White Paper

Considerations for Power Switch Selection in Computing USB-C Power Path

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Introduction

With the spread of USB Type-C connectors in computing market, users can charge their laptop and connect to a monitor, docking or other accessories via the same connector. USB Power Delivery (PD) adoption is accelerating, and functions that once required separate connectors are now consolidated onto a single USB-C interface. The PD specification supports up to 5 A of current for both source and SINK roles, but some applications demand more than 5 A. These higher-current requirements introduce additional considerations when selecting power switches, particularly on the SINK power path.

This paper outlines the key characteristics that should guide power-switch selection in the USB-C SINK power path for computing applications, and how they affect a USB system system. For example, if end users don't want to see any DC reverse current flow from OUT to IN under all conditions (USB Fast Role Swap or slow Voltage Ramp at Output or Input Supply Failure, etc.), then a TRCB (True Reverse Current Block) and Ideal Diode combo function would be mandatory for the power switch selected in this application scenario.

Typical USB PD Notebook Block Diagram

Generally, a USB-C source power switch could be integrated with USB PD controller as a combo solution due to limited source power capability required, while the power switch in SINK path would be a separate one due to power/thermal considerations and requires many other functions integrated except overcurrent protection, as it relies on the power source for protection. These required functions for SINK path power switch include OVP (Over Voltage Protection), Slew rate control, IDTRCB (Ideal Diode True Reverse Current Block), Power limit at soft-start period, etc. and for sure need to take thermal consideration into account.

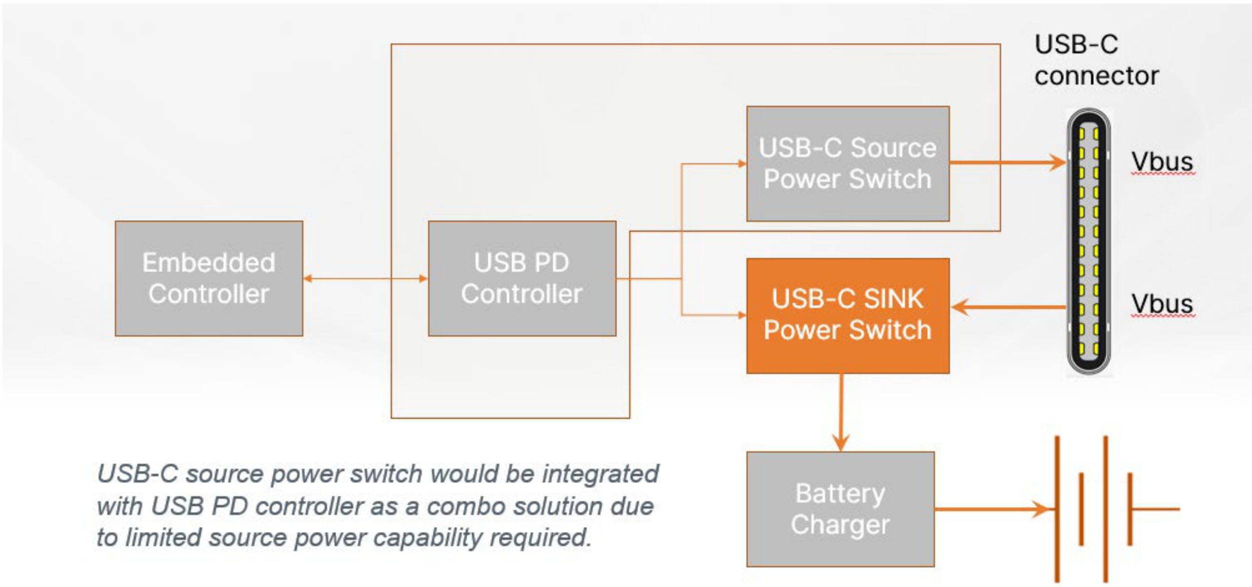

Figure 1. Typical USB PD Notebook Block Diagram

Over Voltage Protection

OVP (Over Voltage Protection) function is mandatory for the Power Switch used in USB-C SINK power path to prevent downstream components on the system board, such as battery chargers. When a high voltage is applied to Vbus, this kind of scenario can happen when a non complaint Type-C cable is purchased by end users. The system design must include circuit protection to ensure that a faulty or non-compliant cable does not damage the system. In addition to non-compliant cables, there are many power adapters that are also non-compliant with the Type-C standard. These adaptors could deliver higher than 20 V of power to VBUS before the PD negotiation begins to support this high voltage. In any cases when there are overvoltage spikes on VIN/Vbus, the power switch should cut-off after they cross the overvoltage lockout threshold (Vovp).

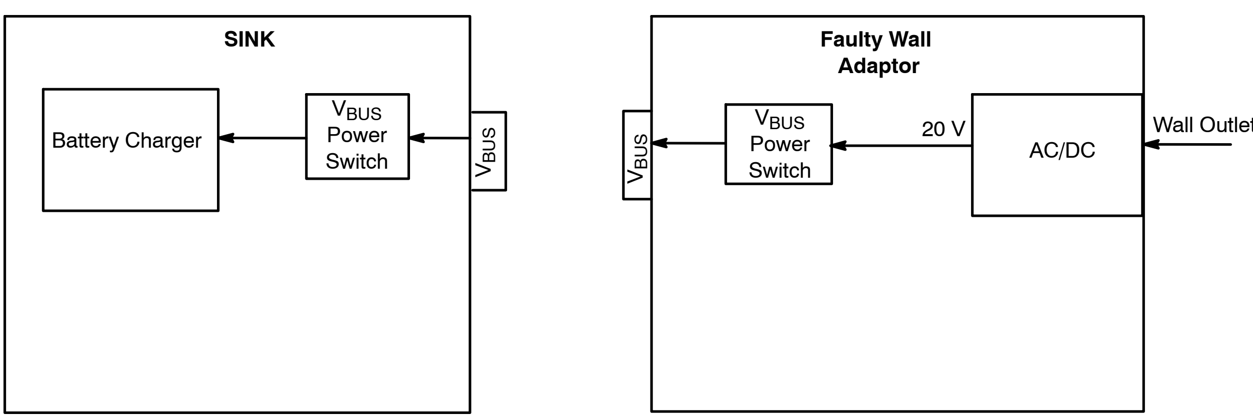

Figure 2. Typical Regular and Faulty Wall Adaptors

For FPF2890, the voltages at VIN pin are constantly monitored once the device is enabled. In case the voltage exceeds the OVLO threshold, over-voltage protection is activated:

1. If the power switch is on, it will be turned off after OVP debounce time (tOVP_DEB) to isolate VOUT from VIN;
2. OVP will prevent power switch to be turned on if it is in off state; In either case FLTB pin is pulled low to report the fault condition. The device can only be reenabled by either toggling EN pin or cycling the input power supply, for OVP response time setting, it is 512 μs in default, can also be removed by different fuse settings.

Slew Rate Control

Inrush currents are caused when capacitors are charged during initial application of voltage. The slew rate of the voltage being applied to the capacitance and the value of the capacitance will determine the inrush current as follows. The inrush current can be expressed as $I_{INRUSH} = C_{OUT} \times dv/dt$, where C_{OUT} is the circuit capacitance being charged, and dv/d is the rate of change of the voltage being applied. Thus, as an example, if the capacitance value equals 10 μF and the rise time of the voltage being applied is 5 V/μs, then the inrush current equals $10 \times 10^{-6} \times 5/10^{-6} = 50$ amps.

During hot-plug events there can be a large inrush current too. If the inrush current is not managed properly, it can damage the input connectors and/or cause the system power supply to droop leading to unexpected restarts elsewhere in the system.

For both inrush current limiting and ensuring safe operation, selecting an appropriate soft-start duration is essential since the inrush current during turn-on is directly proportional to the load capacitance and rising slew rate as mentioned in the above equation, generally the load capacitance value is fixed in system board, so we can select an appropriate slew rate (SR) to limit the inrush current (I_{INRUSH}) for a given load capacitance (C_{OUT}).

Taking the **onsemi** FPF2890 as an example in Figure 3, the device includes a dedicated soft-start (SS) pin that controls the VOUT ramp rate, helping to limit inrush current during startup. When EN pin is asserted high, the slew rate control applies voltage on the gate of the power switch in a manner that the output voltage is ramped up linearly until VOUT reaches VIN voltage level.

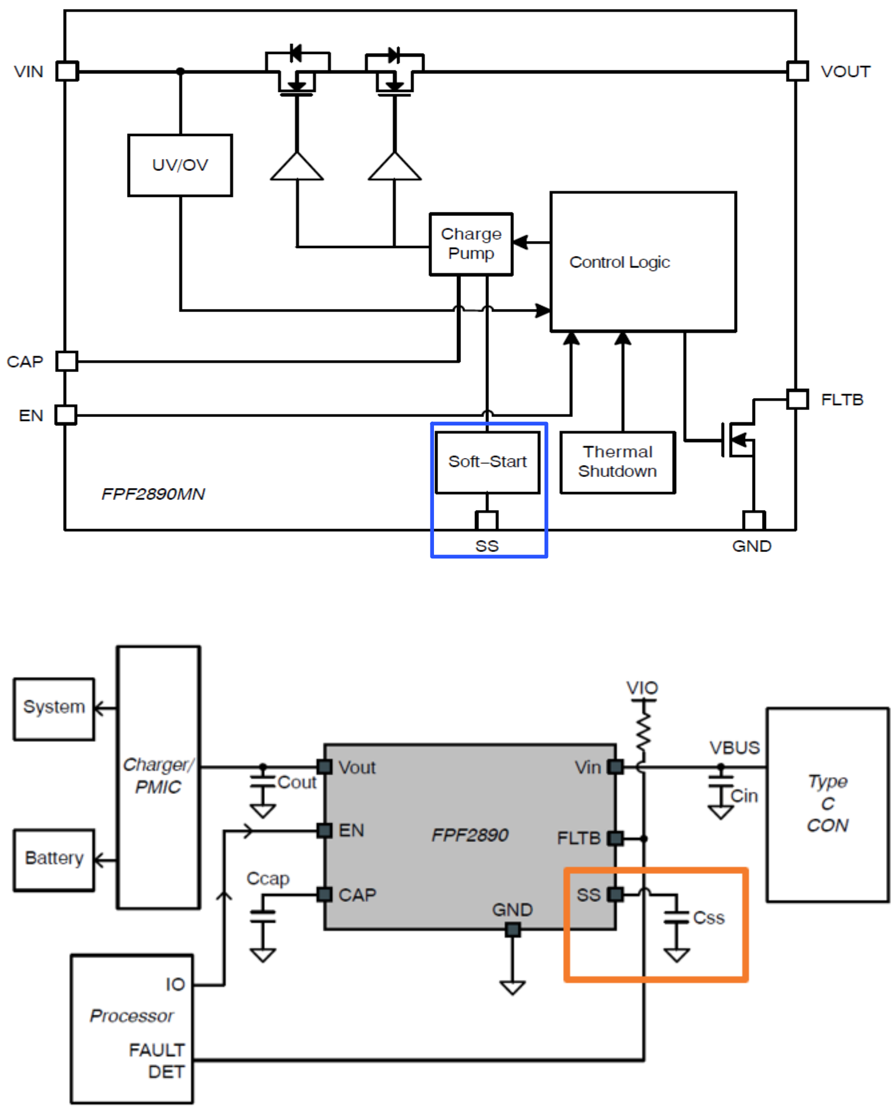

Figure 3. Block Diagram and Typical Applications of FPF2890

The output ramps up time (tON) is programmable by an external soft-start capacitor (CSS). The following formula provides the estimated 10% to 90% ramp up time:

$$t_{ON} = \frac{2 \times C_{SS} \times V_{IN}}{112.5} \times 10^3 \qquad \text{(eq. 1)}$$

Where Css is nF and t_{ON} is μs.

A 2 μA current source initiates the charging of the capacitor connected to the SS pin, the allowable range for the Css value is between 1 nF and 100 nF.

The capacitor connected to the SS pin on the FPF2890 sets the slew rate, as described by the equation that follows.

$$\text{Slew rate} = \frac{56.25\ (\mu A)}{Css\ (nF)}\ V/ms \quad \text{(eq. 2)}$$

The 56.25 μA is an internal current source for Css charging.

So the total soft-start period will be here at VIN = 20 V and Css = 5.6 nF, then SR = 56.25 / 5.6 = 10 V/ms

$$tON\_20V = \frac{VIN}{SR} = \frac{20\ V}{10\ V/ms} = 2\ ms \quad \text{(eq. 3)}$$

In consequence, according to the equation IINRUSH = COUT x dv/dt, the inrush current during start up would be 10 x 10^{-6} x 20/(2 x 10^{-3}) = 100 mA, which is far below the criteria to pull down the output of AC/DC charger or generate sufficient power dissipation to trigger TSD (or damage the device) during soft start stage according to below SOA (Safe Operating Area) curves, and that's the main purpose to set a reasonable soft-start timer.

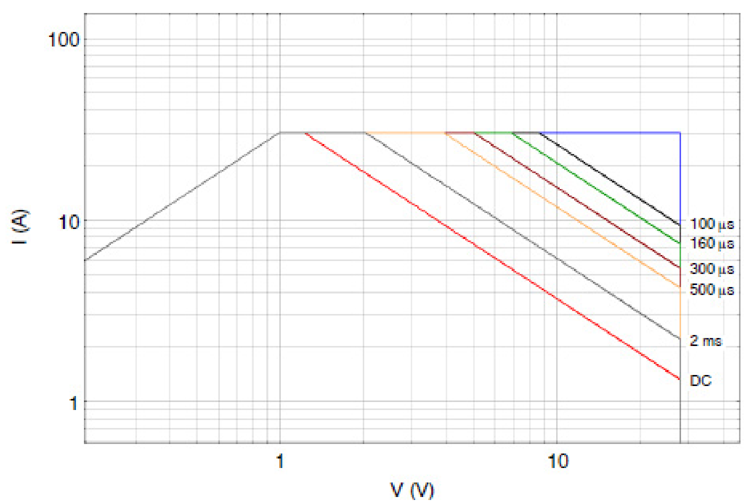

Figure 4. Safe Operating Area

Ideal Diode True Reverse Current Blocking (IDTRCB)

In some application scenarios including Power MUX/ORing, USB Fast Role Swap (FRS). or those systems in need of load side energy holding up storage in case input power supply fails, there is always a chance to generate reverse current flow from output to input when Vout is greater than Vin if there is no Reverse Current Block protection circuit designed in the system, which may cause component damage, functional disorder or safety hazard, etc.

As a power switch used in USB-C SINK path, it's mandatory to make sure the unidirectional current flow from input to output, any reverse current flow from output to input needs to be always blocked, which is the basic functionality of RCB (Reverse Current Block).

RCB (Reverse Current Block) prevents undesired current flow from output to input when the power switch is enabled (in on state), TRCB (True Reverse Current Block) works when the power switch is in either on or off state. Generally this function (RCB or TRCB) is achieved by integrating a fast comparator that turns off the power switch upon detection of VOUT – VIN is higher than VTRCB after TRCB delay time, which means a small leakage current can still be seen before RCB or TRCB being triggered as below:

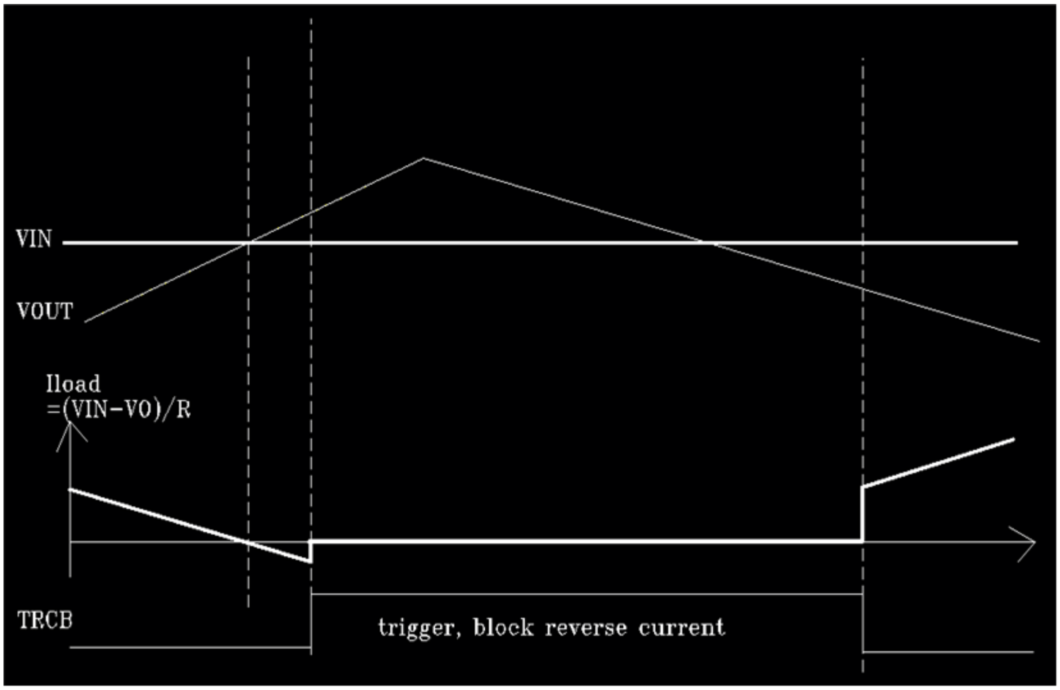

Figure 5. FPF2890 TRCB Behavior

As mentioned above, FPF2890 implements a conventional comparator based reverse blocking mechanism to provide fast response to transient reverse currents, it will turn off the power switch upon detection of Vout – Vin is higher than Vtrcb (50 mV) after TRCB delay time (0.5 μs).

The fast comparator ensures minimum supply droop which is helpful in applications such as Power MUX and USB FRS (Fast Role Swap), it also ensures minimum jump/glitch on the input rail during fast voltage step at output (hot plug).

To further reduce the leakage current before TRCB taking effect, FPF2890 integrates Ideal Diode to enhance TRCB functionality, when the device is ON with no load or under light load conditions, it regulates Vout to be 70 mV below Vin. As the load current is increasing or decreasing, the device adjusts the gate driver to maintain the 70 mV drop from Vin to Vout. As the load current continues to increase the device increases the gate drive until the gate is fully turned on and VIN to VOUT drop is determined by IR drop through the MOSFET. If for any reason VOUT increases such that VIN to VOUT drop to less than 70 mV, the gate driver forces the switch to turn off as below:

Ideal diode-like functions:

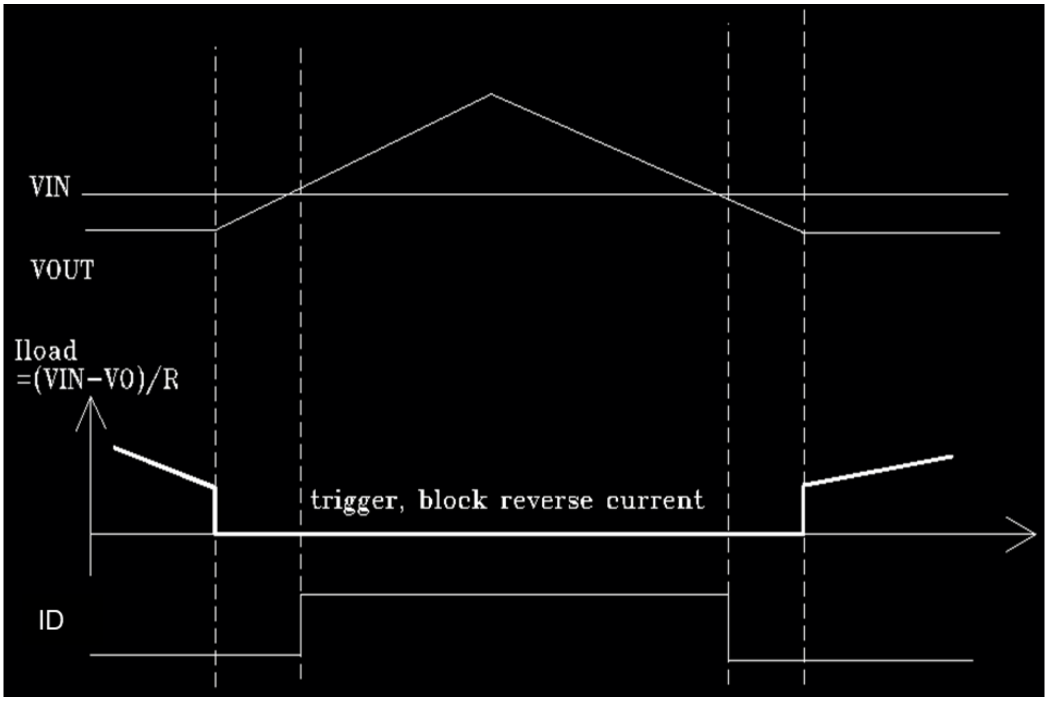

Figure 6. FPF2890 Ideal Diode-like Function Behavior

Also, this mechanism ensures there is no DC current flow from OUT to IN during slow voltage ramp at output to avoid input rail from getting slowly charged up to output voltage, which scenario usually happens when the input supply droops or gets disconnected while the output storage element (bulk capacitor or super capacitor) is charged to the full voltage.

In summary, with the combination of the above two functions (Ideal Diode and TRCB) integrated in one device (such as the FPF2890), it can completely block the DC reverse current flow from OUT to IN under all conditions (USB Fast Role Swap or slow Voltage Ramp at Output or Input Supply Failure, etc.) no matter how fast or how slowly the output voltage increases.

Power Limit and Current Limit During Soft-start Period

To minimize the risk of damage and ensure the internal MOSFET always working in Safe Operation Area (SOA), a fixed timer is set to shut down the power switch once the loading current pass through FPF2890 is higher than the current limitation or the power consumption is higher than the power limitation during start-up condition.

During soft-start period, the power switch is operating in linear mode, its power dissipation is high and often an order of magnitude greater than that of the static power dissipation (during which the power switch is fully on and at its lowest resistance), i.e., during start-up its voltage at VOUT linearly ramps up to the VIN voltage over a period of time set by the soft-start time and its power dissipation is calculated by (VIN − VOUT) x IOUT.

The calculated power is then compared to a pre-set limit, if the sensed power exceeds the power limit, the current is limited to $I\_LIM = P\_LIM / (V\_IN - V\_OUT)$.

Special attention should be paid to scenarios where the output is directly short-circuited to ground, there are two power limitation levels being applied to FPF2890 accordingly as below:

- When VOUT < 1.1 V: Power limit is set to 24 W or Current limit at 4.8 A.
- When VOUT > 1.1 V: Power limit is set to 42 W or Current limit at 8 A.

If VOUT is nearly equal to VIN while power limit is active, then I_LIM can become significantly large. To avoid the situation, a current limiting feature is implemented.

I_LIM = Min (I_(LIM_CL), P_LIM/V_DS), P_LIM is programmed power limit, V_DS = V_IN − V_OUT, I_(LIM_CL) is programmed current limit.

In both scenarios of Power limit and Current limit, if the specified condition persists for more than 512 μs, the switch will be automatically turned off.

Conclusion

USB Type-C connectors have become more popular in electronic devices, including Laptop, Monitor and desktop etc. It's important for system designers to select an appropriate power switch for its source and sink power path considering the function and protection requirements.

onsemi's FPF2890 offers an ultralow Rdson solution with comprehensive functionality integrated to reduce the risk for hard-field failures and increases end-product reliability and brand credibility.

References

[1] FPF2890 product Page https://www.onsemi.com/download/data−sheet/pdf/fpf2890−d.pdf

REVISION HISTORY

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0	Initial document release.	2/13/2026

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