Application Report
SLVA842–November 2016

USB PD Power Negotiations

ABSTRACT

This document describes the Power Delivery (PD) contract negotiation in USB Type-C connections per the USB-IF PD specification, and its implementation using Texas Instruments TPS65982 USB Type-C and USB PD controller. USB PD is required in USB Type-C systems for power levels above 15 W (5 V at 3 A) up to 100 W (20 V at 5 A) according to the specification. This application report describes the digital communication between the transmitter and receiver ends of a connection support USB PD, the flow of USB PD power negotiation, as well as the procedure for implementing and debugging USB PD negotiations using the TPS65982 device and associated software tools.

The TPS65982 device is referred to throughout this application report, but the document also applies to the TPS65981 and TPS65986 USB Type-C and USB PD controllers.

Contents

List of Figures

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

The USB Power Delivery (PD) Specification describes a standard negotiation process for establishing all PD power contracts. Although the USB Type-C standard allows for providing 5 V at up to 15 W of power, following the PD protocol is critical for offering or receiving any voltage higher than 5 V. As a result, any product that requires or delivers power from 5 to 20 V (15 to 100 W of power) must negotiate according to a specific set of standardized rules.

The TPS65982 device is the USB Type-C and PD port controller with the highest level of integration available on the market. The TPS65982 device can automatically detect a Type-C port connection, negotiate a PD contract, and control a set of integrated power switches without the involvement of any other ICs in the system. Because the firmware (FW) of the TPS65982 device, is configurable, any source, sink, or dual-role port (DRP) product possible can be created on top of the core-firmware base of the TPS65982 device, which is compliant to the USB PD protocol. The core FW also prevents problematic situations with noncompliant products and recovers from PD messaging errors with a robust policy engine.

This chapter includes the following:

- A review of the rules and flow of power negotiation following the USB PD Specification
- Steps to set up and modify examples of PD sink and source capabilities used by the TPS65982 FW throughout the negotiation process
- Steps to verify the correct power negotiation flow with the following:
  - Understanding the power negotiation flow of the USB PD Specification
  - Analyzing the results of the PD power negotiation in real-time using decoded PD traces that capture the communication between two products
- Steps to modify the source and sink capabilities of the TPS65982 device instantly using the host interface
- Steps to debug common issues and achieve a successful PD power negotiation

2 USB Power Delivery Specification for Sink and Source Capabilities

The USB PD Specification explicitly describes the format of data that will be sent between the source and sink during a power negotiation. Although knowing the meaning of each bit in the specification is not always necessary, the PD-related registers (received and transmitted) and PD analyzers of the device follow the specification exactly and these similarities are integrated in this chapter.

The source must organize the capabilities of the power supply into a list of power-data objects (PDOs).

Table 1. Generic PDO

Bits	Value	Parameter
31-30	00b	Fixed supply
	01b	Battery
	10b	Variable supply
	11b	Reserved
29-0	Specific power capabilities are described by the PDOs in the following tables.	

Table 2. Fixed-Supply PDO—Source

Bits	Parameter
31-30	Fixed supply
29	Dual-role power
28	USB suspend supported
27	Externally powered
26	USB communications capable
25	Dual-role data
24-22	Reserved – Shall be set to zero
21-20	Peak current
19-10	Voltage in 50-mV units
9-0	Maximum current in 10-mA units

Table 3. Variable-Supply (Nonbattery) PDO—Source

Bits	Parameter
31-30	Variable supply (nonbattery)
29-20	Maximum voltage in 50-mV units
19-10	Minimum voltage in 50-mV units
9-0	Maximum current in 10-mA units

Table 4. Battery-Supply PDO—Source

Bits	Parameter
31-30	Battery
29-20	Maximum voltage in 50-mV units
19-10	Minimum voltage in 50-mV units
9-0	Maximum allowable power in 250-mW units

2.1 USB PD Specification for Source Capabilities

The sink has a similar set of PDOs that contain the same information describing the power input requirements.

Table 5. Fixed-Supply PDO—Sink

Bits	Parameter
31-30	Fixed supply
29	Dual-role power
28	Higher capability
27	Externally powered
26	USB communications capable
25	Dual-role data
24-20	Reserved – Shall be set to zero
19-10	Voltage in 50-mV units
9-0	Operational current in 10-mA units

Table 6. Variable-Supply (Nonbattery) PDO—Sink

Bits	Parameter
31-30	Variable supply (non-battery)
29-20	Maximum voltage in 50-mV units
19-10	Minimum voltage in 50-mV units
9-0	Operational current in 10-mA units

Table 7. Battery-Supply PDO—Sink

Bits	Parameter
31-30	Battery
29-20	Maximum voltage in 50-mV units
19-10	Minimum voltage in 50-mV units
9-0	Operational power in 250-mW units

2.2 USB PD Specification for Sink Capabilities (PDOs)

More common is for the PD source to be unaware of the capabilities of the sink. The source advertises the capabilities and, if a match occurs, the sink returns a request-data object (RDO). Unless a mismatch occurs or the source must limit the power given to a sink partner, the sink PDOs are never explicitly transmitted. A sink RDO is more common than a sink PDO. The following tables list the sink-RDO data structure.

Table 8. Fixed and Variable RDO

Bits	Parameter
31-30	Reserved – Shall be set to zero
29	Object position (000b is reserved and shall not be used)
28	GiveBack flag = 0
27	Capability mismatch
26	USB communications capable
25	No USB suspend
24-20	Reserved – Shall be set to zero
19-10	Operating current in 10-mA units
9-0	Maximum operating current in 10-mA units

Table 9. Battery RDO

Bits	Parameter
31-30	Reserved – Shall be set to zero
29	Object position (000b is Reserved and shall not be used)
28	GiveBack flag = 0
27	Capability mismatch
26	USB communications capable
25	No USB suspend
24-20	Reserved – Shall be set to zero
19-10	Operating power in 250-mW units
9-0	Maximum operating power in 250-mW units

2.3 USB PD Specification for Sink RDO

The most important concept in the RDO is as follows: the value in the object-position field indicates which object is referred to by the RDO in the Source_Capabilities message. A value of 1 always indicates the 5-V fixed-supply PDO because it is the first object following the Source_Capabilities message header. A value of 2 refers to the next PDO and so forth. For more information, see *TPS65982D USB Type-C and USB-PD Controller, Power Switch, and High-Speed Multiplexer* (SLVSDB1).

3 Tx Sink and Source Capabilities Mode Host-Interface Registers

The configuration registers for these modes are the transmit (Tx) source capabilities register (address 0x32) and the transmit (Tx) sink capabilities register (address 0x33).

The USB-PD power capabilities are configured using the Application Customization Tool GUI. The capabilities of the transmitted source are configured using the Tx source capabilities register (0x32). The capabilities of the transmitted sink are configured using the Tx sink capabilities register (0x33). In some cases, a design can have both sink and source capabilities. For example, a laptop can source at least 5 V to charge accessories from the laptop battery but can also charge the battery at up to 20 V. This type of application is called a dual-role port (DRP) and must sometimes initiate or accept power role swaps. This chapter only describes the initial PD power negotiation, and therefore the hardware that sources power is only a source and DFP, and the hardware that sinks power is only a Sink and UFP that operates in dead battery mode.

If the user is developing a source-only design, such as an AC-DC wall adapter, the Type-C port is set to use a pullup resistor (Rp) only, and the PD policy is set to reject power role swaps from the far end. For the source, this chapter only describes how to analyze and modify the Tx source capabilities register (0x32), and that the TPS65982-EVM receives external power from a traditional 20-V DC power supply.

If the user is developing a sink-only design, such as a bus-powered external hard drive, the Type-C port is set to use a pulldown resistor (Rd) only, and the PD policy is set to reject power role swaps from the far end. The TPS6598x FW automatically rejects power role swaps to become the source if the device is operating in dead battery or no battery mode. For the sink, this chapter only describes how to analyze and modify the Tx sink capabilities register (0x32), and that the TPS65982-EVM always operates in dead battery or no battery mode.

3.1 Tx Source Capabilities Example Settings

The TPS6598x Firmware Configuration tool, version 2.8, contains many example projects with different settings for sink and source capabilities that are transmitted to the far end of the Type-C cable during a PD negotiation. For this example, select the project template named *TPS65982_HD3SS460_DRP_Source_Full_2_8.tpl* which is accessed by clicking the *Project* menu and selecting the *New Project* option from the drop-down menu of the configuration GUI.

The configuration of the transmitted source capabilities is set in the Tx source capabilities register at address 0x32.

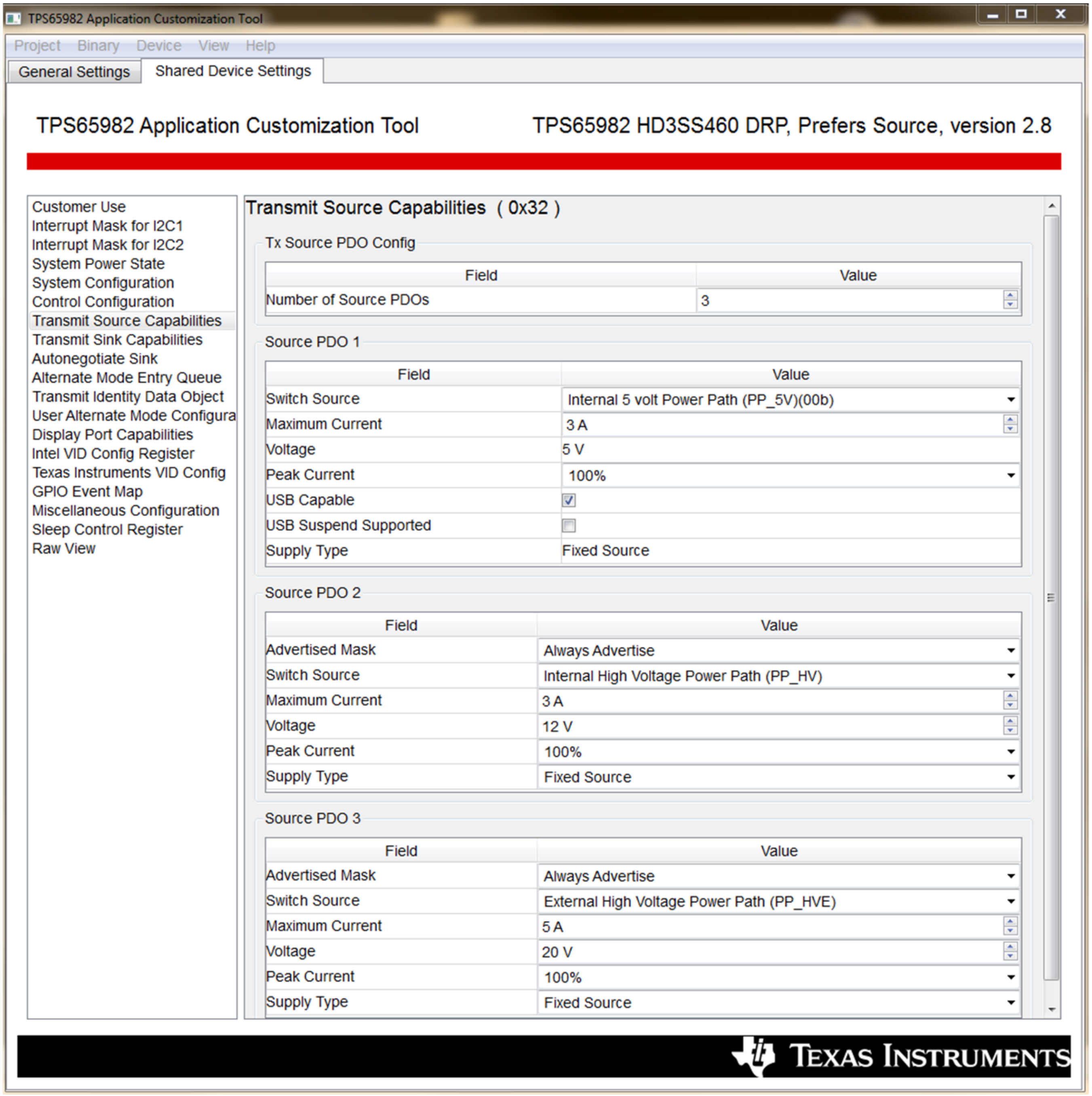


Figure 1. Tx Source Capabilities Register of ***TPS65982_HD3SS460_DRP_Source_Full_2_8.tpl***

Figure 1 shows the Tx source capabilities register (0x32) for the *TPS65982_HD3SS460_DRP_Source_Full_2_8.tpl* example template. This example uses three source PDOs which are displayed in the *Source PDO 1*, *Source PDO 2*, and *Source PDO 3* section of the *Register* tab . To show exactly 3 PDOs, the *Number of Source PDOs* field at the top of the *Register* tab must be set to decimal 3. Figure 2 shows a captured PD trace which verifies that the data in the Tx source capabilities register is transmitted to the sink when a valid Type-C connection is made.

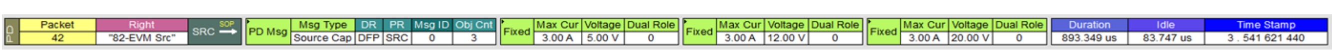


Figure 2. PD Trace of Tx Source Capabilities

3.2 Tx Sink Capabilities Example Settings

The configuration of the transmitted sink capabilities is set in the Tx sink capabilities register at address 0x33.

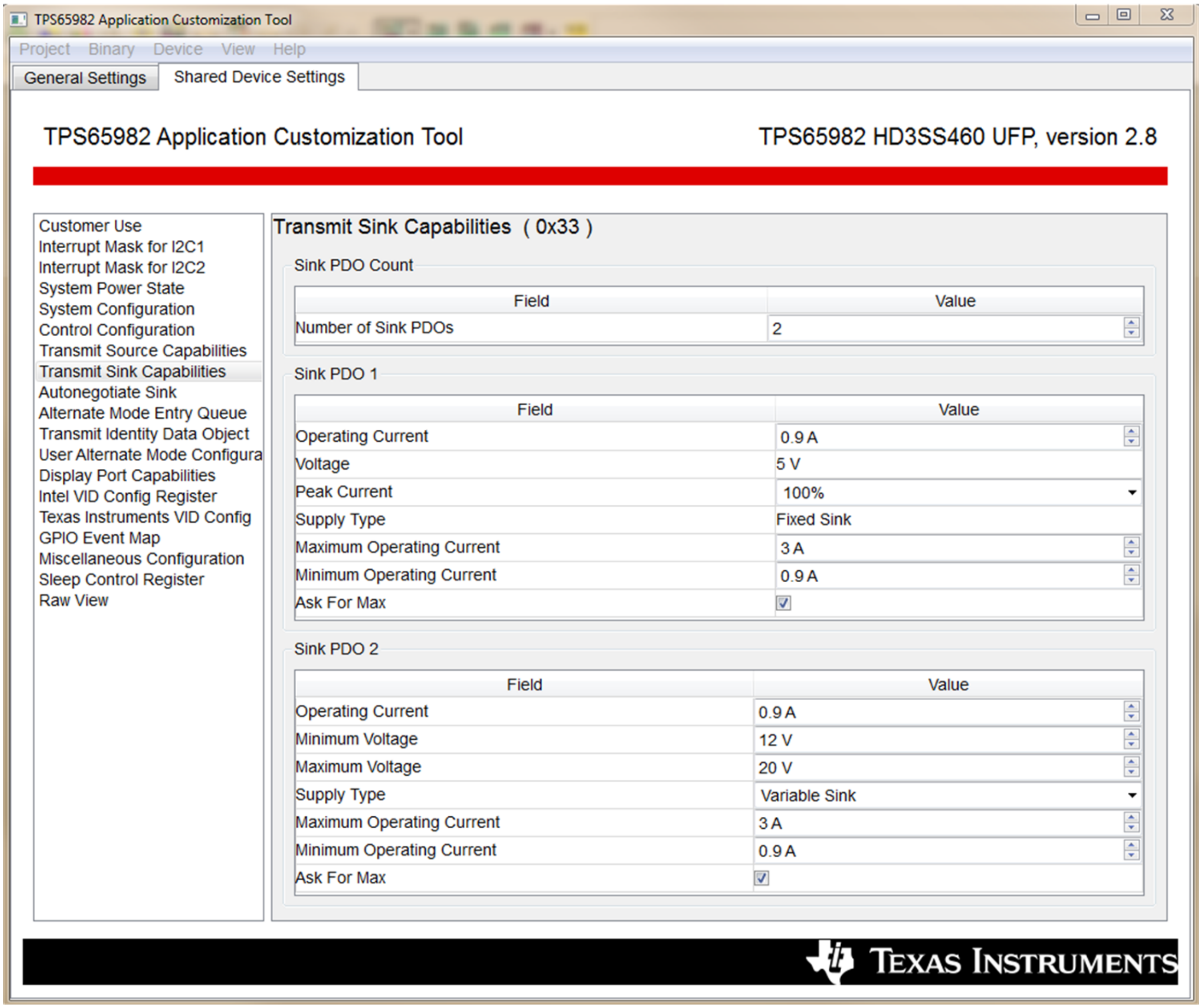


Figure 3. Tx Sink Capabilities Register of ***TPS65982_HD3SS460_UFP_Full_2_8.tpl***

Figure 3 shows the Tx sink capabilities register (0x33) for the *TPS65982_HD3SS460_UFP_Full_2_8.tpl* example template. This example uses two sink PDOs, which are displayed in the *Sink PDO 1* and *Sink PDO 2* section of the *Register* tab. To show exactly 2 PDOs, the *Number of Sink PDOs* field at the top of the *Register* tab must be set to decimal 2. Figure 4 shows a captured PD trace which verifies the data in the Tx sink capabilities register is transmitted to the source in response to a *Get Sink Capabilities* (GSkC) message.

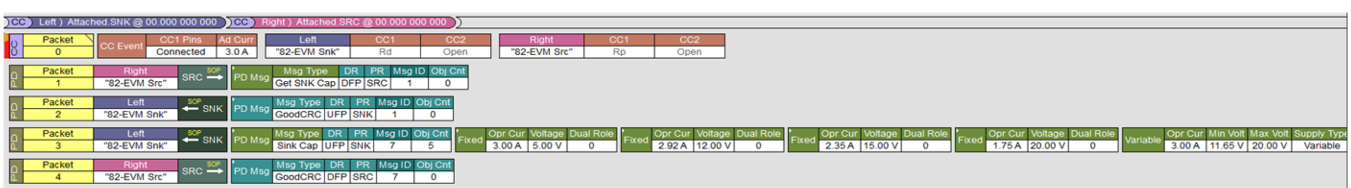


Figure 4. PD Trace of Sink Capabilities after GSkC Command from Source

4 Power Negotiation Flow

4.1 USB Power Delivery Specification for Power Negotiation Flow

Figure 5 shows the official flow of a successful USB PD power negotiation from both the source and sink. The only portion of the power negotiation that can easily be analyzed are the PD messages, or what is sent from the source PHY to the sink PHY and from the sink PHY to the source PHY. Therefore, the focus is on steps 3, 7, 12, 16, 21, 25, 30, and 34 in Figure 5.

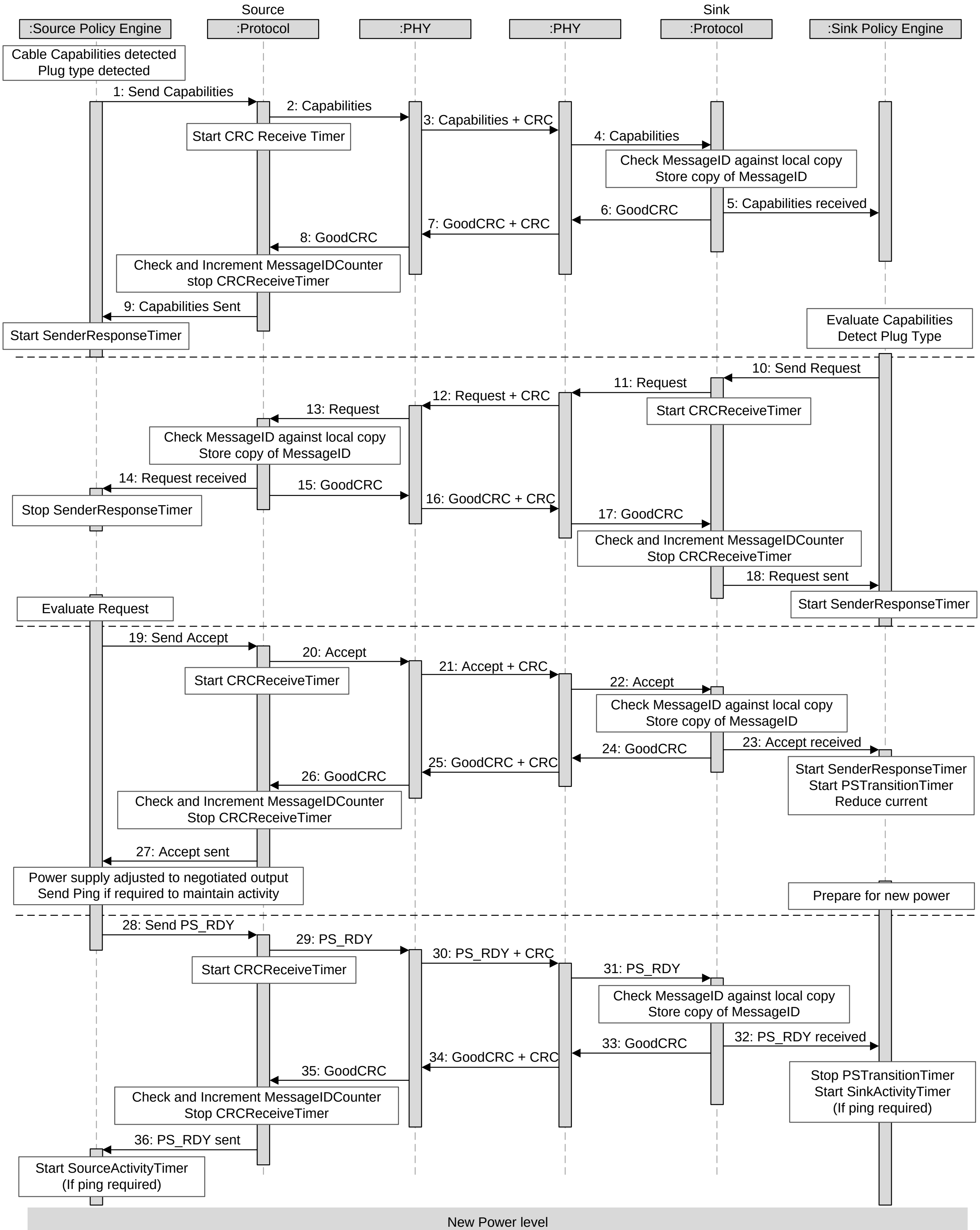


Figure 5. Successful Power Negotiation Flow from USB PD Specification

The USB PD Specification Revision 2.0, Version 1.2 lists 36 successful steps for a successful power negotiation. Because the specification assumes the protocol layer, physical layer, and electrical characteristics are ideal, all steps involving evaluation of available power, timers, and building or evaluating CRC messages have been removed in this discussion of a successful power negotiation.

After these steps are removed, the resulting list is a total of eight steps required to successfully complete a USB PD power negotiation which are as follows:

Step 1. Source detects the cable capabilities or plug type if these are not already known. Source sends a Source_Capabilities message that represents the present capabilities of the power supply with an appended CRC.

Step 2. Sink generates and sends a GoodCRC message.

Step 3. Sink policy engine evaluates the Source_Capabilities message sent by the source, detects the plug type if this is required and selects which power supply to use. The sink forms the data (such as a power-data object) that represents the request into a message and sends the request message.

Step 4. Source generates and sends a GoodCRC message.

Step 5. Source policy engine evaluates the request message sent by the sink and decides if it can complete the request. The source forms and sends an accept message with an appended CRC, and the following occurs:

- The sink enters the SnkStandby period and pulls less than 500 mA.
- The source begins to transition the voltage on the VBUS from VBUS_old to VBUS_new, which is from 5 to 20 V in this case.

Step 6. Sink generates and sends a GoodCRC message.

Step 7. Source device-policy manager informs the policy engine that the power supply has settled at the new operating condition and sends a PS_RDY message with an appended CRC.

Step 8. Sink generates and sends a GoodCRC message.

4.2 PD Trace Analysis of Power Negotiation Flow

Referring to the steps in Section 4.1, this section analyzes an actual PD trace of a power negotiation captured between two TPS65982-EVMs and verifies that it is successful.

The following PD message trace was taken with a Teledyne LeCroy PD analyzer between two TPS65982-EVMs, one loaded with a binary created from the source example template, *TPS65982_HD3SS460_DRP_Source_Full_2_8.tpl*, and the other loaded with the sink example template, *TPS65982_HD3SS460_UFP_Full_2_8.tpl*.

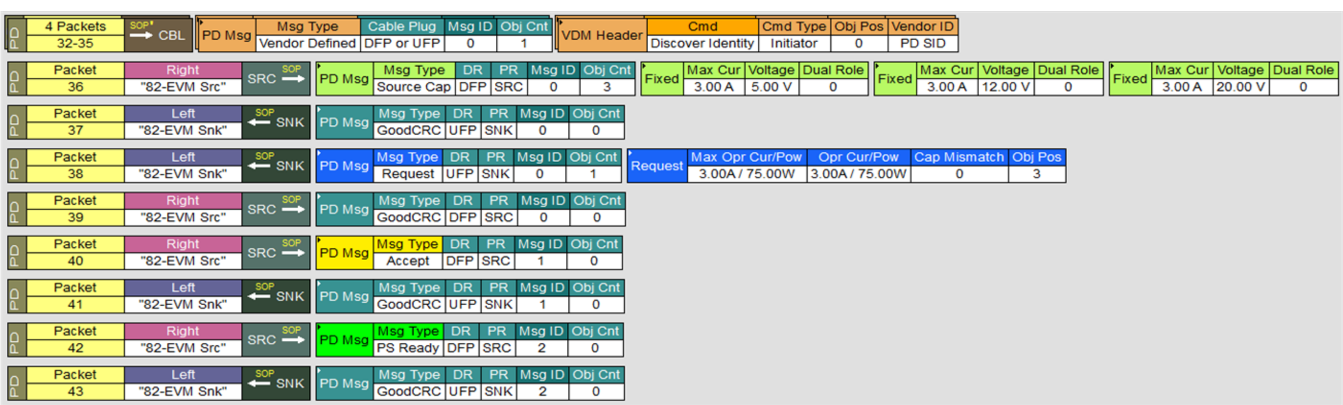


Figure 6. PD Trace of Successful PD Power Negotiation

Figure 6 shows the expected sequence of PD messages for this example and provides specific details on the eight steps introduced in Section 4.1:

Step 1. In packets 32 to 35, the source makes a few attempts to determine if an active or e-marked cable is connected before moving on to sending the source capabilities in packet 36 in the form of PDOs.

Step 2. In packet 37, the sink sends a GoodCRC to confirm the PDOs were received successfully.

Step 3. In packet 38, the sink sends its power needs to the Source in the form of a RDO.

Step 4. In packet 39, the source sends a GoodCRC to confirm the RDO was received successfully.

Step 5. In packet 40, the source accepts the RDO from the sink.

Step 6. In packet 41, the sink sends a GoodCRC to confirm that the source successfully accepted the RDO.

Step 7. In packet 42, the source sends PS_Ready to indicate 20 V is available on VBUS.

Step 8. In packet 43, the sink sends a GoodCRC to confirm PS_Ready was received successfully.

5 Rx Sink and Source Capabilities and Active PDO/RDO Host Interface Registers

Section 4.2 explains how a PD analyzer can be used to confirm that a successful PD power negotiation occurred. This information can also be extracted from the host interface registers of the TPS65982 device. These registers include the following:

- Status registers
  - 0x40, PD status
- Runtime registers:
  - 0x30, received (Rx) source capabilities
  - 0x31, recieved (Rx) sink capabilities
  - 0x34, active PDO
  - 0x35, active RDO

Reading the previously listed registers provides an indication of the power negotiation that occurred, even if a USB PD analyzer is not available in a lab. The TPS6598x Host Interface Utilities Tool provides a low-cost way to analyze, debug, and test to modify the sink and source capabilities of a real system in a couple different ways. Multiple systems can be tested relatively quickly, and this information can be used to determine how much power a source or sink actually can provide or consume. This information can then be used to modify the FW settings in the TPS6598x Configuration Tool to reprogram the SPI flash of the TPS65982 device with new capabilities. Or this information can be used to modify the sink or source capabilities instantly over I^{2}C to try a variety of new settings very rapidly and see the results in real-time to make correct new FW with less SPI writing, prepare to write code for an I^{2}C system controller in a multiport system, or both.

The PD status register (0x40) was read from the source side and the results are displayed in Figure 7, showing that this TPS65982-EVM is indeed acting as a source and that the Type-C role indicates that this port is not acting in sink mode and that an Rd pulldown resistor is activated on the CC1/2 pin. In addition, the power negotiation was successful on the first attempt (no soft or hard resets occurred, which would indicate error recovery was attempted).

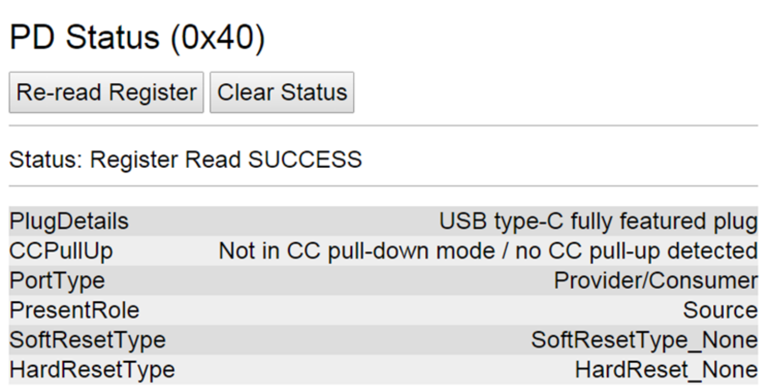


Figure 7. Status Register Read from TPS65982 Acting as Source

The PD status register (0x40) was read from the sink side and the results are displayed in Figure 8, showing that this TPS65982-EVM is indeed acting as a sink and the source advertised 3 A of Type-C current before the PD power negotiation occurred.

PD Status (0x40)

Re-read Register | Clear Status

Status: Register Read SUCCESS

PlugDetails	USB type-C fully featured plug
CCPullUp	3A current
PortType	Consumer/Provider
PresentRole	Sink
SoftResetType	SoftResetType_None
HardResetType	HardReset_None

Figure 8. PD Status Register Read from TPS65982 Acting as Sink

The Rx source capabilities register (0x30) was read from the sink side and the results are displayed in Figure 9, showing that the source advertised three PDOs and matches the default template source settings in Figure 1 and the capture PD trace in Figure 6.

Rx Source Cap (0x30)

Re-read Register | Clear Status

Status: Register Read SUCCESS

numPDOs	3
PDO1: MaxCurrent or Power	3000 mA
PDO1: Min Voltage or Power	5000 mV
PDO1: Peak Current	0 PeakCurrentType_100PercentIOC
PDO1: Dual Role Data	True
PDO1: USB Comm Capable	True
PDO1: Externally Powered	False
PDO1: USB Suspend Supported	False
PDO1: Dual Role Power	False
PDO1: Supply Type	Fixed
PDO2: MaxCurrent or Power	3000 mA
PDO2: Min Voltage or Power	12000 mV
PDO2: Max Voltage	0 PeakCurrentType_100PercentIOC
PDO2: Supply Type	Fixed
PDO3: MaxCurrent or Power	3000 mA
PDO3: Min Voltage or Power	20000 mV
PDO3: Max Voltage	0 PeakCurrentType_100PercentIOC
PDO3: Supply Type	Fixed

Figure 9. Rx Source Capabilities Register Read from TPS65982 Acting as Sink

The Rx sink capabilities register (0x31) was read from the source side and the results are displayed in Figure 10, showing that the source has two sink PDOs which matches the default template sink settings in Figure 3. This data are not shown in the capture PD trace Figure 6. Section 6 explains why and how to populate this register with usable data.

Rx Sink Cap (0x31)

Re-read Register | Clear Status

Status: Register Read SUCCESS

numPDOs	2
PDO1: MaxCurrent or Power	900 mA
PDO1: Min Voltage or Power	5000 mV
PDO1: Peak Current	0 PeakCurrentType_100PercentIOC
PDO1: Dual Role Data	False
PDO1: USB Comm Capable	True
PDO1: Externally Powered	False
PDO1: Higher Capability	True
PDO1: Dual Role Power	False
PDO1: Supply Type	Fixed
PDO2: MaxCurrent or Power	900 mA
PDO2: Min Voltage or Power	12000 mV
PDO2: Max Voltage	20000 mV
PDO2: Supply Type	Variable

Figure 10. Rx Sink Capabilities Register Read from TPS65982 Acting as Source

The active PDO register (0x34) was read from the sink side and the results are displayed in Figure 11, showing that the active PDO matches the default template source settings in Figure 1 and the capture PD trace in Figure 6.

Active PDO (0x34)

Re-read Register | Clear Status

Status: Register Read SUCCESS

MaxCurrent or Power	3000 mA (Max Current)
Min Voltage or Power	20000 mV
Max Voltage	None
Supply Type	Fixed
Peak current	PeakCurrentType_100PercentIOC
USBCommCapable	True
Externally Powred	False
USBSuspendSupported	False
Dual Role	False

Figure 11. Active PDO Register Read from TPS65982 Acting as Sink

The active RDO register (0x35) was read from the source side and the results are displayed in Figure 12, showing that the active requested data object matches the default template sink settings in Figure 3 and the captured PD trace in Figure 6.

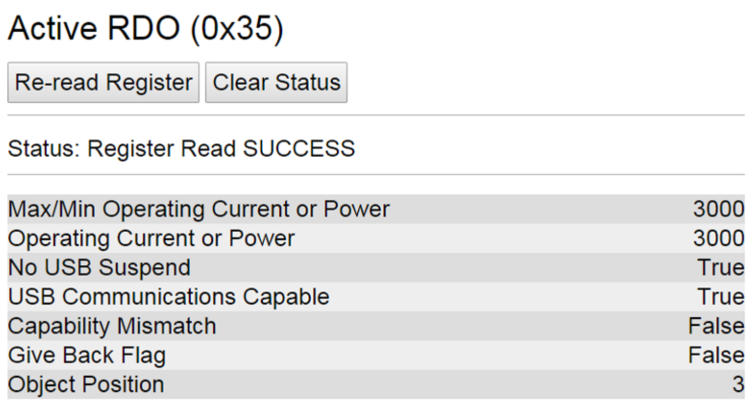


Figure 12. Active RDO Register Read from TPS65982 Acting as Source

Now that all of the status and runtime registers have been introduced and verified to match the initial settings and actual data captured in the PD trace, this information can be used to modify the default templates to match the power requirements of a real system and add more functionality to complex systems. In the final system, these same registers will be used to debug simple problems encountered when testing interoperability of new products being developed with products available in the market.

5.1 Modifying Tx Sink Capabilities to Negotiate Power Based on Actual System Needs

This section explains how to modify the Tx sink Capabilities in the TPS6598x Configuration Tool to match the needs of a system. Although the templates are a great starting point to verify that the FW is successfully negotiating USB PD power contracts, the real system being designed will have very specific power needs.

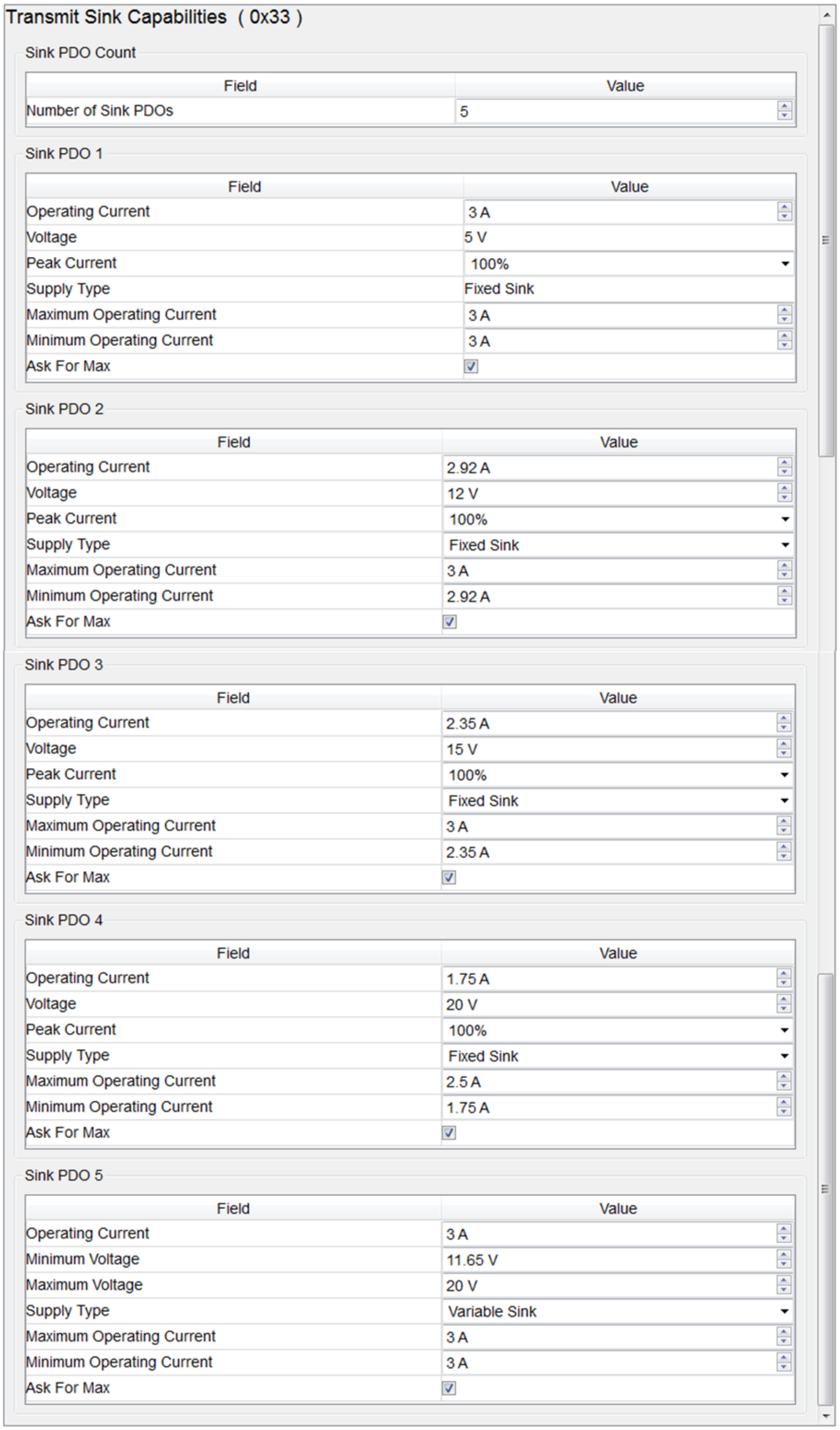
After determining these exact power needs through lab testing, the FW must be modified to successfully negotiate as many Source PDOs as possible. Consider an example where the sink system was measured to need 15 W of power for PDO1 at 5 V to power up the application processor and other critical components on the board.

At 15 W though, the battery of the system cannot be charged. After additional testing, it is determined that the system requires at least 35 W to charge the battery and more than 50 W are not necessary.

To ensure the minimum power will be received at standard USB-PD voltage rails (12 V, 15 V, 20 V), fixed sink PDOs are used to get the exact current required. Assuming the source is a mobile computer or multiport system sharing a limited amount of power, the operating current is calculated shown in Equation 1.

$$\text{Operating Current} = (\text{Minimum Power} / \text{Voltage Rail}) \quad (1)$$

Furthermore, the 12-V and 15-V contracts attempt to request a maximum current of up to 3 A, but the 20-V sink PDO will only request a maximum current of 2.5 A for exactly 50 W. To capture as many nonstandard PD voltages and variable source PDOs as possible, a wide-voltage variable sink PDO is used with a minimum current of 3 A. Figure 13 shows the exact settings used for all five sink PDOs. The project name of *TPS65982_HD3SS460_UFP_Full_2_8.tpl* was renamed to *Snk_35-50W.pjt* in Figure 13 and is no longer a default template.



Transmit Sink Capabilities (0x33)

Sink PDO Count

Field	Value
Number of Sink PDOs	5

Sink PDO 1

Field	Value
Operating Current	3 A
Voltage	5 V
Peak Current	100%
Supply Type	Fixed Sink
Maximum Operating Current	3 A
Minimum Operating Current	3 A
Ask For Max	☑

Sink PDO 2

Field	Value
Operating Current	2.92 A
Voltage	12 V
Peak Current	100%
Supply Type	Fixed Sink
Maximum Operating Current	3 A
Minimum Operating Current	2.92 A
Ask For Max	☑

Sink PDO 3

Field	Value
Operating Current	2.35 A
Voltage	15 V
Peak Current	100%
Supply Type	Fixed Sink
Maximum Operating Current	3 A
Minimum Operating Current	2.35 A
Ask For Max	☑

Sink PDO 4

Field	Value
Operating Current	1.75 A
Voltage	20 V
Peak Current	100%
Supply Type	Fixed Sink
Maximum Operating Current	2.5 A
Minimum Operating Current	1.75 A
Ask For Max	☑

Sink PDO 5

Field	Value
Operating Current	3 A
Minimum Voltage	11.65 V
Maximum Voltage	20 V
Supply Type	Variable Sink
Maximum Operating Current	3 A
Minimum Operating Current	3 A
Ask For Max	☑

Figure 13. New Set of Five Sink PDOs in Modified *Snk_35-50W.pjt* **Project**

Figure 14 shows a capture PD trace after loading the new *Snk_35-50W.pjt* binary FW image on the TPS65982-EVM and connecting it to the unchanged TPS65982-EVM acting as the source and loaded with a binary file from the example *TPS65982_HD3SS460_DRP_Source_Full_2_8.tpl* template project.

NOTE: Object 3 (20-V fixed) is still the active RDO but now the operating current and maximum current fields are 2.5 A.

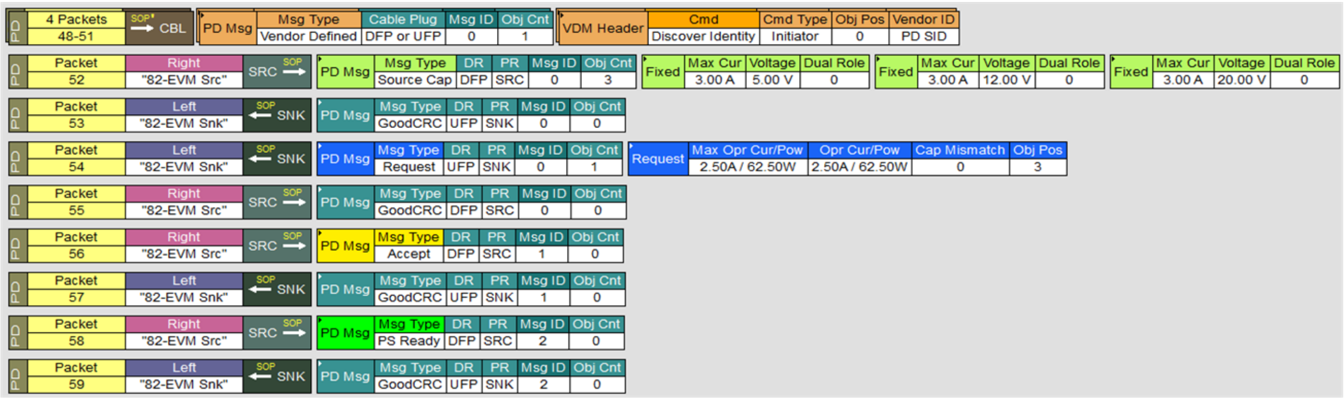


Figure 14. New Initial Power Negotiation Between Source and ***Snk_35-50W.pjt*** **Sink**

5.2 Using Received Data and System Information to Renegotiate Power Contracts

The USB-PD source may sometimes be mobile computers operating off of battery power or multiport systems sharing a fixed amount of power trying to allocate resources to PD sinks on a case-by-case basis.

If the total power available in a USB-PD dock acting as a source is 100 W and 50 W is being used by the sink on port A, then a standard 60-W contract cannot be offered to port B.

After reading the Rx sink Capabilities Register, it is determined that the sink using FW from the “Snk_35-50W.pjt” project only requires 35 W on Port A, so a 60-W contract could be offered to Port B.

In this example, source PDO3 will be reduced to 20 V, 1.75 A and then the TPS65982-EVM acting as the source will send the *Send Source Capabilities* (SSrC) message to attempt to renegotiate the PD power contract at a lower power setting.

NOTE: In Figure 14, the operating current and maximum current fields are now 2.5 A but the new sink capabilities have been modified and the PD source can determine this information. Figure 15 shows the sink capabilities processed by the source after issuing a *Get sink Capabilities* (GSkC) PD command.

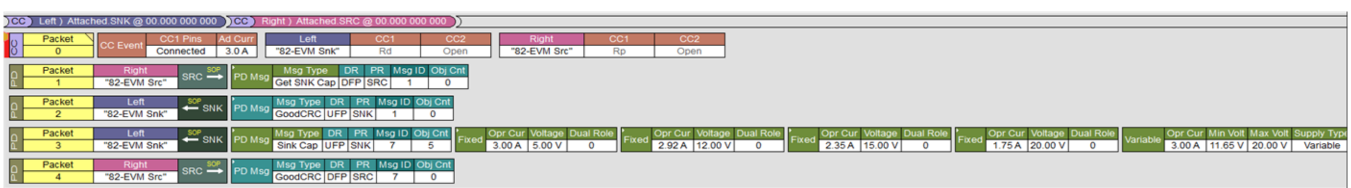


Figure 15. New Sink Capabilities in Reply to GSkC PD Command from Source

Figure 16 shows the source PDO3 being modified on the TPS65982-EVM acting as a source before the SSrC command is issued to the TPS65982 device to resend the *Source Capabilities* PD Message. Modifying the Rx source capabilities register (0x32) and issuing the SSrC command are both performed in the TPS6598x Utilities Tool GUI.

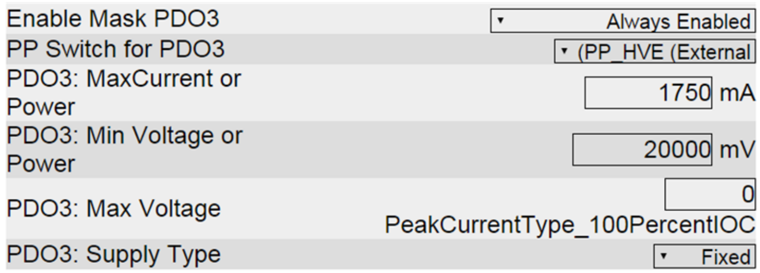


Figure 16. New Source PDO3 of *TPS65982_HD3SS460_DRP_Source_Full_2_8.tpl* Source

Figure 17 shows a PD trace from an analyzer that was recording USB PD traffic before the SSrC command was issued to the source and captures the renegotiation between the two TPS65982-EVMs.

This PD trace confirms that the sink is still accepting with the 20 V, 1.75-A contract offered by the source and the power negotiation is successful again.

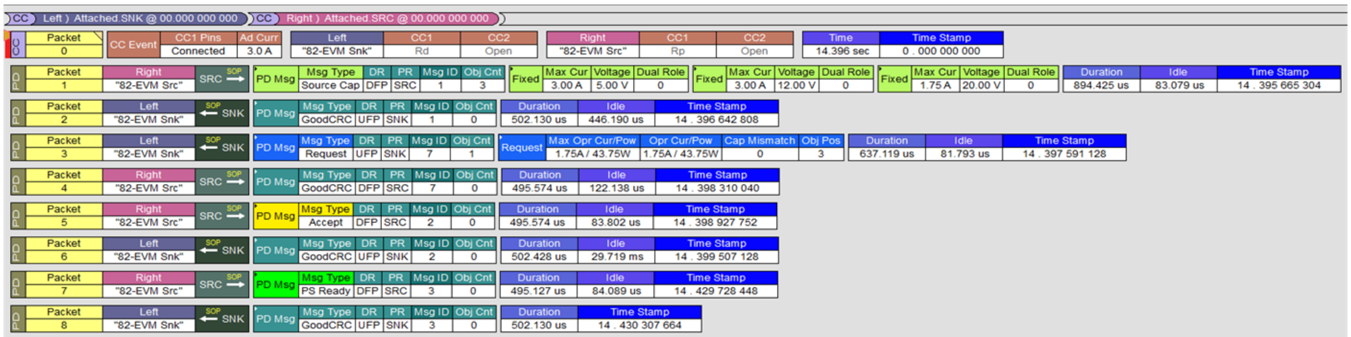


Figure 17. Final Power Negotiation Between Source and Sink after SSrC Command is Sent

6 Debugging Common Power Negotiation Issues

The previous sections discuss what happens when a power negotiation or renegotiation is successful. The following sections discuss debugging options for when the first attempt to establish a power contract is unsuccessful.

6.1 Failure Type 1—PDO1 Accepted With no Mismatch When High-Voltage PDO Available

The most common problem with power contracts is that all eight steps that make up a successful power negotiation (see Section 4.1) are usually completed successfully, with the sequence ending in a *PS_Ready* message sent from the source. Sometimes the accepted PDO is Object 1, meaning that the source provides only 5 V. If the sink has higher voltage capabilities (9, 12, 15, or 20 V) then none of the source PDOs 2 through *X* matched any of the sink PDOs 2 through *Y*. Figure 18 shows this type of failure with the source capabilities modified on the TPS65982-EVM acting as a source to recreate the issue.

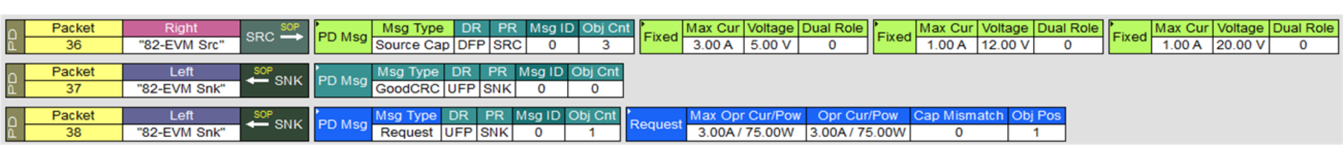


Figure 18. Failure Type 1: PDO1 Accepted With no Mismatch When High-Voltage PDO Available

If the sink capabilities have been well characterized, then the source should be put on a list of PD power supplies that are not compatible with the sink system. If the sink capabilities are not known yet, then the TPS6598x Host Interface Utilities Tool can be used to modify the Tx sink capabilities register (0x33) and lower the current at one of the fixed-source voltages to accept a high-voltage PDO. The system must be retested to ensure it can operate correctly with lower input power, even in Dead Battery Mode.

If the problem continues, the high-voltage source PDO is most likely a variable type and the voltage window is very large. Modifying variable- and battery-type sink PDOs is not strictly defined by the USB specification and debugging this type of problem is outside the scope of this document.

6.2 Failure Type 2—PDO3 Accepted With Capability Mismatch = 1

Another similar problem that can occur is a capability mismatch. Sometimes a PDO is accepted even though no matches occurred. In other words, source PDOs 1 through *X* did not match any of the sink PDOs 1 through *Y*. If this issue occurs, the capabilities mismatch bit in the RDO is set to 1. Figure 19 shows this type of failure with the source capabilities modified on the TPS65982-EVM acting as a source to recreate the issue.

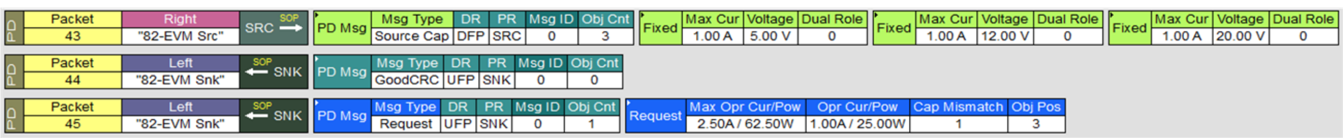


Figure 19. Failure Type 2: PDO3 Accepted With Capability Mismatch = 1

The solution to this failure is the same as the solution to failure 1 (see Section 6.1), but the fact that this failure occurred may not be as obvious because Object 2-X could be requested to get the most power (Object 1 not requested) and VBUS may be higher than 5 V.

6.3 Failure Type 3—Rx Sink Capabilities Register (0x31) Reads all Zeros (0)

The final failure discussed in this section is when the Rx sink capabilities register (0x31) has no data and reads all 0. In previous sections, the Rx sink capabilities register of the source is assumed to always contain the same data as the Tx sink capabilities register of the sink, but this is not entirely true. The data in any received (Rx) register can only display information sent through PD communication. As can be seen in all of the successful power-negotiation PD traces, the sink is never required to send capabilities but is only required to send a request.

Figure 20 shows this failure. The solution is simple and has been explained previously in Section 6.1.

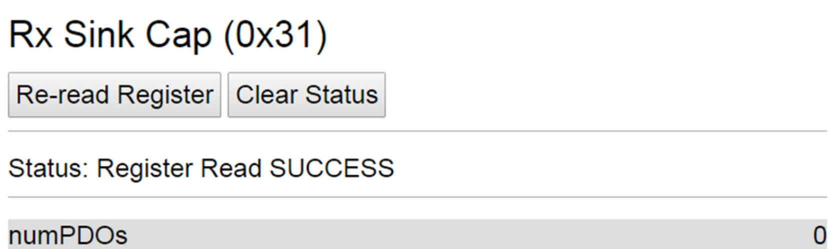


Figure 20. Failure Type 3: Rx Sink Capabilities Register (0x31) Reads all Zeros (0)

Figure 21 shows how to send a *Get Sink Capabilities* PD message from the source using the TPS6598x Host Interface Utilities Tool GUI to populate register 0x31 of the source with real data from the sink.

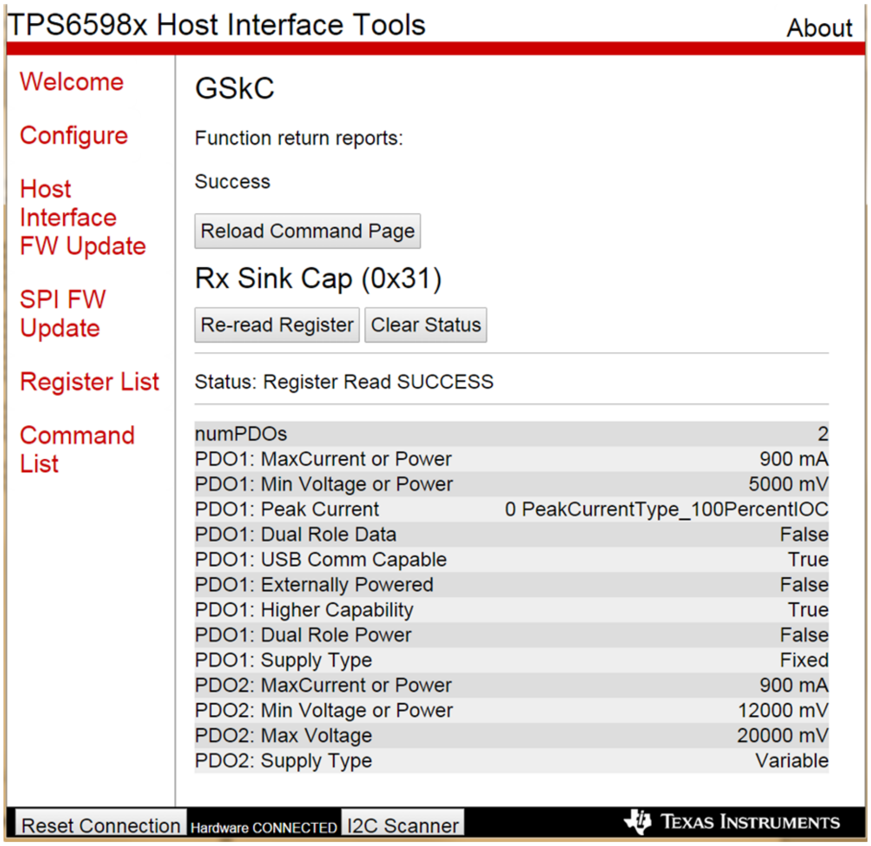


Figure 21. Failure Type 3 Solution: Execute GSkC Command from Source

Figure 21 shows the exact same data as Figure 10, but the data shown in Figure 10 is not populated until a GSkC command is executed.

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