Introduction to USB Power Delivery Over the USB Type-C™ Cable

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INTRODUCTION

The USB Power Delivery revision 2.0 specification details how the Power Delivery (PD) protocol truly “unlocks” the advanced features of the USB Type-C™ cable. Power Delivery protocol allows port-to-port communication that provides mechanisms for: negotiating power roles, negotiating power sourcing and consumption levels, performing active cable identification, exchanging vendor specific sideband messaging, and performing Alternate Mode negotiation allowing 3rd party communication protocols to be routed onto the USB Type-C cable’s reconfigurable pins.

If you are not yet familiar with the USB Type-C, please refer to Application Note AN1953 “Introduction to USB Type-C™” before reading this document.

SECTIONS

REFERENCES

This document is an introduction to USB Power Delivery 2.0 and is not intended to be a replacement to the official specification. Consult the following specifications for technical details not described in this document.

- *USB Type-C™ Specification*
- *USB Power Delivery 2.0 Specification*
- *USB 2.0 Specification*
- *USB 3.0 Specification*
- *USB 3.1 Specification*
- *USB Battery Charging BC1.2*

GLOSSARY

DFP - “Downstream Facing Port”. A USB host-side port or hub downstream port.

UFP - “Upstream Facing Port”. A USB device-side port or hub upstream connection.

DRP - “Dual Role Port”. A USB port that may operate as either a DFP or a UFP.

Source - The provider of VBUS power in a USB connection.

Sink - The consumer of VBUS power in a USB connection.

USB PD - Abbreviation of USB Power Delivery.

SOP* - The Start of Frame field in a USB Power Delivery packet indicates the intended recipient of the packet.

VCONN - the dedicated power supply rail for cables and accessories.

USB-IF - USB Implementers Forum. A non-profit corporation found by the group of companies that developed USB.

1.0 GENERAL INFORMATION

The USB Type-C cable is a reversible 24-pin interconnect created by the USB-IF. The USB Type-C™ specification was first released in August 2014. Power Delivery revision 2.0 is a overhaul of the specification to provide compatibility for the new USB Type-C™ specification. Power Delivery revision 2.0 protocol is what truly unlocks the advanced capabilities of the USB Type-C. These features include:

- Elevated VBUS voltage and current capability.
- Dynamic power contract renegotiation.
- Dynamic power role swapping
- Dynamic Data Role Swapping
- Electronically Marked Cable Identification
- Alternate Modes

1.1 Elevated VBUS Voltage and Current Capability

A standard USB Type-C connection allows for up to 15W (5V at 3A) of power without USB Power Delivery messaging. If Power Delivery messaging is implemented, power levels provided across the cable can be extended beyond the 15W. By default all passive USB Type-C cables support up to 60W of power (20V at 3A). This can be extended up to 100W (20V at 5A) with electronically marked cables that are identified as either an active cable or one that is capable of extended current capability.

See Section 5.0, Power and Data Negotiation for additional details.

1.2 Dynamic Power Contract Renegotiation

USB Power Delivery messaging can be used to dynamically change the power negotiation to any values in the ranges 5V-20V and 0A-5A at any time during a USB Type-C connection.

See Section 5.0, Power and Data Negotiation for additional details.

1.3 Dynamic Power Role Swapping

The roles of power source and power sink may also be changed dynamically via USB Power Delivery messaging. A Source or a Sink may request at any time to change roles.

See Section 5.0, Power and Data Negotiation for additional details.

1.4 Dynamic Data Role Swapping

Either a DFP or UFP may request a data role swap at any time over USB Power Delivery messaging. If the request is accepted by the port partner, the data roles will be reversed. Note that the power role (source/sink) is not affected by a data role swap.

See Section 5.0, Power and Data Negotiation for additional details.

1.5 Electronically-Marked Cable Identification

USB Type-C cables may or may not be electronically marked. Electronically marked cables may also send and receive USB Power Delivery messages to communicate specific attributes.

See Section 4.0, Cable Identification for additional details.

1.6 Alternate Mode

The USB Type-C™ specification allows for additional independently defined and organized specifications which allow for alternate protocols to be transmitted on the USB Type-C cable. There are no specific limitations on Alternate Modes provided the USB Type-C cable can support it and a USB2.0 and USB Power Delivery connection is maintained.

See Section 6.0, Alternate Modes for additional details.

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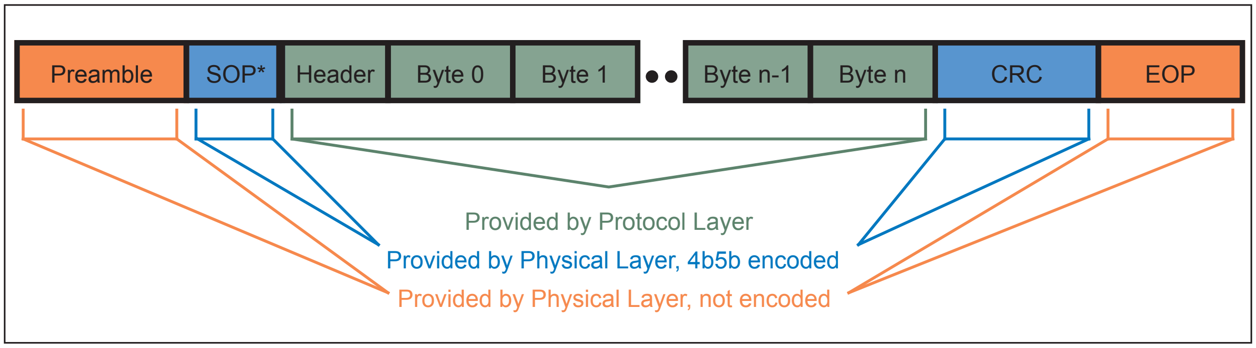
2.0 USB PD PROTOCOL LAYER

The general anatomy of a USB Power Delivery packet is shown in Figure 1 below.

FIGURE 1: POWER DELIVERY PROTOCOL PACKET FORMAT



2.1 Preamble

Every USB Power Delivery packet begins with a 64-bit sequence of alternating 0s and 1s. This preamble is used to train the receiver and achieve lock.

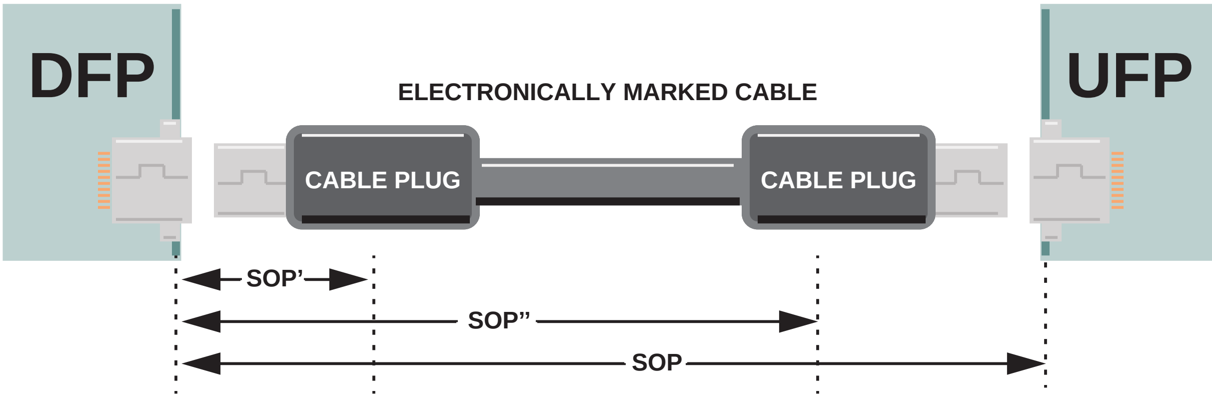
2.2 Start of Packet (SOP*) Signaling

The Start of Packet field typically also indicates the intended recipient. Some fundamental commands can also be sent through the SOP* field. These addresses/commands are collectively called SOP*. Table 1 below defines the SOP signaling.

TABLE 1: SOP* SIGNALING DEFINITIONS

Name	Value	Use
SOP	11000 11000 11000 10001	Communication to UFP
SOP’	11000 11000 00110 00110	Communication to USB Type-C Plug Side A
SOP”	11000 00110 11000 00110	Communication to USB Type-C Plug Side B
Hard Reset	00111 00111 00111 11001	Resets logic in all connected PD devices (UFP and/or Active/Electronically Marked Cable)
Cable Reset	00111 11000 00111 00110	Reset for only Active/Electronically Marked Cable.
SOP’_Debug	11000 11001 11001 00110	Used for debug of USB Type-C Plug Side A
SOP”_Debug	11000 11001 00110 10001	Used for debug of USB Type-C Plug Side B

FIGURE 2: SOP* SIGNALING



Note: SOP’ is assigned to one plug of the cable while SOP” is assigned to the other. The cable plugs cannot tell which side that they are connected to, just that one end may respond to SOP’ addressed messages and the other may respond SOP” addressed messages.

2.3 Header

Every USB Power Delivery message begins with a 16-bit header. The header contains basic information including the length of the data to follow. The header may also be used as a standalone control message if the data length field is zero.

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3.0 PD PHYSICAL LAYER

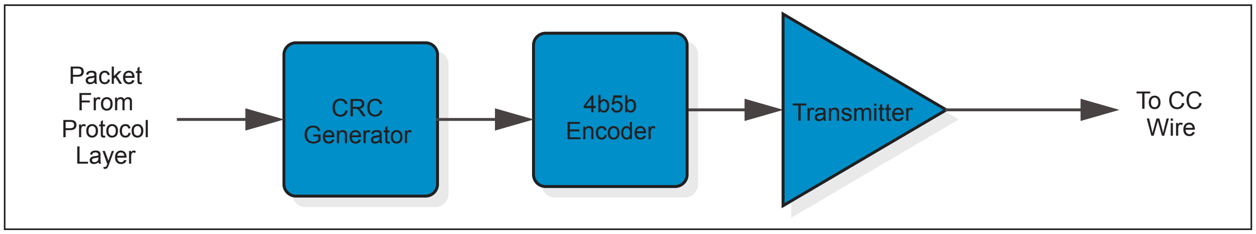
Every USB Power Delivery device must have a PD physical layer that contains both a transmitter and a receiver. All power delivery communication occurs at half duplex over the CC (Configuration Channel) wire on the USB Type-C cable. The DFP is the Bus Master and initiates all communication.

3.1 Transmitter

The transmitter performs the following:

1. Receive raw (non-encoded) packet data from protocol layer.
2. Calculate a CRC and append to end of data packet.
3. Encode the whole packet (with CRC) in 4b5b encoding.
4. Transmit the entire packet (preamble, SOP*, data payload, CRC, and EOP)

FIGURE 3: PD TRANSMITTER

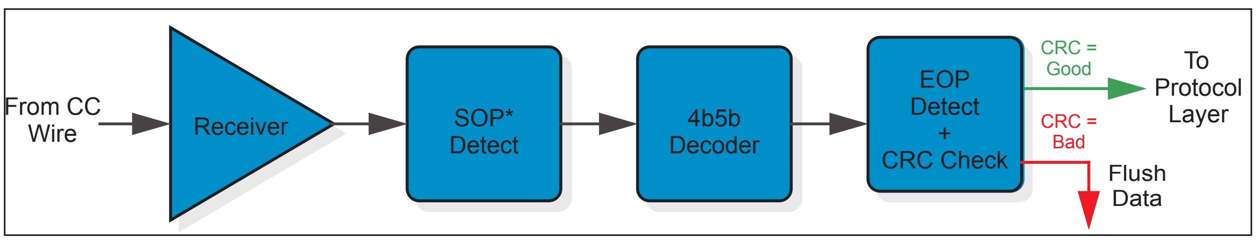


3.2 Receiver

The receiver performs the following:

1. Recovers clock from the packet preamble.
2. Detect SOP*
3. Decode from 4b5b to raw data (included CRC)
4. Detect EOP and validate CRC. If valid, delver packet to protocol layer. If invalid, flush data.

FIGURE 4: PD RECEIVER



3.3 BMC Signaling

All messages are Biphase Mark Coding (BMC), a modification of Manchester coding where a ‘zero’ has one transition and a ‘one’ has two transitions. All messages occur at a 300k Baud rate. The signaling is effectively DC balanced with a nominal voltage swing of 1.125V.

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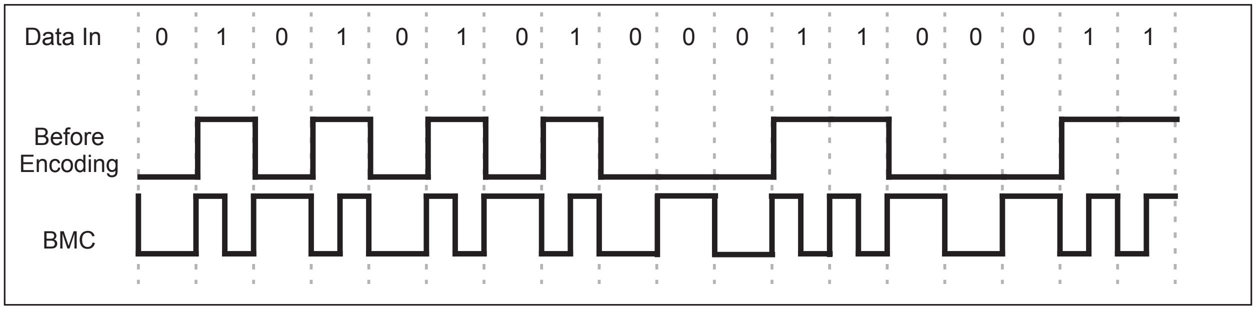
FIGURE 5: BMC SIGNALING



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4.0 CABLE IDENTIFICATION

The USB Type-C™ specification introduced VCONN, the dedicated power supply rail for cables and accessories with electronic marker ICs embedded within. Cables which contain electronic markers must terminate their VCONN line with value *Ra* (1 kΩ) in order to allow the USB Type-C Source (which is also the default DFP upon initial connection) to detect that an electronic marker is present, and source VCONN power in addition to VBUS power.

In particular, active cables (those that include signal conditioning electronics) and cables supporting VBUS currents in excess of 3A are required to include the electronic marker, for storing vendor and other feature details of these cables. Collectively, these details are called the “Identity”.

If the USB Type-C Source is USB PD-enabled, then before any power negotiation begins, the Source should discover the cable’s Identity as described by the following sequence:

1. Source sends **Discover Identity** command message to SOP’ (see Section 2.2, Start of Packet (SOP*) Signaling), directing the message to the cable’s electronic marker.
2. The SOP’ device responds with GoodCRC to confirm proper receipt of the **Discover Identity** command.
3. The SOP’ device then sends a **Discover Identity ACK** response back to the Source, with its Identity information enclosed. This message contains a header and 160 bits of description data for the cable.

Note:	The exact detail of this Discover Identity data is beyond the scope of this application note but to summarize, the data contains fields describing the following: - USB Vendor ID and Product ID - USB Test ID (for USB certification traceability) - Product Hardware & Firmware Revisions - Interconnect Type (USB Type-C Plug or Receptacle) - Cable Latency (specified in nanoseconds) - Cable Terminations - SuperSpeed Data Directionality - VBUS Current Handling Capability (3 or 5 Amps) - USB SuperSpeed Signaling Capability (Gen 1/Gen 2) - Modes Supported? (Boolean, can prompt further Discovery queries)

4. The Source responds with GoodCRC and then evaluates the contents of the Identity.

Not all USB Power Delivery-capable ports are necessarily sensitive to *all* the details returned by an active cable. However, ports designed to be able to supply more than 3 A of current must confirm the cable is designated with the 5 A current capability. Based upon that evaluation, the USB Power Delivery port knows whether or not to “advertise” any power profiles to its port partner which exceed 3 A.

Note:	By USB Type-C™ specification, if there is no electronic marker detected and/or no response from the cable, then it must be assumed that the cable is only capable of supporting current up to 3 A.

5.0 POWER AND DATA NEGOTIATION

In classic USB, the DFP was always the Source and the UFP was always the Sink. However, products which implement USB Power Delivery protocol can dynamically negotiate the following:

- **Increasing/decreasing voltage**
  - Sink may request & sink power from the Source at voltages ranging 5-20 V if both the Source and Sink support it.
- **Increasing/decreasing current**
  - Sink may request & sink power from the Source at currents ranging 0-5 A if the Source, Sink, and cable support it.

Note:	The above voltage and current range allows for up to a 100 W power connection between two USB PD products.

- **Power Role Swap (PR_SWAP)**
  - Original Source (for VBUS) may “swap” to Sink role, and vice versa. When a power role swap occurs, VBUS is discharged to 0 V by the old Source, prior to the new Source driving VBUS, in order to prevent unsafe power scenarios.
- **Data Role Swap (DR_SWAP)**
  - Original DFP/Host may “swap” to UFP/Device role, and vice versa. The partner with the DFP role becomes the USB PD bus master, in addition to the assumed role as USB Host.
- **VCONN Swap (VCONN_SWAP)**
  - Original Source may “swap” its VCONN source responsibility with the Sink.

After the default power and data roles are designated upon USB Type-C connection between two port partners [refer to Application Note (AN 1953) “Introduction to USB Type-C™” for further clarification], these additional power and data negotiations may take place over USB PD protocol when both partners are USB PD-capable, and an explicit power contract has been established between them.

To determine if the default Sink device is USB PD-capable, the default Source attempts to enter an explicit USB PD power contract with the Sink as the following sequence describes:

1. The Source sends a **Source_Capabilities** USB PD message to the Sink which includes a menu of available VBUS power supply options (the first option must be the 5 V default VBUS supply, but may also include up to 6 additional power options).
2. A USB PD-capable Sink will respond first with a **GoodCaRC** message to confirm proper receipt of the **Source_Capabilities**.
3. The Sink replies with a **Request** message indicating which of the power supply options it prefers to use.

Note:	At this point in the transaction, the Source knows the Sink is USB PD-capable and continues with the explicit contract negotiation.

4. The Source responds with a **GoodCRC** message and verifies the **Request** is valid.
5. The Source sends an **Accept** message to the Sink.
6. The Sink replies with **GoodCRC**
7. The Source transitions its power supply to the requested voltage level and current limit. When the power supply is transitioned, the Source sends a **PS_RDY** (power supply ready) message to the Sink.
8. The Sink replies with **GoodCRC** and begins to sink power under the explicit contract’s voltage and current allocation.

Note:	This example describes the USB PD communications between port partners in terms of Source and Sink because no Power Role Swap or Data Role Swap have previously occurred in the session and are therefore still in their default USB Type-C roles. Therefore we can equate the Source as the DFP, and the Sink as the UFP.

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6.0 ALTERNATE MODES

Alternate Modes allow the USB Type-C cable to be reconfigured to support 3rd party (e.g. standards groups or vendors) protocols. This feature is enabled only if both ports support the USB Power Delivery protocol and are both compatible with the specific Alternate Mode.

As long as the cable can support the 3rd party protocol signaling while maintaining a USB2.0 connection and USB Power Delivery connection, then the Alternate Mode can be implemented. The USB Type-C and USB Power Delivery specifications do not define any Alternate Modes themselves; Each 3rd party must maintain its own USB Type-C Alternate Mode specification.

Alternate Mode negotiation is performed via USB Power Delivery protocol between port partners after Alternate mode compatibility is realized using the Discovery messages (Discover Identity, Discover SVIDs, and Discover Modes).

6.1 Reconfigurable Pins

All Alternate Modes must minimally maintain a USB2.0 and USB Power Delivery connection. The following pins/wires may be reconfigured for the use with the Alternate Mode.

FIGURE 6: RECONFIGURABLE PINS ON A FULL FEATURED CABLE

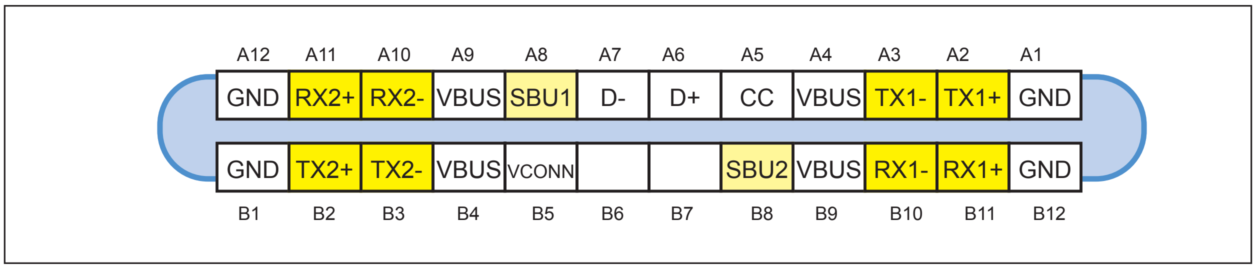
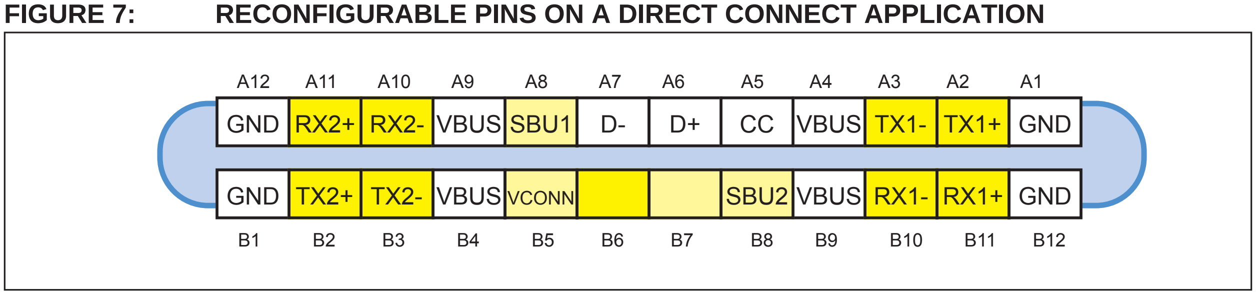


FIGURE 7: RECONFIGURABLE PINS ON A DIRECT CONNECT APPLICATION

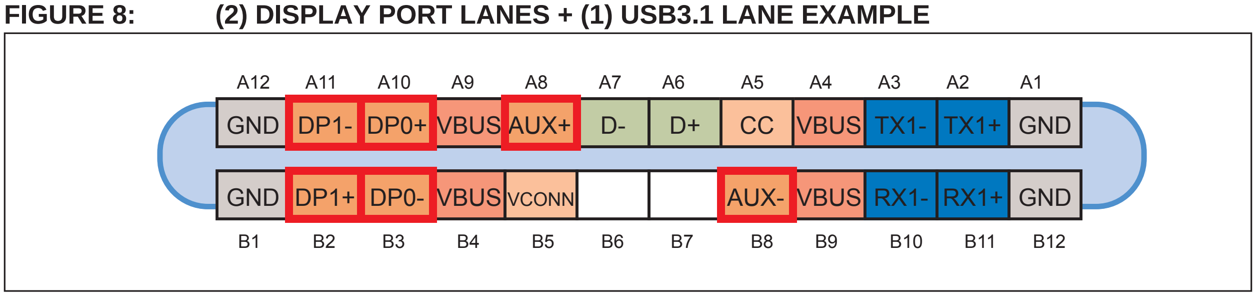


6.2 Alternate Mode Example: DisplayPort

DisplayPort was one of the first 3rd party standards (as defined by VESA) to be specified as a USB Type-C Alternate Mode. The DisplayPort Alternate Mode supports the following modes of operation:

- (2) DisplayPort lanes + (1) USB3.1 lane
- (4) DisplayPort lanes

FIGURE 8: (2) DISPLAY PORT LANES + (1) USB3.1 LANE EXAMPLE



6.2.1 STRUCTURED VENDOR DEFINED MESSAGES (SVDM) FOR DISPLAYPORT

Structured Vendor Defined Messages or SVDMs are a class of USB Power Delivery messages which enable *non-power-related* messages to be communicated between port partners. These messages serve a variety of use-cases including discovery of port partner and cable identity (as described in Section 4.0, Cable Identification), the discovery of supported Alternate Modes (by use of similar Discover SVIDs (Standards/Vendor ID) and Discover Modes commands), and exchange of messages specific to Alternate Modes, once those modes are explicitly negotiated.

DisplayPort's Alternate Mode specification defines three primary SVDMs:

- DisplayPort Capabilities

  This message contains what the UFP's DisplayPort capabilities are (number of DisplayPort lanes supported), USB support, connector type (plug/receptacle), and pin assignments supported.

- DisplayPort Configure

  This message is a command which tells the UFP to reconfigure for a specific DisplayPort pin assignment, reconfigure to operate as a DisplayPort Source or DisplayPort Sink, and which signaling type to use (USB 3.1 Gen 2 vs. DisplayPort v1.3)

- DisplayPort Status

  This message is used to convey: DisplayPort connection state, DisplayPort Hot Plug Detect (HPD) state (High/Low/IRQ), USB mode enabled/disabled, DisplayPort mode enabled/disabled, DisplayPort adapter power status, and whether there is a pending request to exit DisplayPort Alternate Mode.

  The HPD state feature of this DisplayPort Status SVDM is worth noting because in classic DisplayPort, HPD is a dedicated signal that is connected through the DisplayPort cable between the DisplayPort Source and Sink. However, there were not enough reconfigurable pins in the USB Type-C cable to accommodate this signal. Therefore, the DisplayPort specification committee designed this Alternate Mode so that the HPD signal would be bridged between the DisplayPort Source and Sink via USB Power Delivery protocol.

  The DisplayPort Sink drives the HPD pin, and the UFP's USB Power Delivery controller detects that state, encodes it in a DisplayPort Status message for receipt by the DFP. The DFP then regenerates the HPD pin state locally for the DisplayPort Source, therefore completing a virtual circuit which is backward compatible with legacy DisplayPort ASICs.

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APPENDIX A: APPLICATION NOTE REVISION HISTORY

TABLE A-1: REVISION HISTORY

Revision Level & Date	Section/Figure/Entry	Correction
Note: AN1974, Revision A replaces the previous SMSC version.		

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