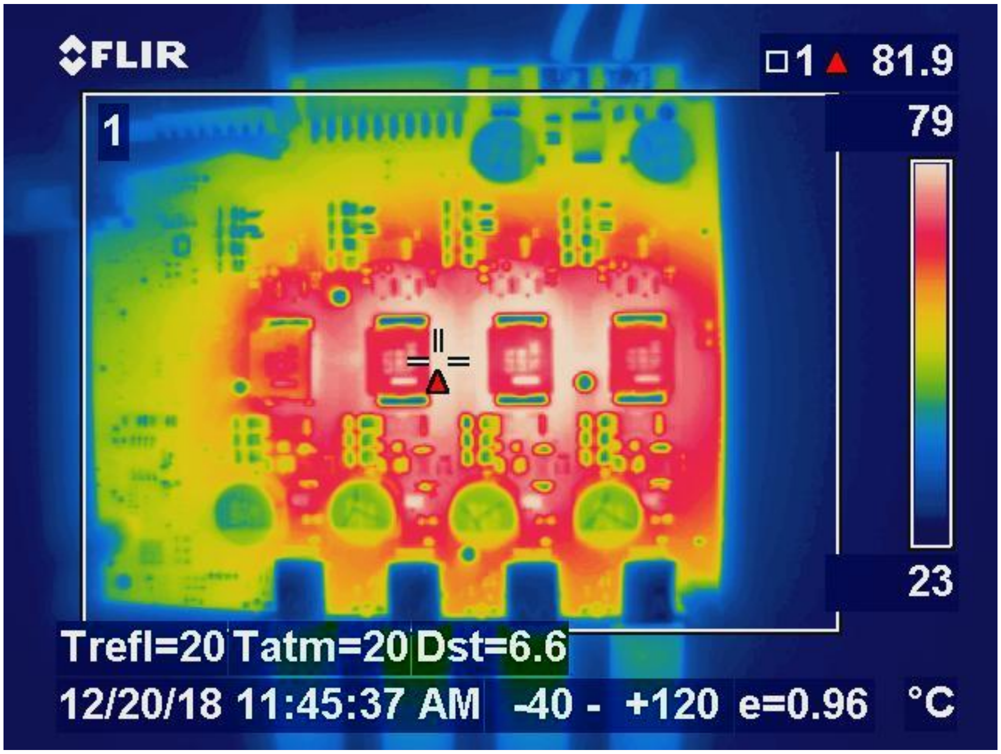


Figure 15 – Four Ports: 50W each

200W LLC with PFC - Introduction

This unit is a highly efficient 200W power supply powered from the mains. It can work as a standalone 24V power adapter or can be combined with almost any downstream DC-DC converter that accepts 24V input. In the current application it powers four USB-PD down converters.

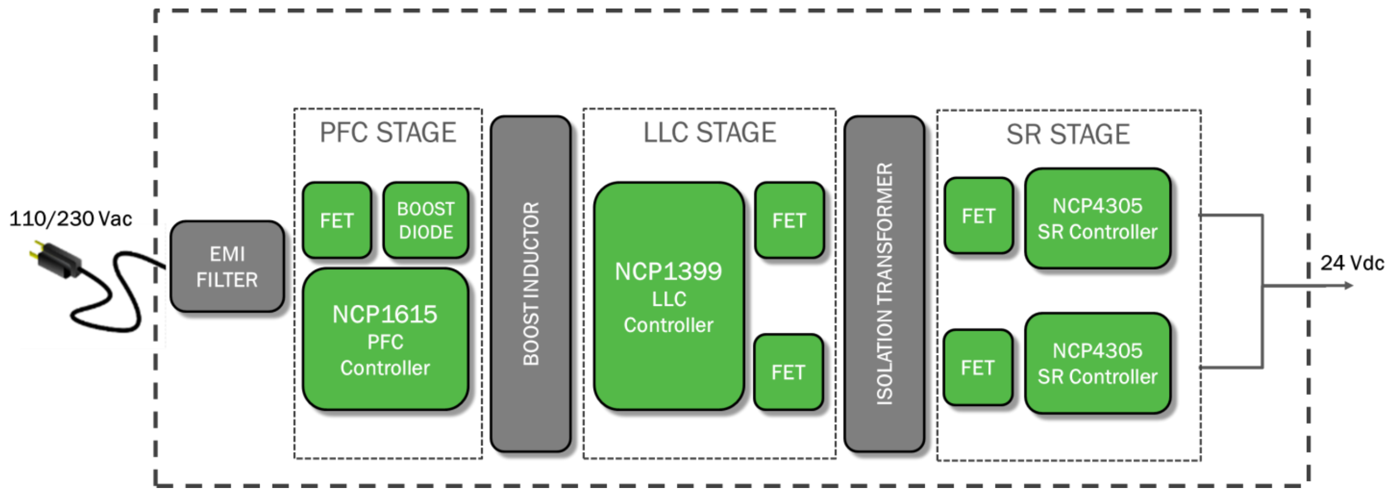
Features

- Input range: 90 – 265 Vac / 50-60 Hz
- Max output power: 215 W
- Output voltage: 24V
- Max output current: 9A
- Power factor corrected
- Efficiency > 92.5% at max load
- Over current, over voltage, over temperature protection
- Extremely low standby power consumption < 0.2W

Applications

- Power Supplies
- USB-PD Fast Chargers

Block diagram



Functional Description

The PFC stage uses the NCP1615 controller which operates in critical conduction mode. In this mode the MOSFET turns on at zero current and the boost diode is not exposed to reverse recovery. All this contributes to very good efficiency at mid and heavy load. At lighter load the controller transitions to a mode where it linearly reduces its switching frequency thus maximizing efficiency at light load.

When running at no load, the PFC starts running intermittently and only sends a short burst every few seconds to maintain the bulk capacitor voltage within the range of roughly 350 – 390 Vdc. This ensures an adequate voltage input voltage for the LLC stage that follows.

The LLC stage uses the NCP1399 which is a state of the art current mode controller for half-bridge resonant converters (LLC). The resonant mode allows for zero voltage switching of the primary MOSFETs and zero current switching of the secondary rectifiers, thus maximizing efficiency at medium and heavy loads. At lighter load the controller enters a skip mode in order to maintain high efficiency.

In standby mode when there is only an absolute minimum power needed at the output (for example to keep a micro controller in standby), the LLC can enter a sleep mode when it stops operation for several tens of seconds and the output slowly decays from 24 V down to 5 V and then suddenly recovers in a fraction of a second and so on. In this mode input power consumption is below 200 mW.

Waveforms

The following is a collection of waveforms that are typical to different modes of operation.

Power up

Within less than half a second of applying AC voltage to the unit, the PFC section starts operation and raises the high voltage buss (HV Buss) to 390 Vdc. Upon reaching this level a PFC_OK signal is generated which enables the LLC converter and the 24 V output comes up right away with no overshoot.

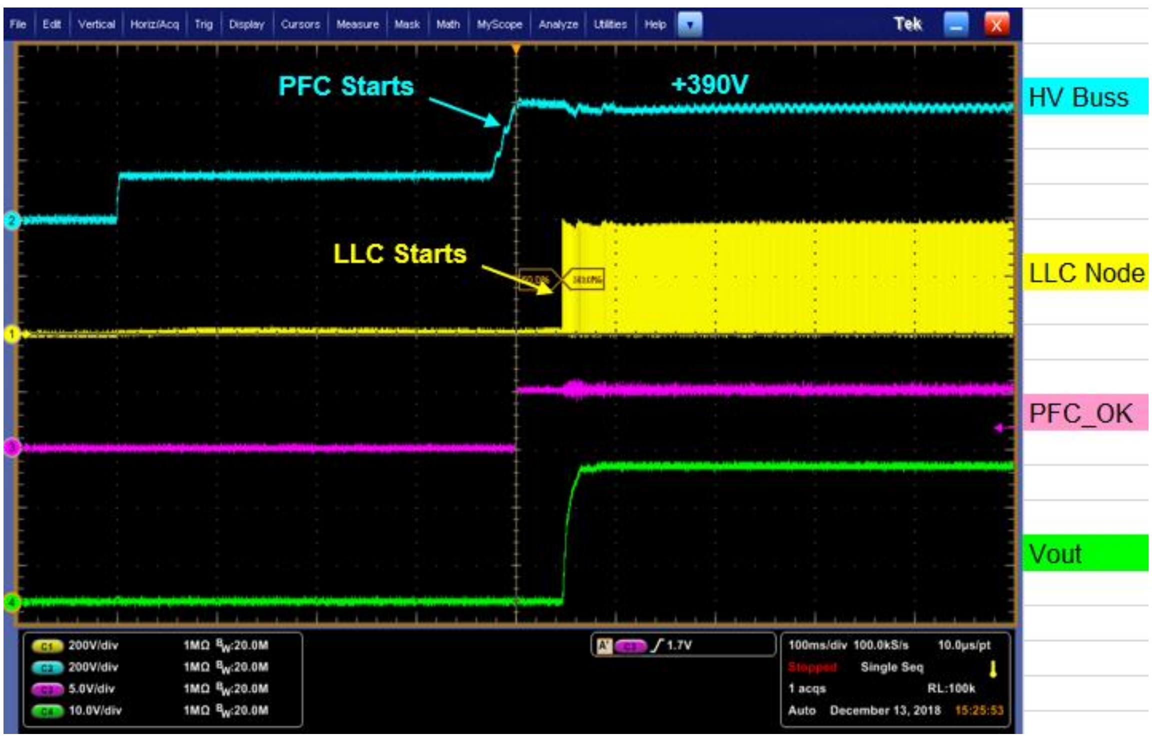


Figure 16 – Power up from 110 Vac

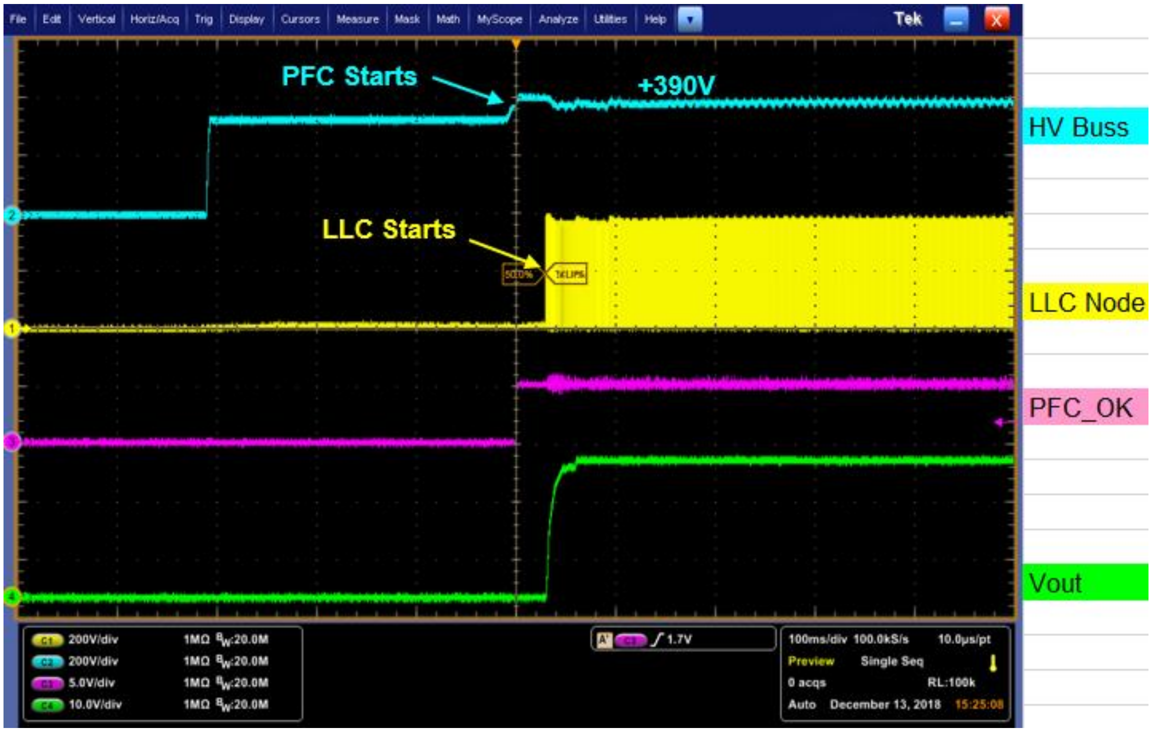


Figure 17 – Power up from 230 Vac

Power down

Upon removing AC input voltage, both PFC and LLC sections stop operating and output voltage decays to zero.

Figure 18 – Power down

Operation at maximum load

The LLC switches at roughly 80 kHz. As expected for a resonant converter, no ringing or overshoot can be noticed. The secondary synchronous rectifiers are driven 80° out of phase with a minimum of dead time in between.

Figure 19 – Running at maximum load (215 W)

Operation at lighter load

For output currents of roughly 1 A or lower, the LLC enters a skip mode while the PFC is still maintaining a constant HV buss.

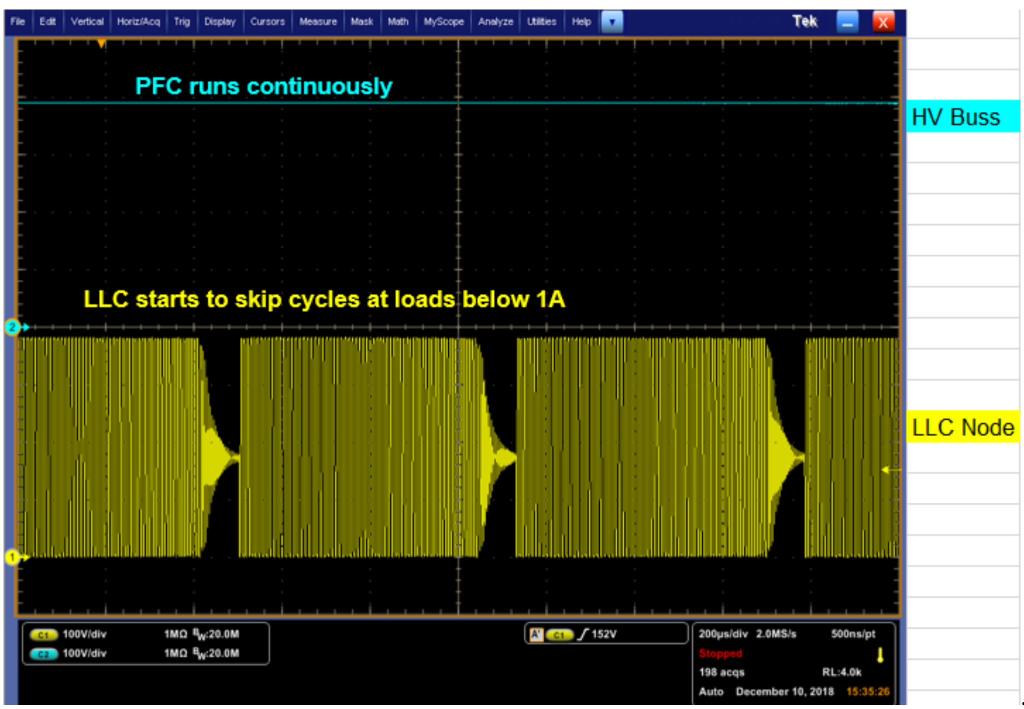


Figure 20 – Running at lighter load

No load operation

The PFC runs intermittently only to replenish the bulk capacitor and maintains the HV Buss voltage in the 350 – 390 V range. The LLC continues to run all the time, but stays in skip mode (can't be noticed in the scope shot).

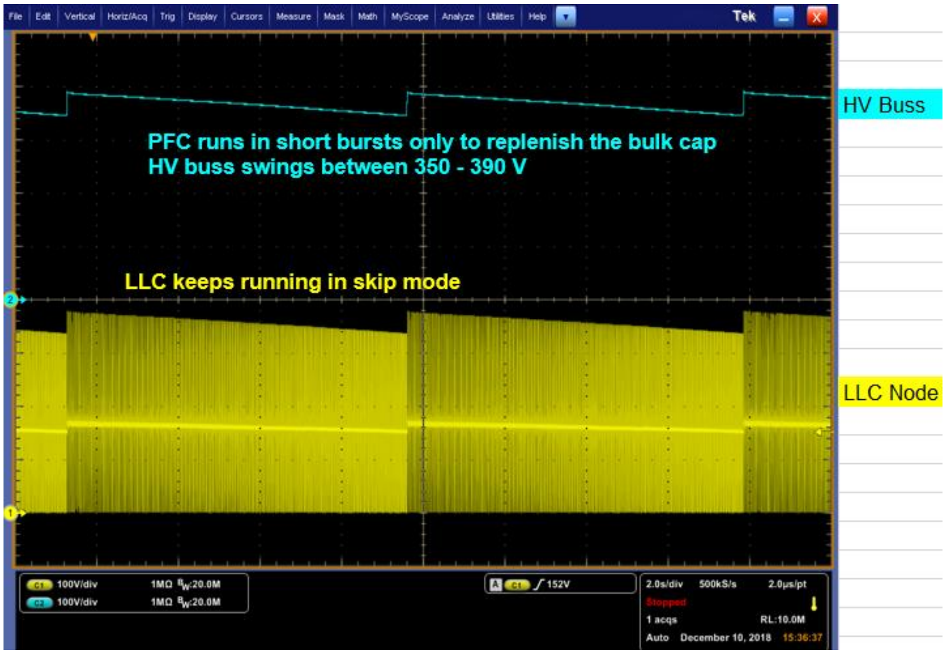


Figure 21 – No load operation

Transition from some load to no load and back

The unit seamlessly transitions to no load mode and back.

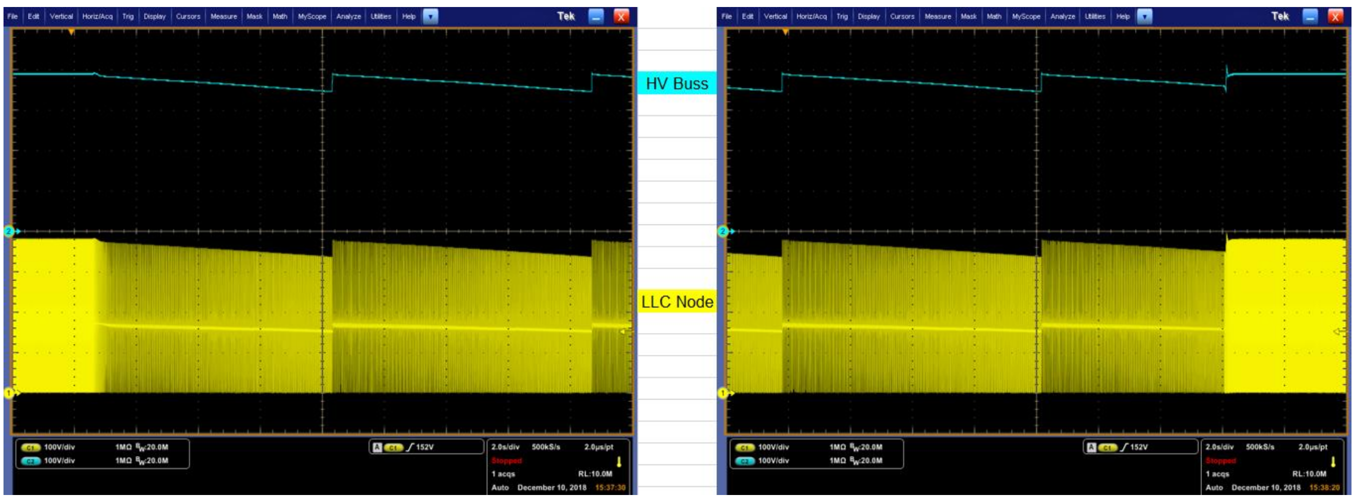


Figure 22 – Transition from some load to no load and back

Transition through all the possible modes

The screen shot bellow captures the unit behavior as it transitions through all the possible modes. Vout is seen to stay in regulation even during the no load mode. If minimum power consumption is to be achieved during the no load situation, then a SLEEP signal coming from a downstream microcontroller can set the unit in sleep mode. Note that sleep mode should be tested without any other board attached. In sleep mode, both PFC and LLC converters will stop operation and output voltage Vout will then slowly decay from 24 V down to 5 V. When Vout reaches 5 V, the PFC and LLC will momentarily wake up to bring Vout back to 24 V and then stop operation again. The minimum 5 V level should be enough to maintain a downstream microcontroller in standby via a 3.3 or 5 V LDO. This mode of operation results in long intervals of inactivity (20 – 30 seconds) and allows achieving less than 200 mW input power consumption.

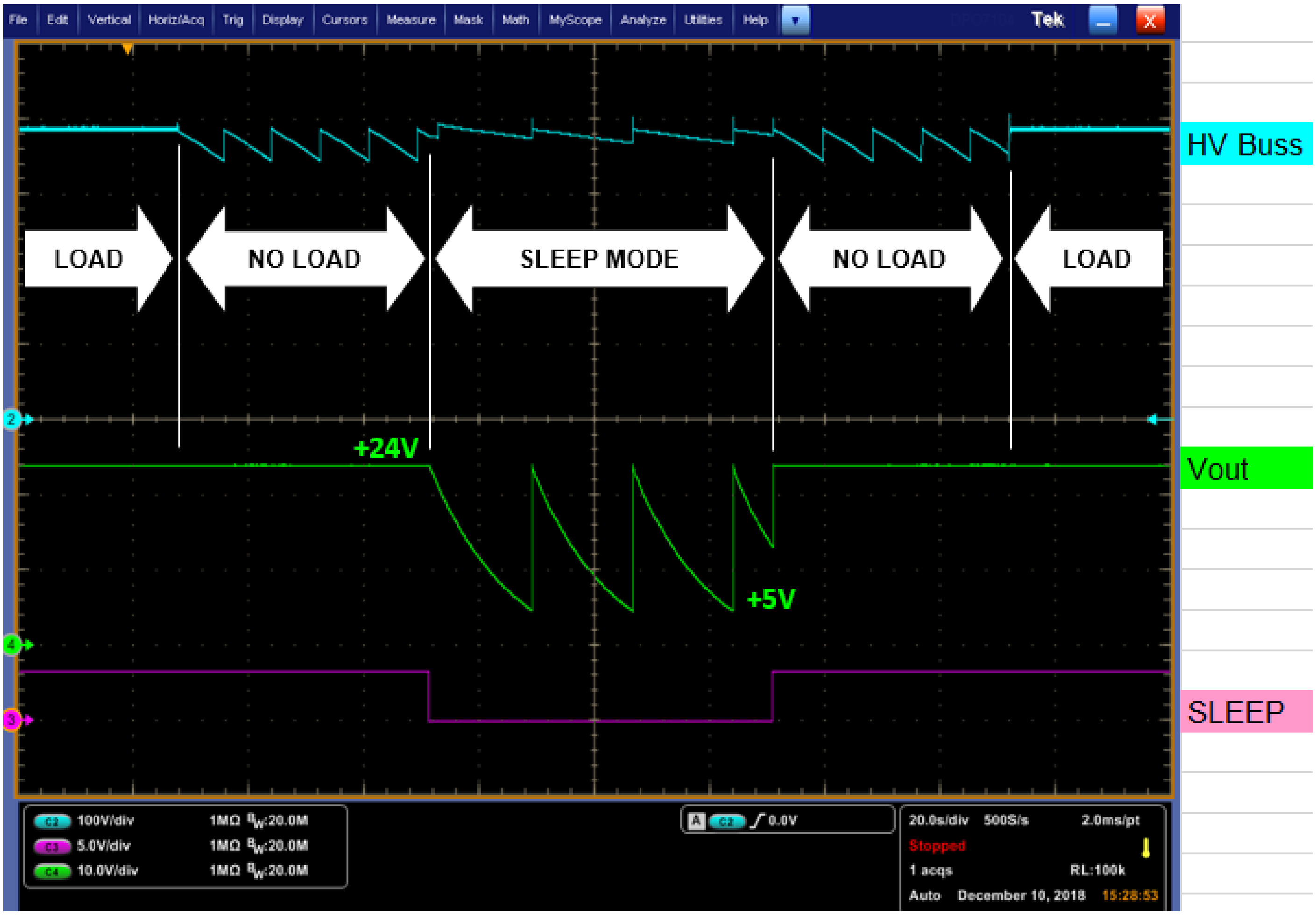


Figure 23 – Transition through various modes

Abnormal conditions

Shorted output

If a short is present at the output, the unit will make a 2nd attempt to power up one second after the first failed one. If 2nd attempt fails too, the unit will latch. After removing the short and recycling the AC, the unit will power up normally.

Figure 24 – Power-up into a shorted output

Momentary short at the output

A short duration short circuit at the output will cause the unit to stop operation and to make an attempt to recover after one second. If the short is removed before that, the unit will restart.

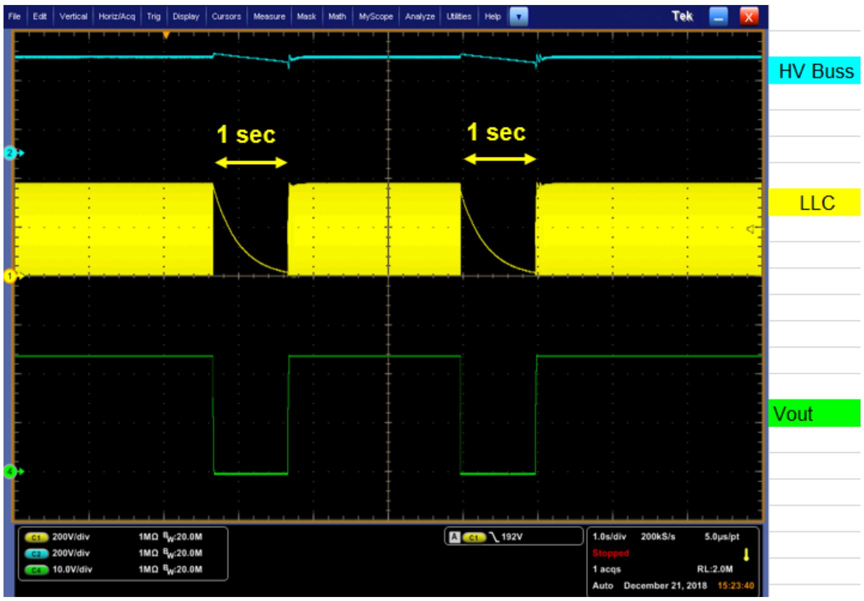


Figure 25 – Momentary shorted output

Permanent short at the output

If a shorted output occurs while running, the unit will stop and after one second will make an attempt to recover. If the short is still present, the unit will not start and will latch. After removing the short and recycling the AC, the unit will power up normally.

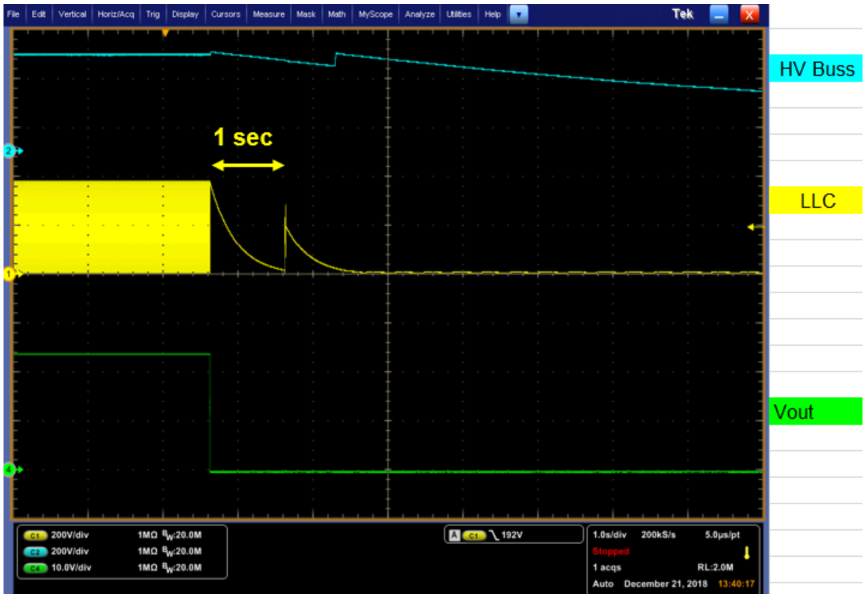


Figure 26 – Permanent short occurring

Overload

If an overload condition occurs, the unit will start hiccupping to limit the dissipation and to protect its own power semiconductors from heating. Normal operation is resumed after removing the overload.

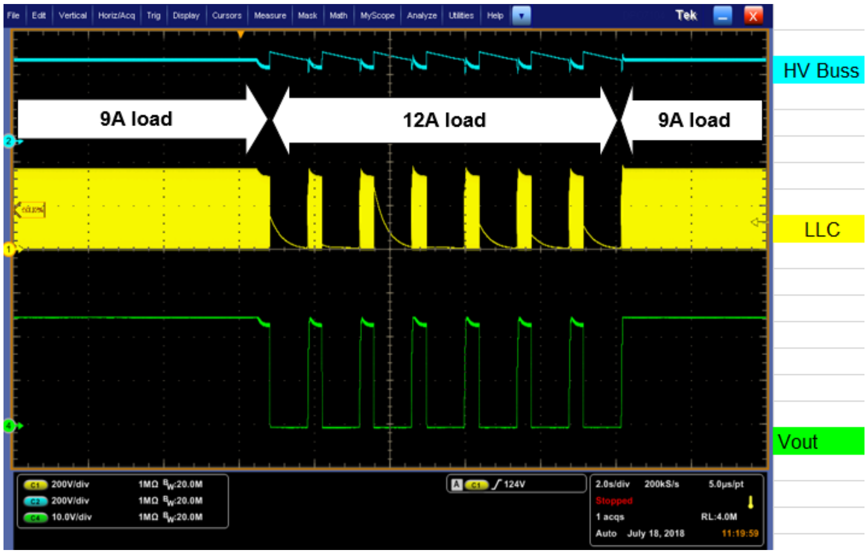


Figure 27 – Overload condition

Thermals

Thermal pictures taken with an IR camera show no excessive heating when running at full power in free air at 22°C. Adequate cooling and ventilation needs to be provided if unit is mounted in an enclosure.

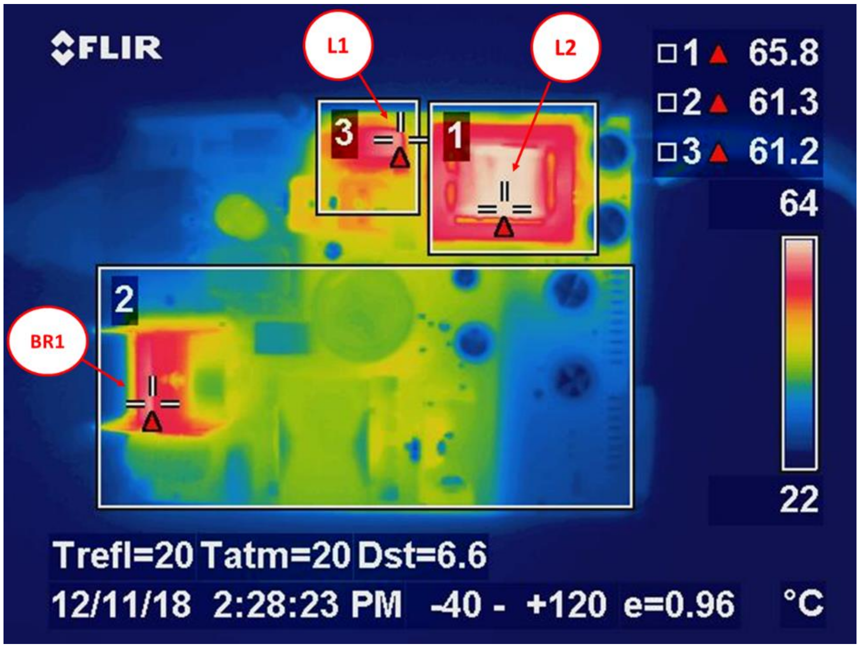


Figure 28 – TOP thermal image

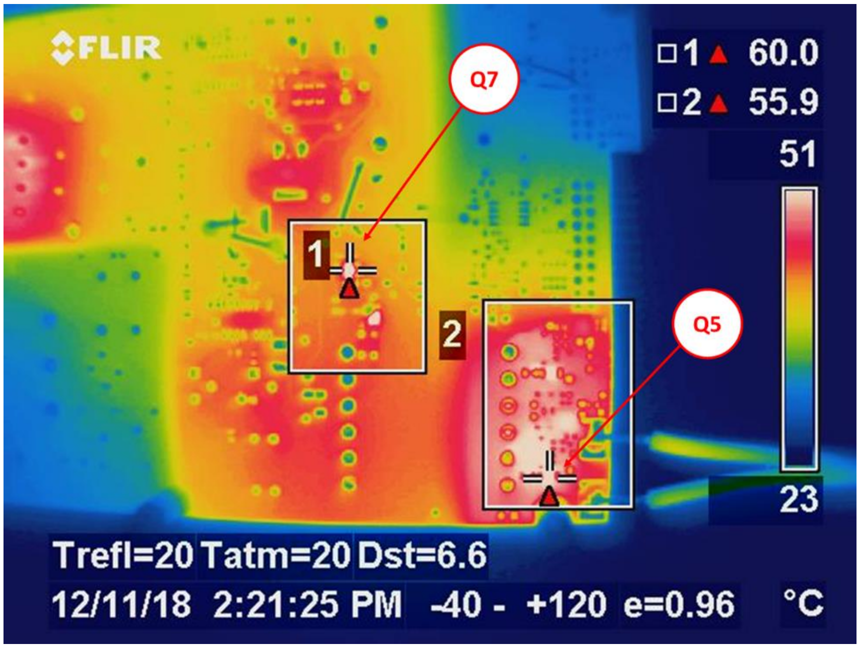


Figure 29 – BOTTOM thermal image

Efficiency

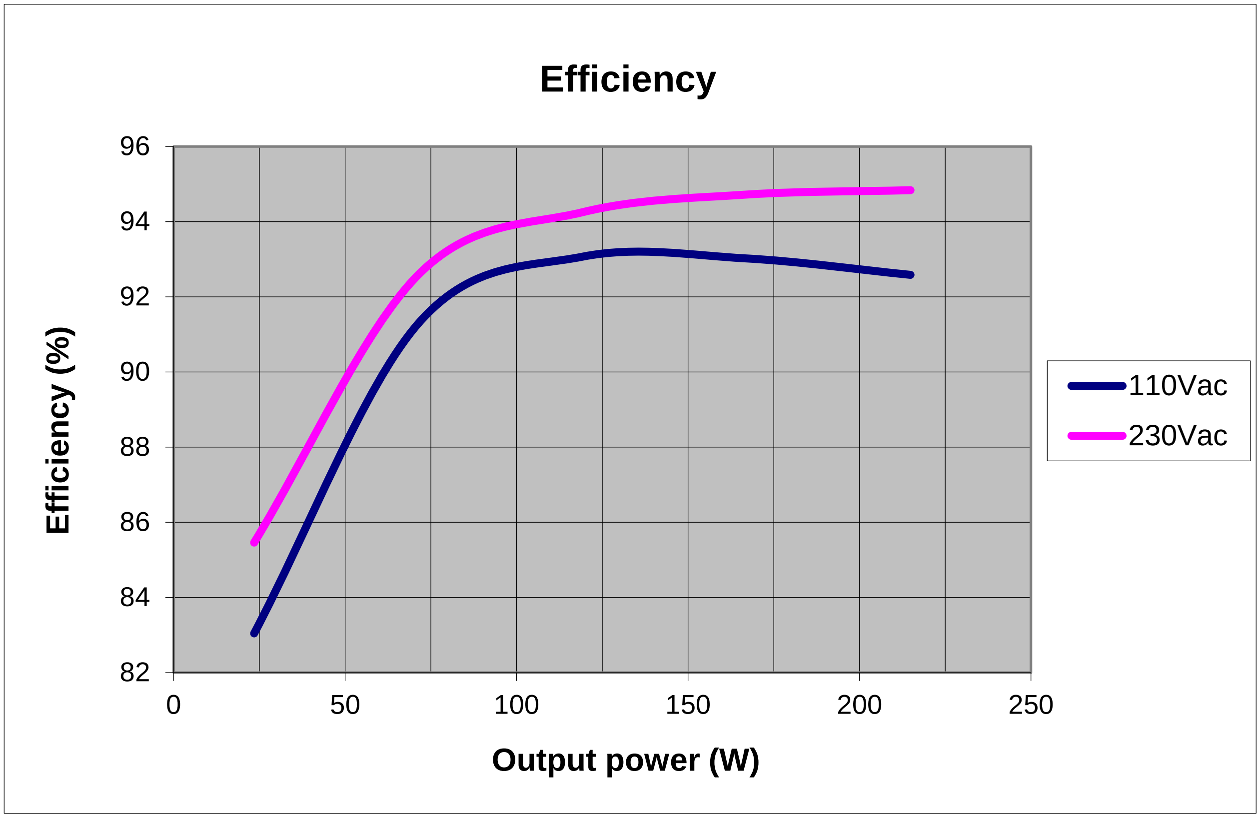


Figure 30 – Efficiency curves

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