Application Report

SLVA782 – June 2016

TPS65982 Designs for Supporting Voltages in USB-PD "Power Rules"

ABSTRACT

The TPS65982 is a stand-alone USB Type-C® and Power Delivery (PD) controller providing cable plug and orientation detection at the USB Type-C connector. The latest revision of the USB Power Delivery specification outlines a new set of “Power Rules” requiring the following voltages to be sourced by a compliant product: 5, 9, 15, and 20 Volts. Existing reference designs of the TPS65982 followed the “Power Profiles” put forth in the original USB PD specification. In USB PD releases up to Revision 2.0, Version 1.1 the required voltages were limited to 5, 12, and 20 Volts. In order to comply with the new standard and keep design effort simple, this application report outlines a few options for a new power circuit to meet the new USB PD “Power Rules”. Although more than one power circuit will work, the simplest and most cost-effective solution is explained in detail with an example block diagram and schematic provided to use as a reference for Type-C and PD applications.

Contents

List of Figures

NexFET is a trademark of Texas Instruments.
USB Type-C is a registered trademark of Universal Serial Bus Consortium.

Copyright © 2016, Texas Instruments Incorporated

1 Introduction

The goal of this application report is to explain the changes in standard voltages of the new USB Power Delivery (PD) Specification, compare the original and new standards, outline the power circuit used to meet the original standard, and offer a new power circuit as a solution to comply with the new standard using the TPS65982.

2 Related Material

The TPS65982 data sheet (SLVSD02), the USB Power Delivery Specification Revision 2.0, Version 1.2, the *TPS65982 Evaluation Module* user's guide (SLVUAF8), the TPS6598X-CONFIG Configuration Tool, the TPS54335A data sheet (SLVSCD5), and the LM3489 data sheet (SNVS443) are resources used as reference material for this application report.

Although this application report is written specifically for the TPS65982 as an example, it also applies to the TPS65986 and TPS65981.

3 Background of Power for USB PD as a Source

3.1 PD 2.0 Version 1.1 Specification Source "Power Profiles"

In the ***USB Power Delivery Specification Revision 2.0 (PD 2.0), Version 1.1*** released on May 7th, 2015, voltages for power delivery (PD) sources were defined in a set of "Power Profiles".

Profiles are numbered 0–5, with profile #5 delivering all voltage and current options of the previous 4 profiles. Profile #5 = 5 V at 2.0 A, 12 V and 20 V at 5 A. Variations on current capabilities are allowed, but required PDO object voltages are fixed at 3 values: 5, 12, and 20 Volts.

3.2 PD 2.0 Version 1.2 Specification Source "Power Rules"

In the **USB Power Delivery Specification Revision 2.0 (PD 2.0), Version 1.2**, voltages for a PD Source are defined in a set of "Power Rules." These "Power Rules" are also retroactively applied to the ***USB Power Delivery Specification Revision 2.0, Version 1.2*** released on March 25th, 2016 and will also be included in the PD 3.0 Specification. The new "Power Rules" follow a mathematical equation outside the scope of this document, but in the new "Power Rules" there are 4 source voltages required to cover the entire range of PD power up to 100 Watts: 5, 9, 15, and 20 Volts.

Copyright © 2016, Texas Instruments Incorporated

3.3 TPS65982-EVM, an Ideal PD 2.0 Power Source

The TPS65982-EVM uses firmware (FW) that emulates a variety of products that are part of the USB Type-C and PD ecosystem: dock, laptop, tablet, dongle, AC adapter, and high-power bus-powered devices. These different configurations are selected by a set of DIP switches and will advertise different sets of sink and *Source Capabilities*, but the hardware of the TPS65982-EVM remains the same. When configuration ID #7 is selected to emulate an AC adapter, the “Power Profile” of the TPS65982 offers 5 V at 3 A, 12 V at 3 A, and 20 V at 5 A as its *Source Capabilities*. Figure 1 shows the power path of the TPS65982-EVM.

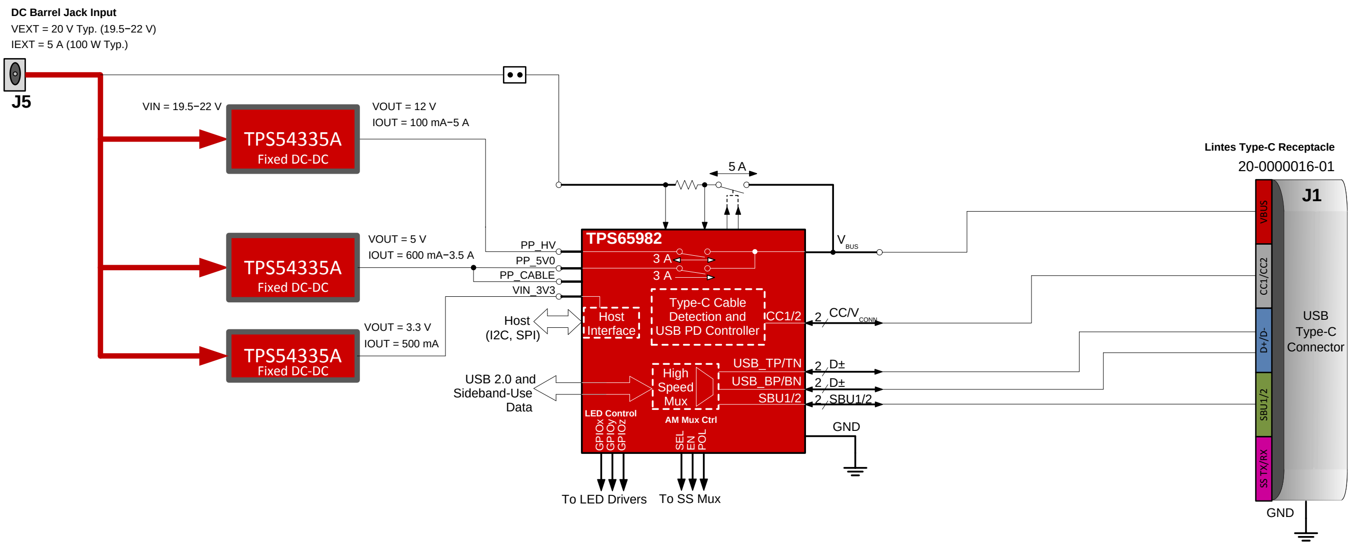


Figure 1. TPS65982-EVM Power Path Block Diagram

Attempting to deliver 9 V and 15 V instead of 12 V using the TPS65982 seems like a difficult problem to solve, and the TPS65982-EVM cannot easily be modified to support this need. However, the embedded processor inside the TPS65982 and many FW-configurable GPIOs make it simple to design a new circuit supporting the four voltages required for the “Power Rules”.

3.4 Sourcing "Power Rules" Voltage Rails to VBUS With the TPS65982

The voltages required by the new “Power Rules” are 5, 9, 15, and 20 Volts.

The **Power Multiplexer** and the **Variable DC-DC** converter are two different circuits that can solve this problem. Either of these two circuits may be preferred depending on the number of Type-C ports in a system, the output wattage required, the available parts in a PCB library, and so forth. A combination of these two architectures may also be suitable for the needs of an application.

The TPS65982 PD policy engine automatically negotiates power contracts and alternate modes, then controls SuperSpeed multiplexers, LED indicators, and power circuitry using GPIOs linked to a set of pre-defined *GPIO Events*. These Events are easily mapped to any GPIO pin on the TPS65982 device to match the schematic of the application.

Copyright © 2016, Texas Instruments Incorporated

3.4.1 Source PDO GPIO Output Events in TPS65982 FW

The firmware (FW) of the TPS65982 allows any GPIO to be mapped to a pre-defined list of *Events* in the TPS6598X-CONFIG configuration tool. To prepare for the “Power Rules”, a set of 7 *GPIO Events* has been set aside to control the voltage of external power circuitry. Each of these *GPIO Events* indicates that a *Source PDO* from the *Source Capabilities* list has been negotiated at the Type-C port.

The first 4 Events, called *“Source PDO # Negotiated”*, cause a single GPIO to be high when the corresponding PD contract is negotiated. These *GPIO Events* are shown in Figure 2. For most applications, these discrete *GPIO Events* for up to 5 different voltage outputs (5 V is always provided through the PP_5V0 power path) are sufficient.

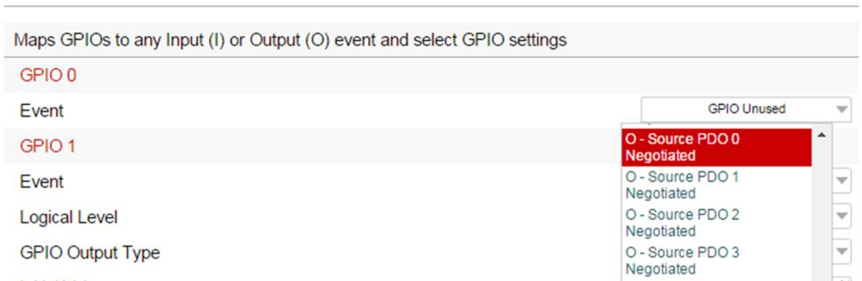


Figure 2. Discrete GPIO Events Named “Source PDO # Negotiated”

The last 3 Events, called *“Source PDO Negotiated Truth Table, Bit #”*, can be used to control a power circuit with digital logic as an input, such as a digital power supply or the LM10011 Feedback Signal Generator, to generate up to 8 different voltages from a single power supply. These *GPIO Events* are shown in Figure 3.

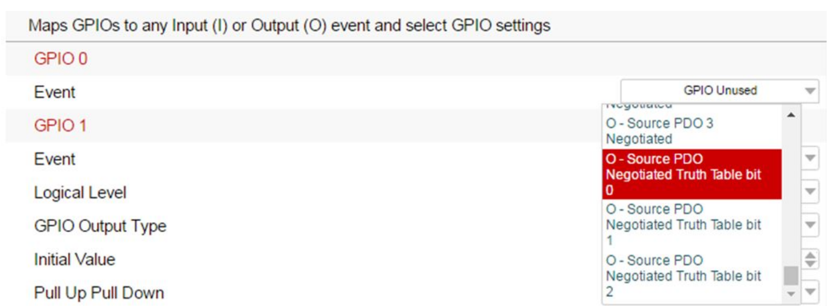


Figure 3. GPIO Events Named “Source PDO Negotiated Truth Table, Bit #”

Practical applications of the 4 *“Source PDO # Negotiated” GPIO Events* are discussed in the remaining sections of this application report.

Copyright © 2016, Texas Instruments Incorporated

3.4.2 Power Multiplexer Circuit

Figure 4 shows the power multiplexer block that can be inserted into the power circuit to switch between one of the three high-voltage rails before being connected to one of the high-voltage power FETs that source power to VBUS. The switches in this multiplexer are automatically controlled by *GPIO Outputs* from the TPS65982 with a simple driver circuit.

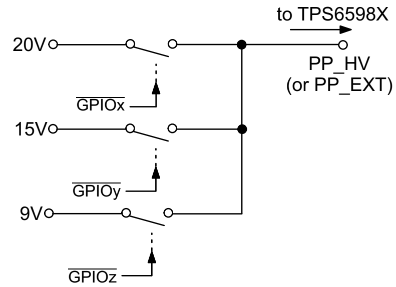


Figure 4. Power Multiplexer Block

Figure 5 shows the power multiplexer block connected to the TPS65982 in a simple dual-role port (DRP) block diagram. This circuit does not reduce the number of DC-DC converters in a 1 Type-C port design, but when 2 Type-C ports are used, each voltage rail can be delivered to both ports. As a result, the total number of DC-DC buck converters used in the **Power Multiplexer** circuit is the same as in the **Variable DC-DC** circuit for an application with 2 Type-C ports. The **Power Multiplexer** circuit will not be described in detail for two reasons:

- **Simplicity** – Although additional PFETs are needed, driving these switches does not require a complex circuit and follows the same logic as the non-obvious circuit used in the **Variable DC-DC** design.
- **Cost** – In many Type-C and PD applications, only 1 port will be required and the cost of the overall circuit is reduced by using the **Variable DC-DC** design.

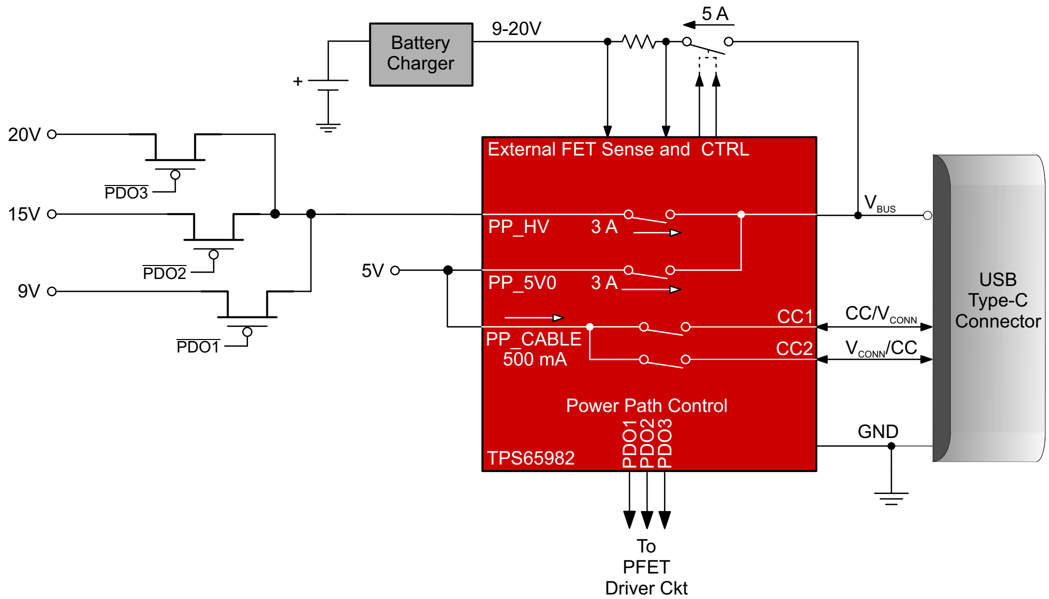


Figure 5. Power Multiplexer and TPS65982 Block Diagram

Copyright © 2016, Texas Instruments Incorporated

3.4.3 Variable DC-DC Converter Circuit

Figure 6 shows the variable DC-DC converter block that can be inserted into the power circuit to dynamically change the voltage on the VOUT node of the DC-DC converter before being connected to the TPS65982. The voltage of this DC-DC converter is automatically controlled by *GPIO Outputs* from the TPS65982 with a simple resistive network.

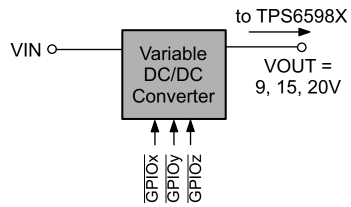


Figure 6. Variable DC-DC Converter Block

Figure 7 shows the **Variable DC-DC** converter block diagram connected to the TPS65982 in a simple source-only design such as a dock or monitor. In this type of application, the highest voltage available from a DC barrel jack is normally 20 V and can be passed directly to VBUS through the low-resistance PP_EXT external power NFETs.

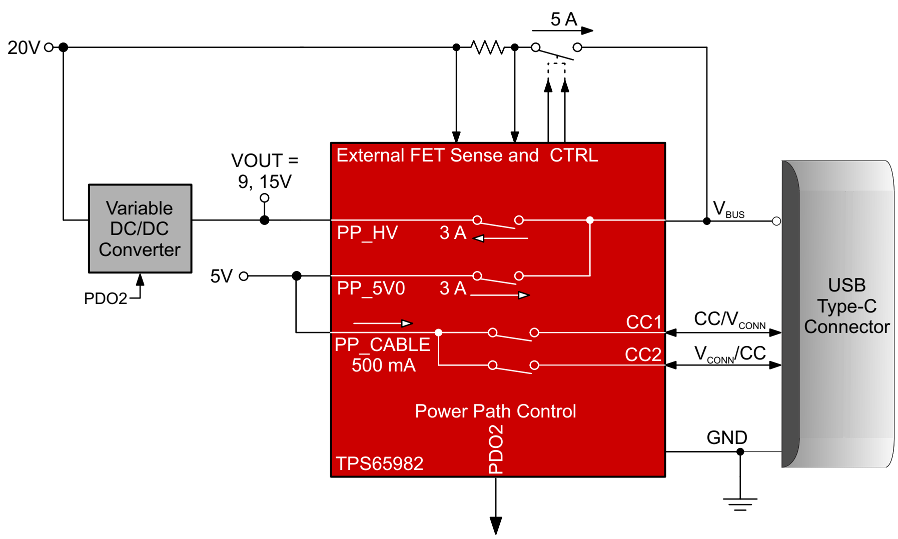


Figure 7. Variable DC-DC and TPS65982 Block Diagram

Any DC-DC converter circuit producing a fixed output voltage can be turned into a **Variable DC-DC** converter. All DC-DC converters use the basic principle of voltage feedback to determine the output voltage of the power circuit. For example, the TPS54335A used in the TPS65982-EVM design delivers a fixed output voltage, VOUT = 12 V, by solving Equation 1 for R_2 if R_1 is given. VSENSE is the feedback pin of the TPS54335A, which in steady-state settles at a fixed voltage of VSENSE = V_{REF} = 0.8 V. Using the TPS65982-EVM as a reference, R_1 = R102 = 100 kΩ, and Equation 1 is used to solve for R_2.

$$R_2 = \frac{V_{REF}}{V_{OUT} - V_{REF}} \times R_1 = \frac{0.8\ \text{V}}{(12\ \text{V} - 0.8\ \text{V})} \times 100\ \text{k}\Omega = 7.14\ \text{k}\Omega \quad (1)$$

Since a resistance of 7.14 kΩ is not a standard value for resistors, the closest value is used in the TSP65982-EVM where R_2 = R104 = 7.15 kΩ.

In order to turn the TPS54335A into a variable DC-DC converter to provide multiple output voltages, the equation is solved for R_2 twice, once for a 9-V output voltage in Equation 2 and again for 15 V in Equation 3.

$$R_{2,9V} = \frac{V_{REF}}{V_{OUT,1} - V_{REF}} \times R_1 = \frac{0.8\ \text{V}}{(9\ \text{V} - 0.8\ \text{V})} \times 100\ \text{k}\Omega = 9.75\ \text{k}\Omega \quad (2)$$

Copyright © 2016, Texas Instruments Incorporated

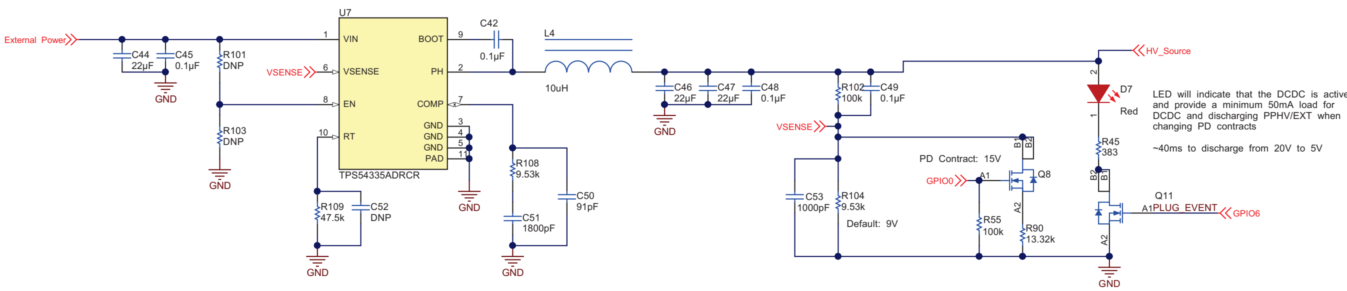
$$R_{2,15V} = \frac{V_{REF}}{V_{OUT,2} - V_{REF}} \times R_1 = \frac{0.8\ V}{(15\,V - 0.8\,V)} \times 100\ k\Omega = 5.63\ k\Omega \quad (3)$$

The easiest way to realize this circuit is to keep the existing feedback circuit with R_1 and the new $R_{2,9V}$ as the default option and add another resistor in parallel with $R_{2,9V}$ that can be switched into the circuit when a GPIO is driven high. This resistor will be called R_{2A}, where $R_{2,9V}$ // R_{2A} = $R_{2,15V}$. Equation 4 shows that $R_{2,15V}$ is equivalent resistance of $R_{2,9V}$ in parallel with R_{2A}, but the equation needs to solve for R_{2A} because $R_{2,15V}$ is already known. Equation 5 solves for R_{2A}.

$$R_{2,15\,V} = \frac{R_{2,9\,V} \times R_{2\,A}}{R_{2,9\,V} + R_{2\,A}} \quad (4)$$

$$R_{2\,A} = \frac{R_{2,9\,V} \times R_{2,15\,V}}{R_{2,9\,V} - R_{2,15\,V}} = \frac{9.75\ k\Omega \times 5.73\ k\Omega}{9.75\ k\Omega - 5.73\ k\Omega} = 15.32\ k\Omega \quad (5)$$

Figure 8 shows the circuit for using the TPS54335A as a variable DC-DC converter to deliver 9 V or 15 V depending on the USB PD contract negotiated as a *PD Source*. The GPIOs are automatically driven by the TPS65982 when the FW is configured properly in the TPS6598X-CONFIG Configuration tool. By default, 9 V is generated by R102 and R104, where R_1 = R102 and $R_{2,9V}$ = R104 in the default feedback voltage divider in Equation 2. When a 15-V PD contract is negotiated, GPIO0 is driven high by the TPS65982 (not shown in this schematic), putting R90 in parallel with R104. The on-resistance of Q8 is negligible compared to 13.32 kΩ, so the output of 15 V is generated by R102 and R104 // R90 where R_1 = R102 and $R_{2,15V}$ = $R_{2,9V}$ // R_{2A} = R104 // R90 = in Equation 4 and Equation 5.



Copyright © 2016, Texas Instruments Incorporated

Figure 8. TPS54335A Variable DC-DC Circuit for 9-V and 15-V Output Voltages

3.5 Dual-Role Port (DRP) Delivering 4+ Voltage Rails

The **Power Multiplexer** and the **Variable DC-DC Converter** discussed in the previous section will both work in many USB Type-C and PD applications, but the **Variable DC-DC** has advantages in a system with only 1 Type-C port because less DC-DC buck converters are used and the overall component count is reduced significantly.

The **Variable DC-DC** buck converter can theoretically support as many different voltages as needed by the application, so a DRP that needs to sink power on the PP_EXT FET path of the TPS65982 should be able to deliver 9 V, 15 V, and 20 V through the PP_HV FET path as a *Source*. Some applications will also need to provide 12 Volts to support legacy USB PD devices that only accept a 12-V PD Contract.

The problem with a USB PD DRP that needs to provide 9 V, 12 V, 15 V, and 20 V from a single DC-DC converter is that the DC barrel jack voltage is exactly 20 V and most DC-DC buck converters cannot support *100% Duty Cycle* operation.

The next section explains in detail how that problem is solved and presents a design that will source the new voltages to comply with the “Power Rules” of the latest USB PD Specification.

Copyright © 2016, Texas Instruments Incorporated

4 TPS65982+LM3489 Variable DC-DC Converter for "Power Rules" Voltages

The block diagram in Figure 9 shows the TPS65982 controlling the LM3489 as a **Variable DC-DC** buck converter to deliver 9, 12, 15, and 20 Volts through either the PP_HV internal high voltage path or the PP_EXT external high voltage path, while the path not used as a *PD Source* is used to sink power from VBUS. As a result, this design can be used as a DRP that is capable of being line-powered from a barrel jack or bus-powered over Type-C.

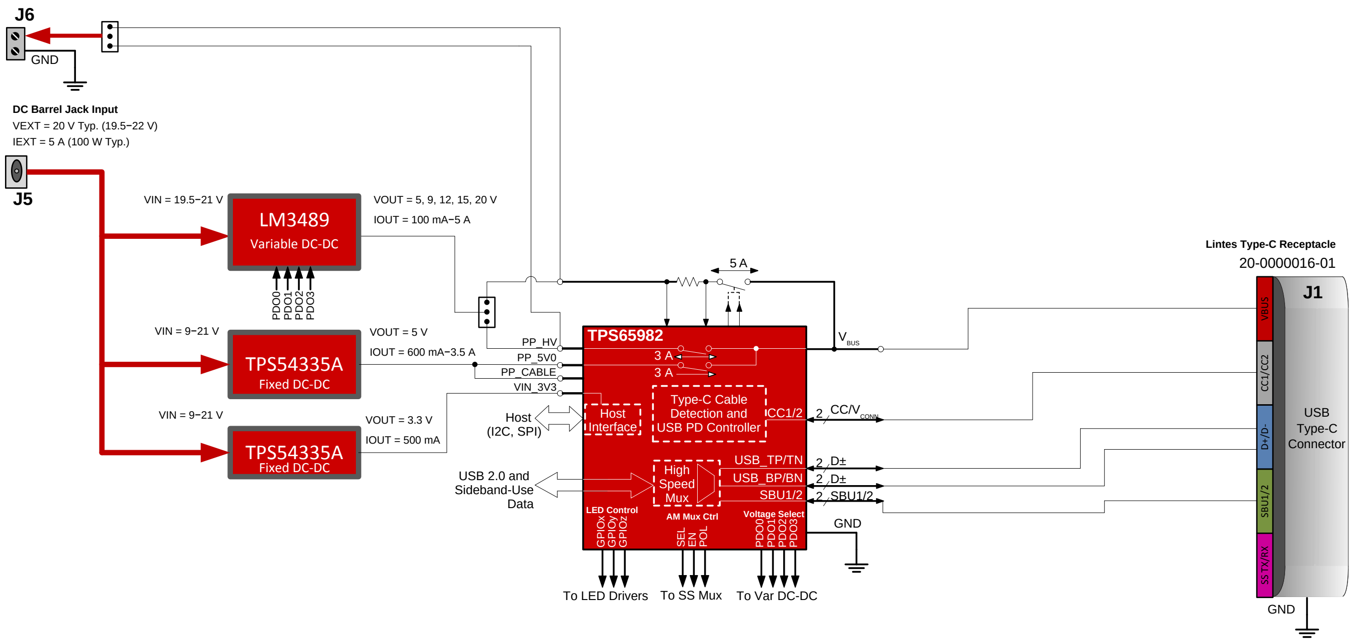


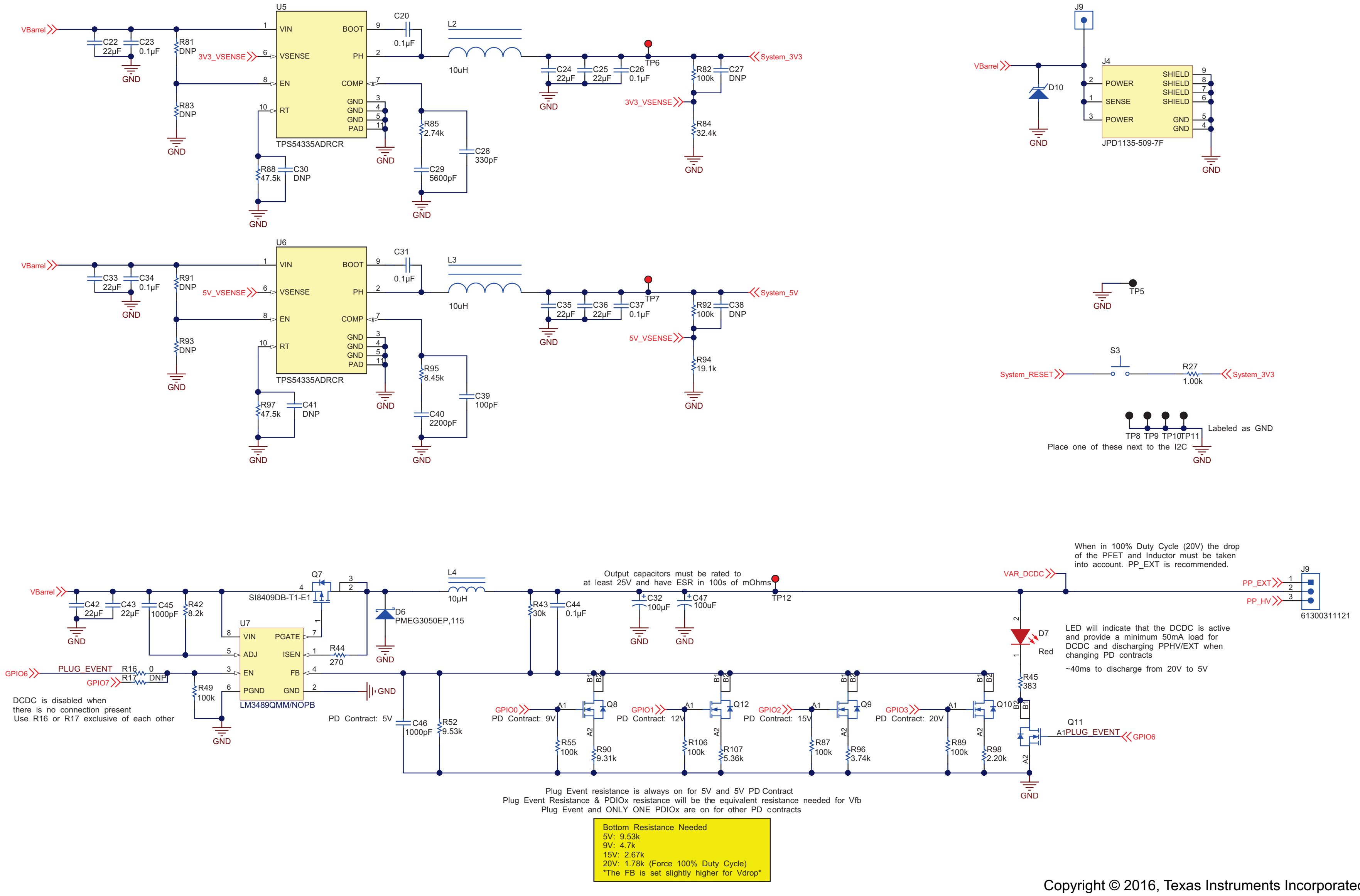
Figure 9. Block Diagram of TPS65982+LM3489 Variable DC-DC Design

The schematics for this design are shown in Figure 10 and Figure 11, where Figure 10 shows the power path containing the LM3489 and Figure 11 shows the Type-C connector and TPS65982 PD controller. GPIOs 0–3 are outputs from the TPS65982 that switch in the correct resistor in the LM3489 circuit to deliver the appropriate voltage when a *Source PDO* contract is negotiated. The LM3489 can achieve 100% duty cycle because it is a Hysteretic PFET type of DC-DC buck controller, meaning that when 20 V is required, the PFET is driven on 100% of the time and is effectively a switch that is closed.

GPIO6 is also an output from the TPS65982 that is used to drive the EN pin of the LM3489 high only when a Type-C connection is present. GPIO6 simultaneously turns on LED D7, which is used to “bleed” the voltage from a higher voltage to a lower voltage when necessary. For example, the system may be delivering 20 V to a laptop which is removed and quickly replaced with a tablet that only needs 9 V to charge its battery. The TPS65982 automatically discharges VBUS to meet the USB PD specification, but if LED D7 were not present, the PP_HV (or PP_EXT) node would be stuck at 20 V until it discharges naturally. This natural discharge could take seconds to minutes when an un-plug and re-plug event at the Type-C port could happen in as little as 1 second.

Certain DC-DC converter ICs can perform this “voltage bleed” automatically, and this feature is referred to as “output discharge” or *forced continuous conduction mode* (FCCM). For more details on FCCM as a way to remove LED D7 and save power, refer to the TPS53353 data sheet. The original high voltage NexFETs™ used in the TPS65982-EVM have been replaced with CSD87501L (Q1 in Figure 11), a single back-to-back N-channel NexFET™ IC in a small WCSP package. The additional passive circuitry and connectors in Figure 10 and Figure 11 not discussed in this application report are the same as the TPS65982-EVM.

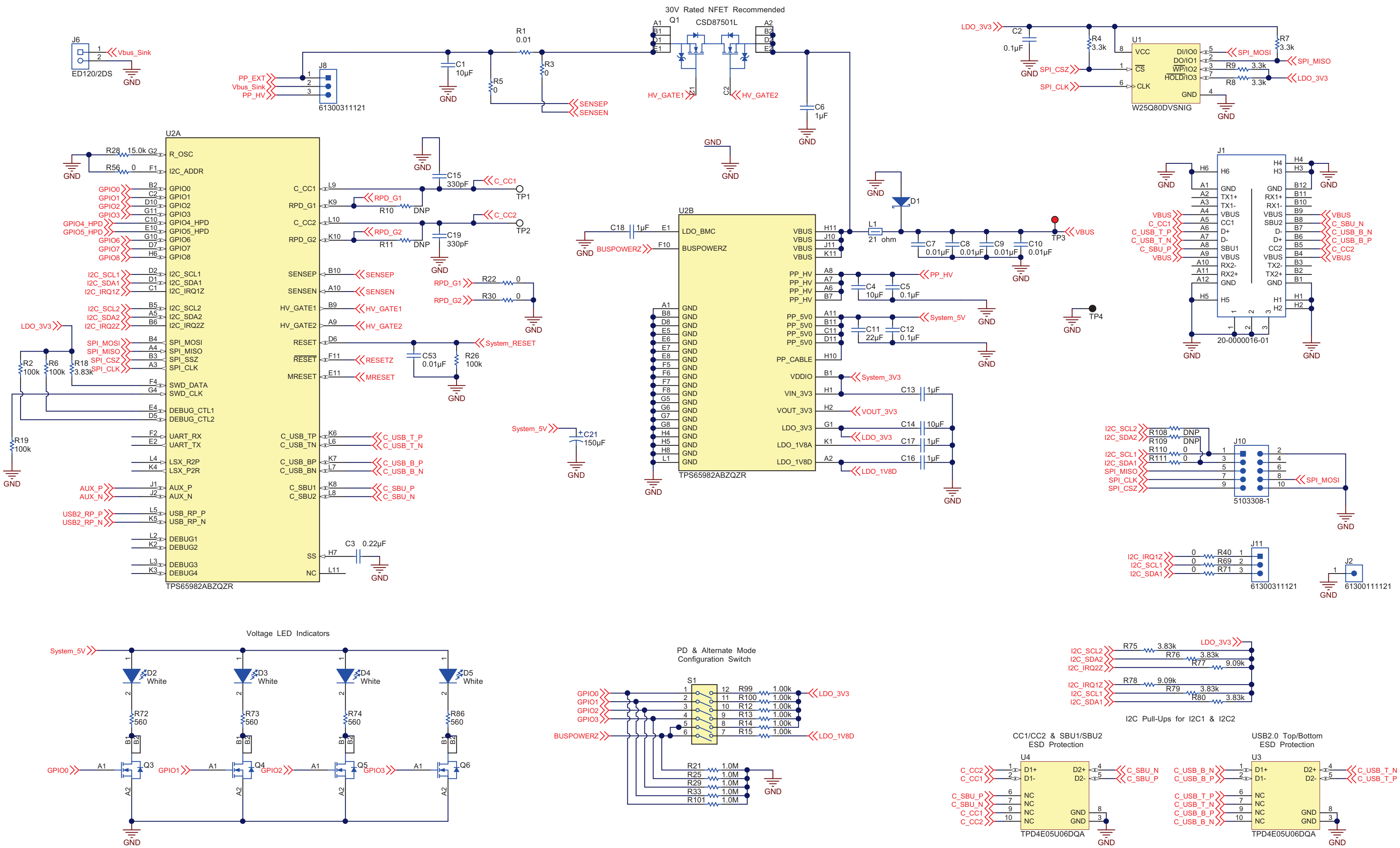
Copyright © 2016, Texas Instruments Incorporated



Copyright © 2016, Texas Instruments Incorporated

Figure 10. Power Path Schematic of TPS65982+LM3489 Variable DC-DC Design (Page 1 of 2)

Copyright © 2016, Texas Instruments Incorporated



Copyright © 2016, Texas Instruments Incorporated

Figure 11. Type-C and Power Delivery Schematic of TPS65982+LM3489 Variable DC-DC Design (Page 2 of 2)

Copyright © 2016, Texas Instruments Incorporated

5 Summary

This application report introduced the new voltages required by the “Power Rules” in the USB PD 2.0, Version 1.2 and PD 3.0 specifications, briefly discussed the numerous circuits that can be used to provide these voltages to VBUS as a *PD Source*, and selected the best option to use in a single Type-C port application with low cost as the primary goal.

Since the new design appears complex at first, a review of the voltage feedback principles of DC-DC controller ICs was needed to see that this solution is relatively simple to implement. Combining the *GPIO Output* capabilities of the TSP65982 firmware and the ability of the LM3489 to deliver voltage at 100% duty cycle, a cost-competitive solution was designed and described in detail that will work in many Type-C and *PD Source*, and DRP applications including notebooks, monitors, and docks.

6 References

- TPS65982 data sheet (SLVSD02)
- *TPS65982 Evaluation Module* user’s guide (SLVUAF8)
- TPS6598X-CONFIG Configuration Tool
- USB Power Delivery Specification
- TPS54335A data sheet (SLVSCD5)
- LM3489 data sheet (SNVS443)

Copyright © 2016, Texas Instruments Incorporated

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2016, Texas Instruments Incorporated