Application Note

Buck-Boost NVDC Battery Charger for Notebook Application Design Using BQ25720

TEXAS INSTRUMENTS

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ABSTRACT

As USB Type-C and USB Power Delivery (PD) is widely adopted in different personal electronics devices, more and more notebooks use Type-C interface as power input in recent years. The Type-C port is a universal standard connector for transmitting both data and power on a single cable, and in particular, supporting PD standard for notebook fast charging technology.

This application report introduces a buck-boost NVDC battery charger BQ25720 that supports wide input voltage for notebook battery charging applications.

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1 Introduction

1.1 Type-C Power Delivery (PD) Connection

Figure 1-1 shows a typical Type-C Power Delivery (PD) connection that includes three key components: USB PD controller, Battery Charger and Battery Gauging, respectively. USB PD controller controls all of the USB Type-C and PD negotiations, and also controls the battery charger over SMBus communication. This battery charger IC manages all the system output power and battery charging process. In addition, it works as a reverse buck-boost to provide power in on-the-go (OTG) mode. The gauging IC is used for cell balancing to ensure all battery cells remain at an equal voltage and manage battery pack status including capacity, voltage, current, and temperature for safety. Type-C ESD IC provides protection from electrostatic discharge (ESD) and VBUS to CC short.

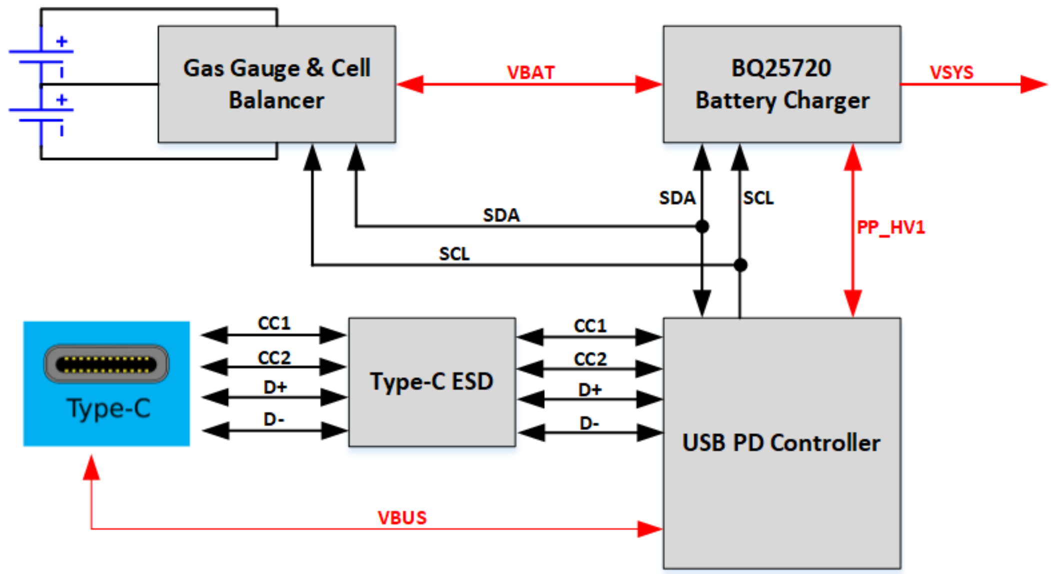

Figure 1-1. Type-C Power Delivery Connection Block Diagram

1.2 Type-C Battery Charging Topologies

The main challenge in the power delivery architecture is how to use 5 V-20 V adapter voltage to charge a 3 V to approximately 16.8 V battery (from 1 cell battery completely discharged to 4 cells battery full charged). In most cases, the input voltage range can vary from below the battery voltage to above the battery voltage. Figure 1-2, Figure 1-3, and Figure 1-4 list three common topologies for Type-C charging.

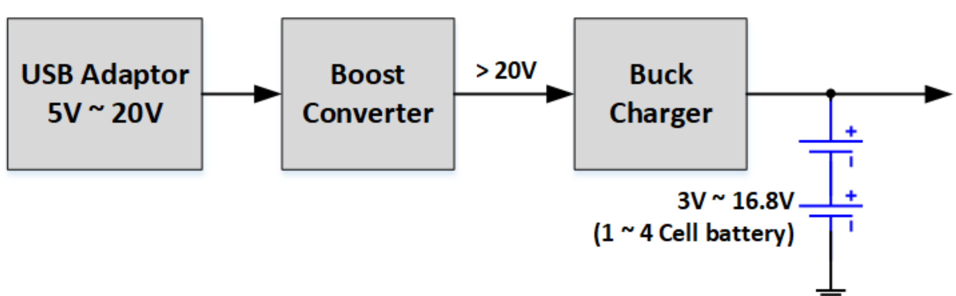

Figure 1-2. Pre-Boost Topology

The first way is to use a pre-boost topology, as shown in Figure 1-2. This approach boosts USB adapter voltage to a level higher than the highest USB adapter voltage (>20 V) and then uses a buck charger to charge the battery. The additional boost converter provide a stable high voltage to buck charger, however additional circuit increases total solution cost and board size, and reduces the overall efficiency due to the additional power loss in the boost converter.

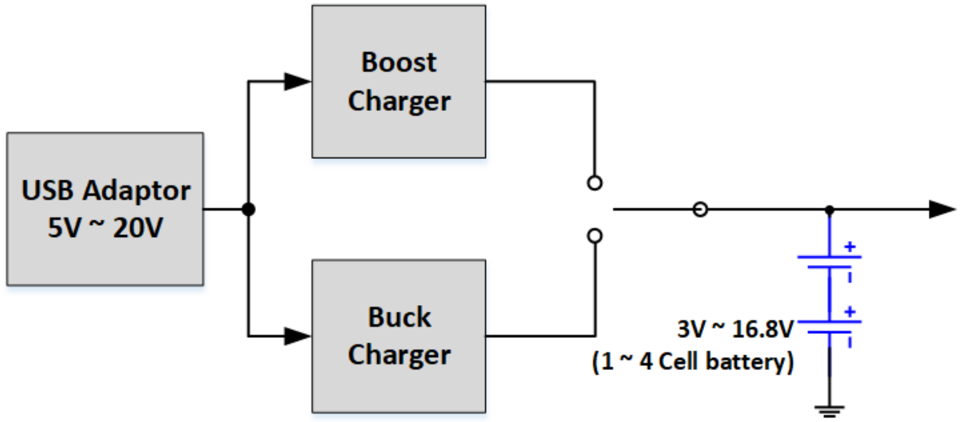

Figure 1-3. Buck Charger + Boost Charger Topology

Figure 1-3 shows a topology using either buck charger or boost charger. It needs to monitor input voltage and output voltage, and automatically select buck charger or boost charger. This topology could eliminate the additional power loss in the pre-boost approach, however, still requires an additional boost charger, which increases total solution cost.

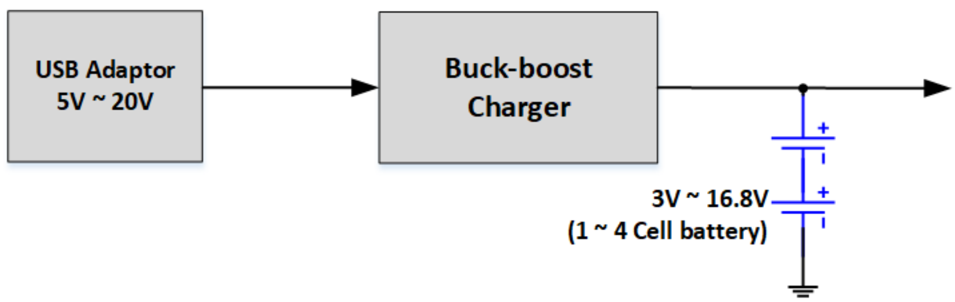

Figure 1-4. Buck-Boost Charger Topology

The buck-boost charger topology has become increasingly popular, which is shown in Figure 1-4. Buck-boost charger is able to charge a battery from nearly any source, regardless of whether the input voltage is higher or lower than the battery voltage. It could achieve a better design with the smallest solution size and the best overall efficiency.

1.3 BQ25720 Overview

The BQ25720 is a synchronous buck-boost battery charge controller to charge a 1-cell to 4-cells battery from a wide range of input sources including USB adapter, high voltage USB-C PD sources, and traditional adapter. It features an NVDC architecture that allows the system to be regulated based on battery voltage, but not drop below system minimum voltage.

It is compliant with IMVP8/IMVP9 system features for the latest Intel platform, which includes Enhanced Vmin Active Protection (VAP), comprehensive $\overline{\text{PROCHOT}}$, two-level discharge current limit, and system power monitoring (PSYS). The BQ25720 monitors adapter current, battery current, and system power, and programmed $\overline{\text{PROCHOT}}$ output goes directly to the CPU for throttle back when needed by SMBus.

Also, it supports input current and voltage regulation (IINDPM and VINDPM) against source overload and integrated Fast Role Swap (FRS) feature following USB-PD specification.

BQ25720 is a solution that supports low quiescent current and offers the flexibility to charge notebook 2-cells battery or 4-cells battery. Combined with low impedance external operating FET and inductor, engineers can further extend the battery running time for applications requiring long periods of operation.

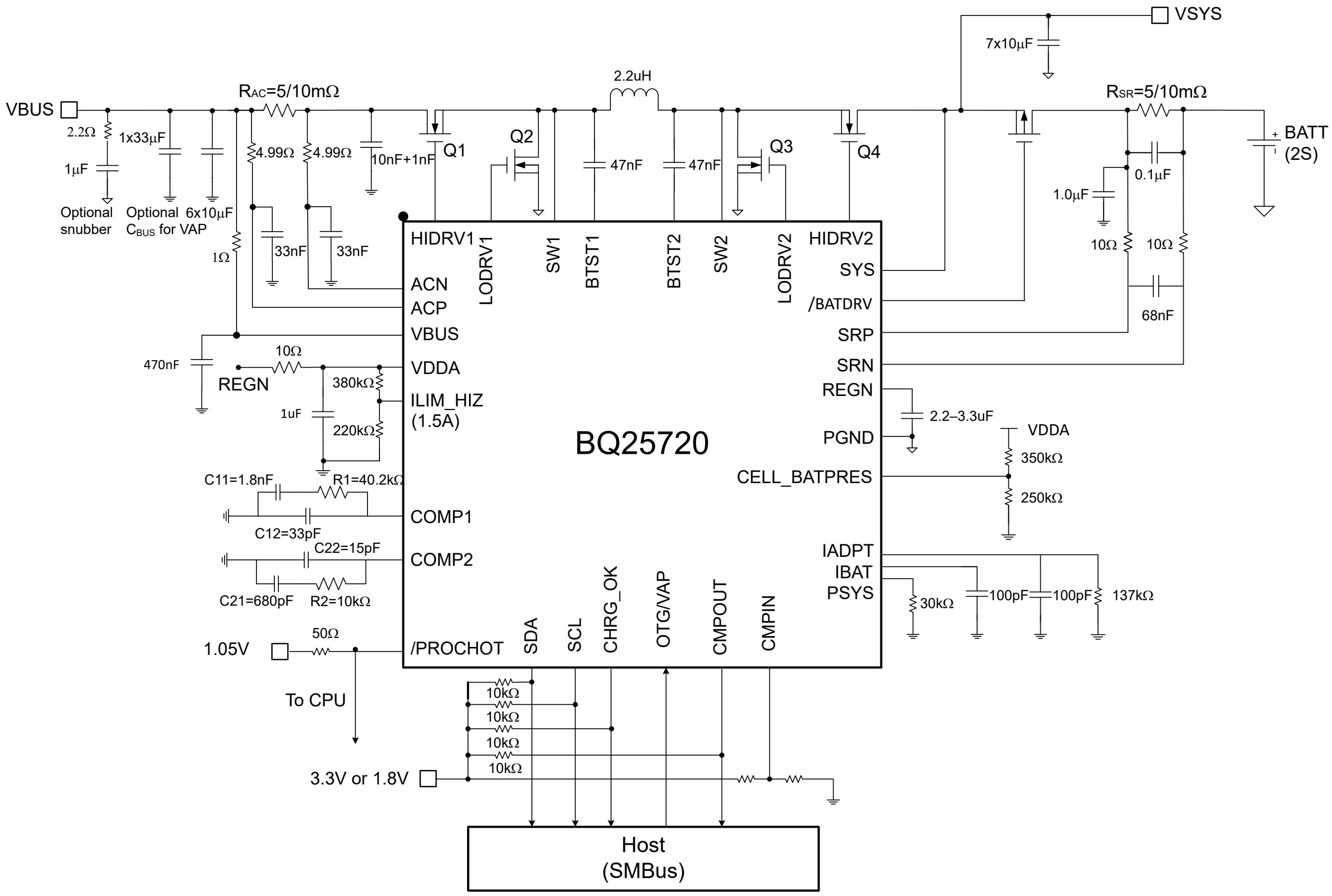

Figure 1-5. BQ25720 Typical Application Diagram

2 Design Considerations for Notebook Applications

2.1 Vmin Active Protection (VAP)

The BQ25720 integrates latest the Intel Vmin Active Protection (VAP) feature which the device charges up the VBUS voltage from the battery to store some energy in the input decoupling capacitors and releases it to the system during a system peak power demand. The high system peak power can cause the VSYS to drop below the minimum system voltage due to impedance from the battery to the system, and then limits the power that can be drawn without crashing the system.

When only the battery powers the system and no external load is connected to the USB OTG port, the charger can be configured to store energy in the input capacitors by charging them up to a programmable voltage level. This VAP supplements the system during periods of high demand to improve system turbo performance that is strongly recommended by Intel.

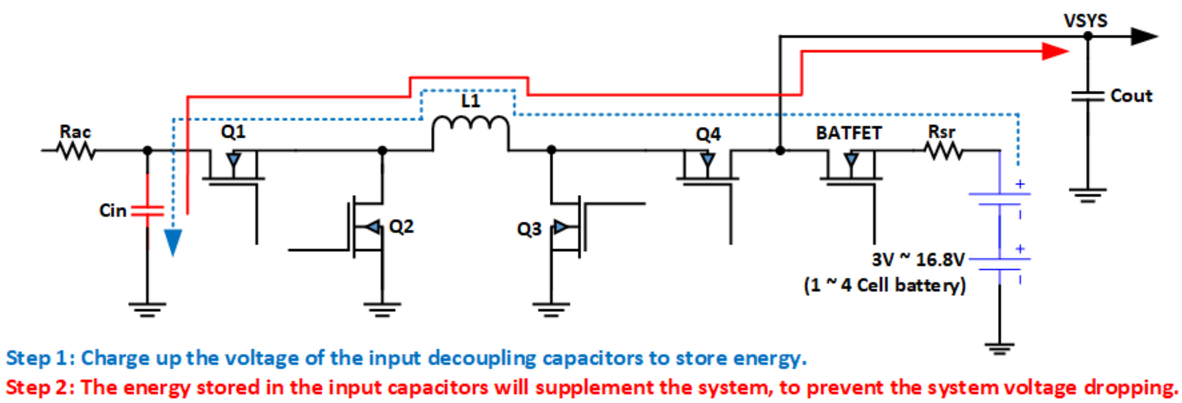

Figure 2-1. Energy Flow in Supplement Mode

2.2 Fast Role Swap (FRS)

This device integrates Fast Role Swap which is a great new feature which is defined in the latest USB PD version 3.0 specifications, affects further Type-C interface power design. The charger quickly swaps from power sink role to power source role to provide OTG output voltage to accessories when the original power source is disconnected

Figure 2-2 shows a traditional power solution for FRS. Notebook uses a USB PD controller to detect the FRS signal and notify the host. After FRS event is detected, the buck-boost charger stops operation, and 5 V DCDC converter is enabled with its input from battery pack. It needs a complicated power mux, and only supports a fixed OTG voltage which is set by DCDC output voltage.

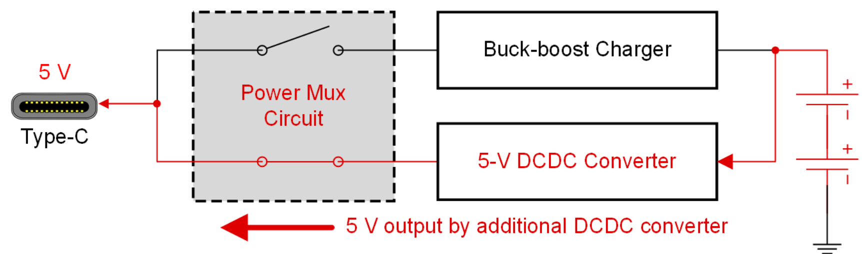

Figure 2-2. Traditional Power Solution for FRS

Figure 2-3 shows a new solution that the buck-boost charger is able to operate in forward and reverse operation due to its symmetrical architecture. To compare with the traditional power solution (Figure 2-2), the new solution (Figure 2-3) eliminates the DCDC converter and power mux. Most importantly, the new solution provides USB On-the-Go (OTG) full 5 V - 20 V seamlessly after FRS event, while the typical solution cannot.

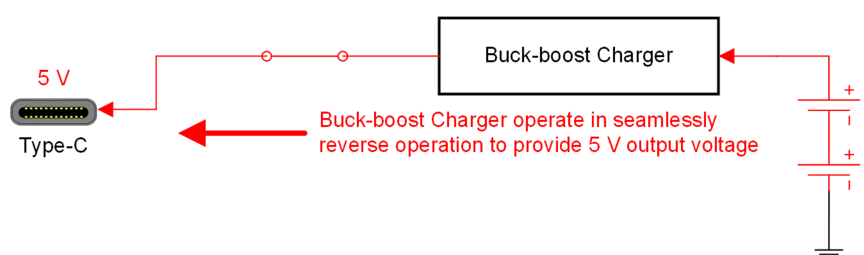

Figure 2-3. New Power Solution for FRS

2.3 Processor Hot Indication

$\overline{\text{PROCHOT}}$ is an active low open-drain output to support Intel IMVP protocols. It continues to monitor input current, battery discharge current, and system voltage. If any event in the $\overline{\text{PROCHOT}}$ profile is triggered, a pulse is asserted to the CPU so that the CPU adjusts its performance to the power available to the system.

The events monitored by the processor hot function are listed in Table 2-1. For more $\overline{\text{PROCHOT}}$ event details, see the *BQ25720 SMBus 1- to 4-Cell Narrow VDC Buck-Boost Battery Charge Controller With System Power Monitor and Processor Hot Monitor Data Sheet*.

Table 2-1. Processor Hot Function

Function	Description
ICRIT	110% of Ilim2, adapter peak current. The deglitch time could change from 15 µs to 800 µs.
INOM	Adapter average current, as 110% of IIN_DPM
IDCHG1	Battery discharge current level 1
IDCHG2	Battery discharge current level 2, IDCHG2 > IDCHG1
VBUS_VAP	VBUS threshold to trigger $\overline{\text{PROCHOT}}$ in VAP mode 2 and 3
VSYS	System voltage. The deglitch time is 4 µs.
Battery Removal	To detect battery be removed
CMPOUT	Independent comparator output (CMPOUT pin HIGH to LOW)
VINDPM	VBUS lower than 83%/91%/100% of VINDPM setting. For more details, see the device-specific data sheet.
EXIT_VAP	Charger exits VAP mode.

2.4 Two-Level Battery Discharge Current Limit

To prevent triggering overcurrent protection and avoiding battery wear-out, BQ25720 includes a two-level battery current limit (IDCHG_TH1 and IDCHG_TH2) for more precise battery discharge current protection.

When the battery discharge current exceeds IDCHG_TH1 for at least IDCHG_DEG1 deglitch time, $\overline{\text{PROCHOT}}$ is asserted immediately. If the discharge current reduces to lower than IDCHG_TH1, the time counter resets automatically.

When the battery discharge current exceeds IDCHG_TH2 for at least IDCHG_DEG2 deglitch time, $\overline{\text{PROCHOT}}$ is asserted immediately. If the discharge current reduces to lower than IDCHG_TH2, the time counter resets automatically.

Additionally, if discharge current is higher than 133% or 200% programmable IDCHG_TH2 after 250 µs deglitch time, battery overcurrent protection (BATOC) fault is triggered. BATOC is not a latch fault, so after BATOC fault is removed, with 250 ms relax time, the converter resumes switching automatically.

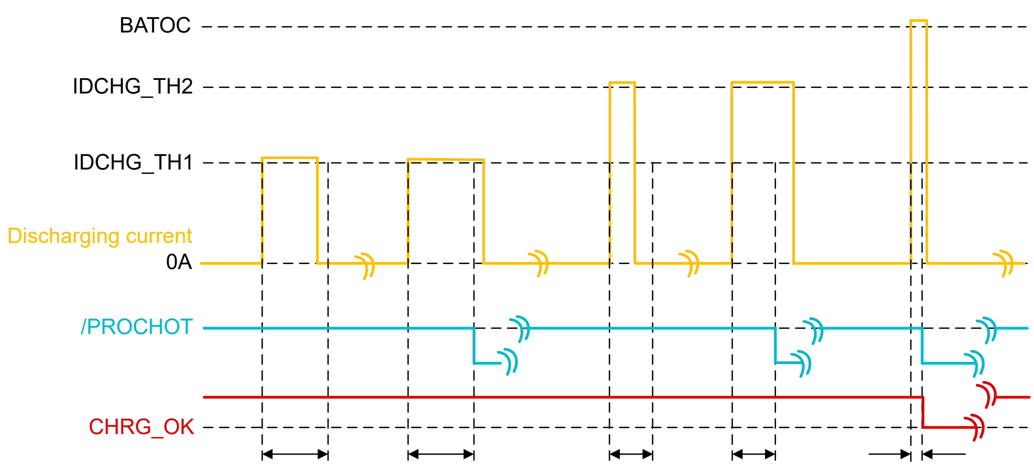

Figure 2-4. Two-Level Battery Discharging Current and BATOC Fault

2.5 Pass Through Mode (PTM) Operation

When a USB PD3.0 PPS adapter is available, BQ25720 could operating in Pass Through Mode (PTM) to directly charging a battery to improve efficiency over the full load range. In PTM, BQ25720 keeps Q1 and Q4 always on, and Q2 and Q3 always off. The input power is passes through Q1, inductor, and Q4 to the system and through BATFET to battery.

The charger could switch operating mode from buck/buck-boost/boost to PTM and switch back from PTM to buck/buck-boost/boost by internal register setting EN_PTM. Also, the BQ25720 includes voltage protection, current protection and seamless transition for mode swapping.

2.6 Seamless Mode Transition

BQ25720 operates in buck, buck-boost, boost, depending upon the VBUS, and VSYS and load level. The buck-boost can operate seamlessly across the three operation modes and it enables low noise output with highest efficiency.

2.7 Current and Power Monitor

Two different current sense amplifiers (CSA) monitor adapter current in forward charging, or reverse current in OTG mode (IADPT) and the battery charge/discharge current (IBAT), separately. One CSA amplifiers the input sensed voltage of ACP-ACN by 20x or 40x through the IADAPT pin. The other CSA amplifiers the input sensed voltage of SRP-SRN by 8x or 16x through the IBAT pin.

It is worth noting that current sense values are not limited to symmetrical both 5 mΩ or both 10 mΩ. For defined current sense resistors (10 mΩ/5 mΩ), PSYS function is still valid when RAC=10 mΩ and RSR=5 mΩ, vice versa.

2.8 Input Source Dynamic Power Management

The charger features Dynamic Power Management (DPM), which continuously monitors the input current and input voltage. When input source is over-loaded, either the input current exceeds the input current setting (IINDPM), or the input voltage falls below the input voltage limit (VINDPM), the charger decreases the charge current to provide priority to the system load.

When the charger current drops to zero, but the input source is still overloaded, the system voltage starts to drop. Once the system voltage falls below the battery voltage, the device automatically enters the supplement mode where the BATFET turns on and the battery starts discharging.

2.9 Power Up USB Port From Battery (USB OTG)

The device supports USB OTG operation to deliver power from the battery to accessories through USB port. The OTG voltage can change from 3.0 V to 24 V at the USB port with 8 mV resolution. Also, OTG current could change from 0A to 6.35A with 50 mA resolution under 10 mΩ input current sensing. Both OTG voltage and OTG current are qualified for Type-C programmed power supply (PPS) specification in terms of resolution and accuracy.

3 Test Results

The following are the results tested using BQ25720EVM with a 2-cells battery.

In Figure 3-1 (left), when charge current is set to 1A and VBUS voltage increases from 5 V to 20 V, the operating modes transition from boost to buck-boost, then to buck mode. The charging current is always kept at 1A regardless of VBUS.

In Figure 3-1 (right), when charge current is set to 1A and VBUS voltage decreases from 20 V to 5 V, and operating modes transition from buck to buck-boost, then to boost mode. The charging current is always kept at 1A regardless of VBUS.

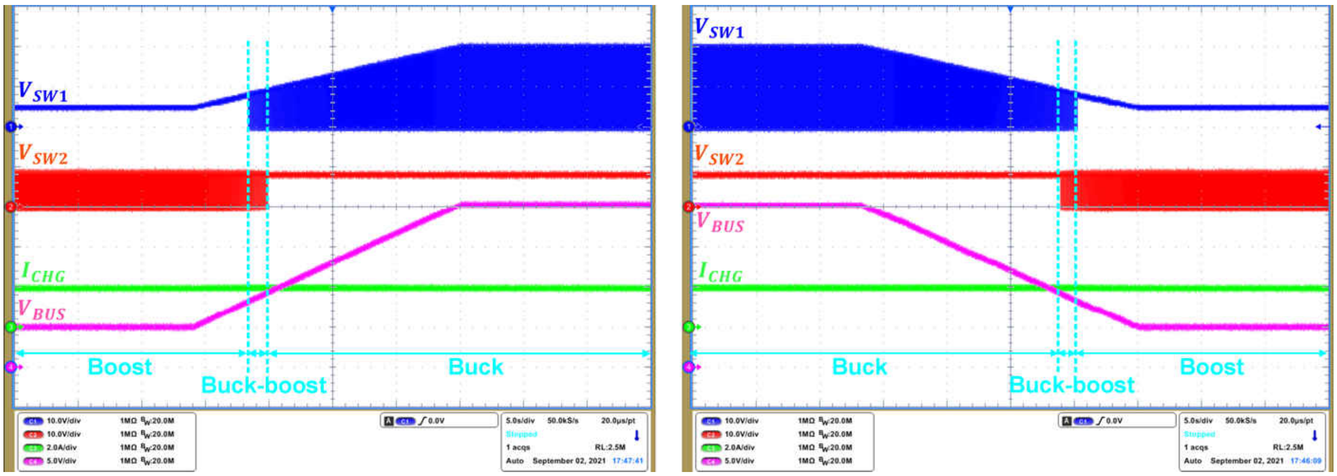

Figure 3-1. Seamless Transition Among Different Operation Modes

Figure 3-2 shows FRS transition waveform, which ensures that the power role swapping occurs in a timely manner to avoid experiencing momentary power loss or glitching.

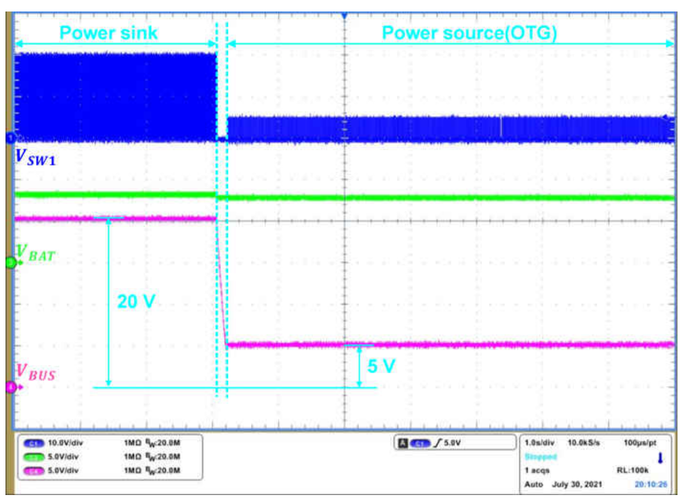

Figure 3-2. FRS Transition From Power Sink to Power Source

4 Summary

The USB Type-C/PD adapter is gaining popularity and becoming a universal charging standard. The buck-boost battery charger is a preferable solution for notebook applications with a wide input range provided by USB Type-C ports. BQ25720 is equipped with smooth transitions between operation modes, adaptability for different adapters, and extensive safety features. BQ25720 is an ideal solution for notebook applications that use a Type-C interface as power input.

5 References

1. Texas Instruments: *BQ25720 SMBus 1- to 4-Cell Narrow VDC Buck-Boost Battery Charge Controller With System Power Monitor and Processor Hot Monitor Data Sheet*
2. Texas Instruments: *Combining buck-boost battery chargers and USB Type-C Power Delivery for maximum power density*
3. *Understanding USB-C Buck-Boost Battery Charging* Renesas, White Paper
4. Texas Instruments: *Dual Port USB Type-C Power Delivery (PD) Power-Bank Design Guide*

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