



[METHODOLOGY: DEVELOPMENT AND TESTING OF BLIND-MATE UNIVERSAL QUICK DISCONNECT]

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Executive Summary

Liquid cooling of datacenter servers is not new, however air cooling has been the dominate method of datacenter cooling for the past few decades (Voices of Industry - Dror Shenkar, 2020). With processors and memory modules trending toward higher and higher power densities the advantages of air cooling are starting to lessen, and liquid cooling is looking more favorable. Cold plate cooling has become a popular option to add liquid cooling into an existing air cooled datacenter. These systems are fitted with cooling loops to direct cooling fluid to internal hot spots. These cooling loops are made of various ingredients such as tubing, cold plates, and quick disconnects (Gullbrand, Luckeroth, Sprenger, & Winkel, 2019). Datacenter owners are familiar with purchasing systems with readily available air-cooling solutions from multiple suppliers. Liquid cooling ingredients are not as widely available, and many solutions are single sourced proprietary kits that are not easily interchangeable. Intel Corporation has been engaged in enabling fluid loop ingredients for this reason and have teamed with several large global suppliers to develop interchangeable fluid connectors UQD's (Universal Quick Disconnects). The hand mate version Universal Quick Disconnect (UQD) is published under OCP Specification (Sprenger, 2020). Intel's enabling efforts include a blind mate specification for 2021 and is the topic of this paper which will detail the development approach and the strategy to leverage the existing published UQD specifications.

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Scope & Overview

This paper is focused on the development of UQDB specifications covering dimensional, performance and cosmetic requirements. The starting point for this effort is the released specification for Universal Quick Disconnect hand-mate connector or UQD. The strategy was to leverage, wherever practical, the dimensions and performance of the hand-mate version to maximize the commonality between the hand-mate and blind-mate connectors. The goal for commonality is to enable suppliers to maintain tooling and part numbers for internal valve components and ease the cost and time span of the blind-mate product design cycle. In addition, a strategy is employed to create a minimum specification to ensure interchangeability while allowing the flexibility for suppliers to maintain their own differentiating IP.

Terms & Definitions

UQD	Universal Quick Disconnect
UQDB	Universal Quick Disconnect Blind-Mate
Plug	Often referred as the male side of the coupling
Socket	Often referred as the female side of the coupling
Cv	Flow coefficient defined as $Cv = Q \cdot \sqrt{(SG/\Delta P)}$, where Q is flow rate in gallons/min (GPM) and ΔP is pressure drop in lbs/in ² (psi) for water at 60 degrees F, and SG is the specific gravity of water and is assumed to be one.
Termination	Both plug and socket have terminations on the ends to connect a tube or pipe to the coupling
Fluid Loss	This is referring to the amount of fluid that can be external to the sealed fluid in the system upon disconnect. This amount of fluid will exist on the now exposed wetted surfaces of the connector. For dripless connectors this amount of fluid would adhere to the connector surfaces.

Key Performance Parameters

The following Key Performance Indicators (KPI's) are important parameters to ensure operable UQDB pairs when interchanged with various suppliers. Each of these performance parameters will be explicitly defined in the specification.

- Operating Pressure Rating
- Burst Pressure Rating
- Cv

UQDB Nomenclature

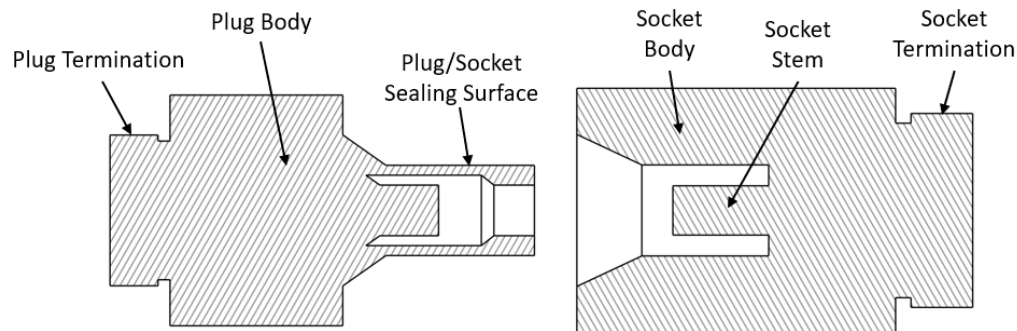


Figure 1 UQDB Naming Convention

Feature and Dimensional Specifications

For universal connectors, the interfacing elements are prescribed in the specification. Notice the areas where dimensions are not prescribed. These areas are left to the discretion of the manufacturers in order to allow for differentiation as well as incorporation of supplier IP.

Dimensional Specification

Figure 2 below shows the prescribed dimensional specification for the UQD and UQDB socket. Notice the additional definition on the UQDB socket body. The outer diameter W and length V must be known by the IT equipment manufacturer in order to design the interfaces for the blind mate within a cabinet and IT equipment. Also note the difference in the termination style selected as the default termination. The UQD hand-mate version is assumed to be on the end of a reinforced flexible tubing while the blind-mate version is assumed to hard mount to an ISO port.

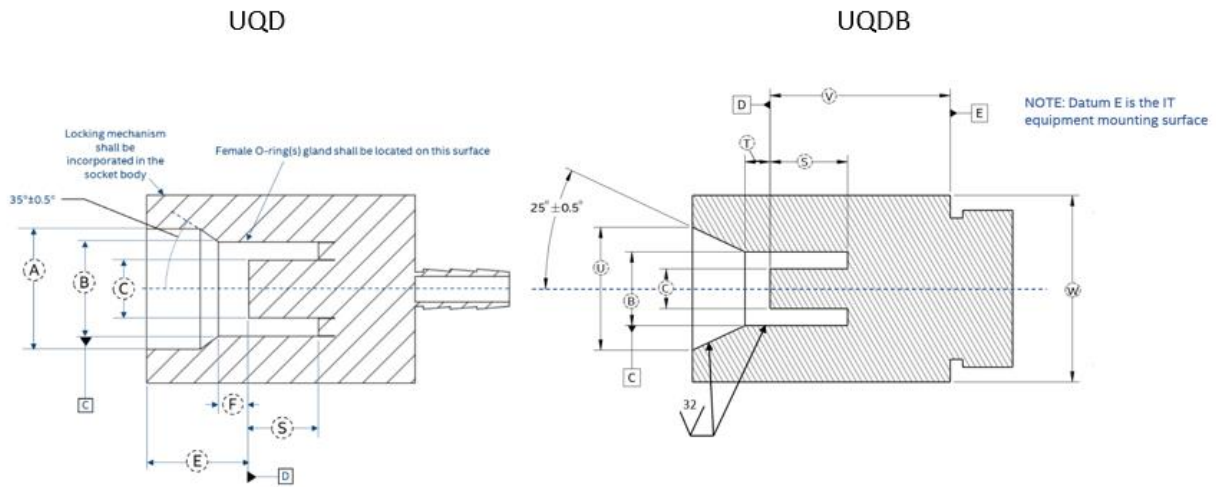


Figure 2 UQD (Hand-Mate) versus UQDB (Blind-Mate) Socket Definition

Figure 3 shows both the UQD and UQDB plug. Like the socket the plug definition now includes the Dimension X and Dimension W as well as Datum E which defines geometry necessary for Cabinet and IT equipment designers to ensure design meets the fit and function of the blind mate connector. Dimensions G, J, N, P, Q, R are removed for the UQDB (Sprenger, 2020), however, all other dimensions having the same letter are equal in nominal dimension and tolerance. This includes Dimensions H, K, L, M. The removed dimensions include the latching area of the UQD. Dimension Y was added to the UQDB as a keep out dimension which would allow a UQD plug to be inserted into a UQDB socket. UQDB also added dimension SA which stands for self-alignment. The UQDB plug has a radial allowance for self-aligning up to $\pm 1.0\text{mm}$.

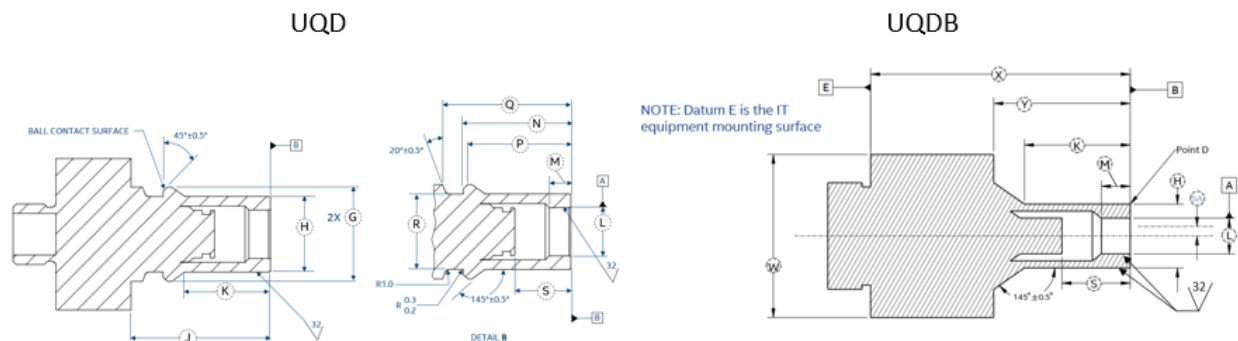


Figure 3 UQD (Hand-Mate) versus UQDB (Blind-Mate) Plug Definition

Physical features of the plug and socket shall conform by specification to the above prescribed dimensions. Where no definition is given it is left to the discretion of the supplier. The Intel design verification test plan includes an interchangeability test where each plug and socket are interchanged with all participating suppliers to ensure dimensional fit.

Panel to Panel Distance Definition

For the UQDB the additional dimensional definition and datums are necessary to define the closed and locked position within the Rack and IT equipment.

Datum E on the socket is the mating surface to the chassis datum and controls the location of the mounting surface relative to Datum D. On the plug, Datum E is the mating surface to the IT equipment and controls the location of the mounting surface relative to Datum B. Datum D and Datum B are the flush-mount surfaces on the socket and plug respectively. This allows IT equipment to be designed to accept a UQDB by using the following equation to calculate the nominal fully engaged distance between mating surfaces: $X(\text{Plug}) + V(\text{socket}) - S = \text{nominal distance}$.

From this we get the panel-to-panel requirements as shown in Figure 4 below. This sets the distance between the panel datums when the IT equipment is inserted and latched is in the locked position.

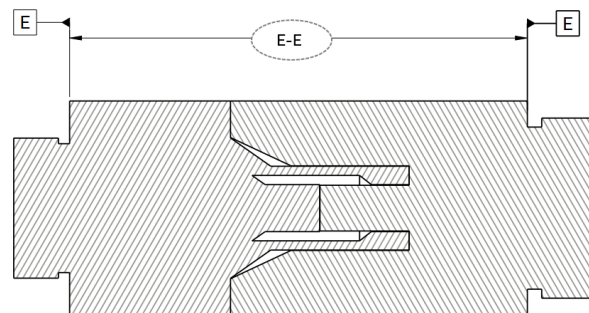


Figure 4 Panel to Panel Design Requirements

Because of tolerances, we have included a requirement to allow for a range in plug and socket engagement. For the engagements defined in Table 1 Table 1 UQDB Minimum Engagement Defined the plug and socket pairs shall meet Cv and Flow rating and performance requirements.

Table 1 UQDB Minimum Engagement Defined

Size	Nominal Engagement Stroke	Min Engagement*
UQD02	7.1	6.1
UQD04	10.4	9.4
UQD06	13.2	11.7
UQD08	16.0	14.5

Plug and Socket Terminations

Termination options are left to the discretion of the manufacturer, however, the panel-to-panel distance should be accounted for in the design. At a minimum, a straight thread O-ring boss (ORB) termination on the socket and plug shall be available in the sizes described in the specification. For instance, the UQDB02 plug would have -04 O-ring boss per ISO 11926-3 and the UQDB02 socket would have an -06 O-ring boss per ISO 11926-3 to mate with ports defined by ISO 11926-1.

Outer Envelope Requirements

The UQDB specification explicitly defines the outer envelope keep in requirements whereas the UQD did not. Because this outer envelope is necessary for rack and IT designers the maximum envelope must be known. For the UQD hand-mate connector, direction is provided in the specification that the limiting case is the pitch between connectors is 1RU (1.75") and suppliers should minimize the envelope to allow for finger access.

Latching Requirements

The UQDB connector has no latching components associated with it. It is assumed the latching mechanism would be designed into the IT equipment. The person installing the equipment would have a mechanical feature set that would allow them to engage the connectors and overcome any connection forces to fully mate the IT equipment to the rack.

Coupling Forces

The UQDB specification defines coupling forces explicitly. The UQD specification recommends minimization of coupling forces and requires that suppliers publish the coupling force versus pressure. Because rack and IT equipment designers must understand the coupling force requirements, the UQDB specification explicitly

defines the maximum coupling force. As of the time of this writing this force is still to be determined from initial tests. A target of <12 lbf for UQDB04 was established as a starting point.

Performance Requirements

Shelf and Service Life

Shelf life and service life were not changed from the UQD specification. Currently a shelf life of 5 years and a service life of 10 years is specified. It is assumed that a period of service life would begin immediately after being put in use, ending the shelf life period regardless of the time the item spent on-the-shelf if less than 5 years.

Durability Requirements

Current durability requirements for both UQD and UQDB are 5000 make and break cycles. 5000 cycles was determined through a conservative use case analysis with a 2+ multiplier. Suppliers have questioned whether this is too stringent a test for these couplings. This requirement is currently under review.

Fluid Loss on Disconnect

No change between UQD and UQDB of the same nominal sizes. The fluid loss requirements are listed in Table 2. Ideally connectors would be non-dripping, or the surface tension is enough to hold the water on the wetted and exposed surfaces upon disconnect. For comparison a drop of water is approximately .05 mL (Schadow, 2017).

Table 2 Maximum Fluid Loss on Disconnect

Parameter	UQDB02	UQDB04	UQDB06	UQDB08	Priority
Maximum fluid loss per couple/decouple cycle at 0 psi	0.020 ml	0.025 ml	0.035 ml	0.070 ml	Required

Each supplier will verify their ability to meet the above specification. The specification is defined at 0psi.

Flow Rate, Pressure and Temperature Requirements

The requirements below that are not TBD are the same as for UQD hand-mate connectors. Cv is TBD as of this writing. Cv is a function of internal geometry and restrictions. In practice the UQDB will have a tolerance stack

in the amount of engagement between the coupled pair. This stack-up is controlled by the rack and IT equipment design tolerances with a 1mm span of travel requirement set by the UQDB specification. Because the Cv value may be higher in the fully engaged pair it is assumed the Minimum Cv would be defined at the minimum engagement. The design verification testing of Cv will be done at minimum engagement and this will help to finalize the table below.

Table 3 UQDB Pressure, Cv, Flow Rate and Temperature Requirements

Parameter	UQDB02	UQDB04	UQDB06	UQDB08	Priority
Maximum operating pressure	100 psi				Required
Minimum burst pressure	300 psi				Required
Minimum Cv ¹ at minimum engagement	0.25	0.80	1.55	1.40	Required
Flow Rating ²	At least 0.55 GPM	At least 1.7 GPM	At least 3.0 GPM	At Least 4.7 GPM	Recommended Manufacturer discretion (ratings shall be published by supplier)
Operating temperature range ³	17°C - 65°C				Required
Shipping temperature range ⁴	-40°C – 75°C				Required

¹ Cv are reported for water.

² Flow rating is for water.

³ Support for higher temperature range is desirable as an option as there are known solutions that may operate in the range 17°C - 75°C. It is expected that rating would be published by supplier. The operating temperature range of 65C as the upper bound is based on the maximum temperature, where we want potential polymers in the TCS loop to operate.

⁴ Shipping may include charged systems.

Marking Requirements

Identification requirements as Universal Quick Disconnect indicating universal interchangeability and size on both plug and socket is as follows. Ex. UQDB02 with either red for warm fluid or blue for cold fluid. Marking should be visible and readable.

Identification

Within digital or printed catalogs, suppliers shall identify products meeting these requirements as “Dimensional & performance requirements conform to OCP Universal Quick Disconnect Blind-Mate (UQDB) Specification Rev 1.0”

Wetted Materials

Supplier to ensure materials used in the construction of UQDB are compatible with end user cooling loop fluid.

Safety and Regulatory

In order for systems to comply with end-product Information Communication and Technology (ICT) equipment safety standards, liquid filled component (LFC) component manufacturers need to ensure parts are compliant with IEC 62386-1:2018 (or later) standard, clause G.15.

Design Verification Testing

The purpose of this testing is to verify the design meets the requirements of the specification with respect to fit, form and function of the interchanged UQDB's which includes the KPIs listed earlier in this paper, namely Operating Pressure, Burst Pressure, and Cv. To determine Operating Pressure and Cv, testing must determine the pressure drop from combining a socket and plug from different suppliers. The goal is to achieve a pressure drop curve by testing a variety of flow rates using standard test procedures as a guide (International Standards Org, 2017). In addition, testing provides fit and function testing between interchanged parts. Burst pressure will be verified using a hydraulic ram.

Cv Testing with Alignment/Engagement Capability

The Cv testing is conducted based on the flow test described in ISO 18869, with an additional tare test to account for the pressure drop through the test fixture and hoses. Previous UQD testing has shown that accurate

Cv values can be determined with three flow set points ($R^2 > 0.99$) instead of the six specified by the ISO 18869 standard. To verify this for UQDBs as well, testing will begin with six initial flow setpoints and check if three flow rates would produce the same data. Fewer flow rates per sample will result in more time for testing of more suppliers and more test samples, resulting in higher statistical reliability of reported Cv values.

To determine the exact test procedure, flow rate set points are first chosen based on the inner diameter of the UQDB under test with a maximum fluid speed of 1.5 m/s. The length of hose between the differential pressure sensor and the test sample is calculated for an appropriate entry length to achieve uniform flow. Once the test is set up, pressure drop and flow rate data is collected on the hoses and fixture with a straight-flow connector installed instead of a UQDB pair. This calibration, or tare, run is necessary to determine accurate Cv values in data post processing.

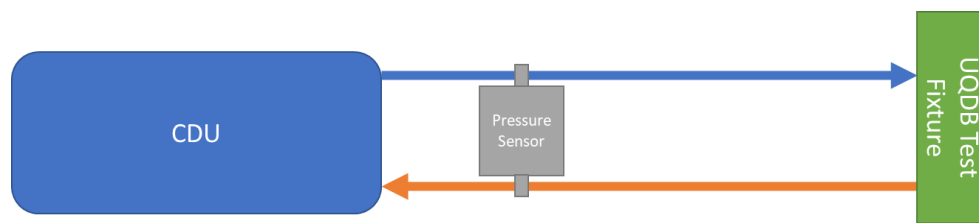


Figure 5 General CV Test Setup

The test fixture controls the engagement and alignment of the socket and plug during flow testing. Testing with misalignment and various engagements is unique to the blind-mate connector, due to the lack of a latching mechanism and the position of the plug and socket being controlled by the components they are attached to. It is expected to see some variance in the Cv values when alignment and engagement of the socket and plug are adjusted. The initial round of testing will consider all combinations of engagement, alignment, and flow direction resulting in eight unique sets of data per supplier plug and socket combination. A subset of all possible supplier plug and socket combinations will be tested for each condition as shown in Figure 6, and then the condition with the lowest Cv values will be determined from the data. The cells colored blue with checkmarks represent trials that will be run during testing with the plug from that row and the socket from that column.

The remainder of the testing will be done in the arrangement that produced the lowest Cv values, and each supplier combination will be tested to determine if the pair meets the requirements of the specification. In order to have statistical reliability, five unique plugs and sockets will be tested from each supplier. Each supplier's UQDB pairs will be numbered from one to five. All plugs and sockets of the same number from

different suppliers will be tested with each other. The majority of the testing will be focused on combinations of plugs and sockets from different suppliers rather than from the same supplier, as shown in Figure 7. As in Figure 6, the cells colored blue represent trials that will be run during testing.

	Socket Supplier						
Plug Supplier	A	B	C	D	E	F	G
A			✓		✓		✓
B	✓			✓		✓	
C		✓			✓		✓
D	✓		✓			✓	
E		✓		✓			✓
F	✓		✓		✓		
G		✓		✓		✓	

Figure 6 Reduced Initial Test Matrix with Seven Suppliers

	Socket Supplier						
Plug Supplier	A	B	C	D	E	F	G
A		✓	✓	✓	✓	✓	✓
B	✓		✓	✓	✓	✓	✓
C	✓	✓		✓	✓	✓	✓
D	✓	✓	✓		✓	✓	✓
E	✓	✓	✓	✓		✓	✓
F	✓	✓	✓	✓	✓		✓
G	✓	✓	✓	✓	✓	✓	

Figure 7 Full Test Matrix of Seven Suppliers without Same Supplier Combinations

Figure 8 below provides an overview of the fixture used during testing, with the key components called out. The port blocks have threaded ports which the plug, socket, and barbed adapters thread into. The alignment rod and radial block help maintain the orientation and positions of the port block by reducing the horizontal misalignment. The engagement block is sized to the nominal panel to panel distance of the plug and socket, which are each seated against the port blocks so that when the port blocks are flush against the engagement block the plug and socket will be held at their nominal panel to panel distance. The panel-to-panel distance is directly related to the engagement, so control of the panel-to-panel distance is used to determine the engagement. In order to produce the minimal engagement, a 1mm gauge block is added in series with the engagement block to increase the panel-to-panel distance.

The flow direction can be altered by switching the connections to the pump, while the connections to the fixture remain unchanged. The self-alignment requirement is tested by adding a 1mm gauge block underneath the plug side port block in order to raise the plug by 1mm, creating an offset between the plug and socket.

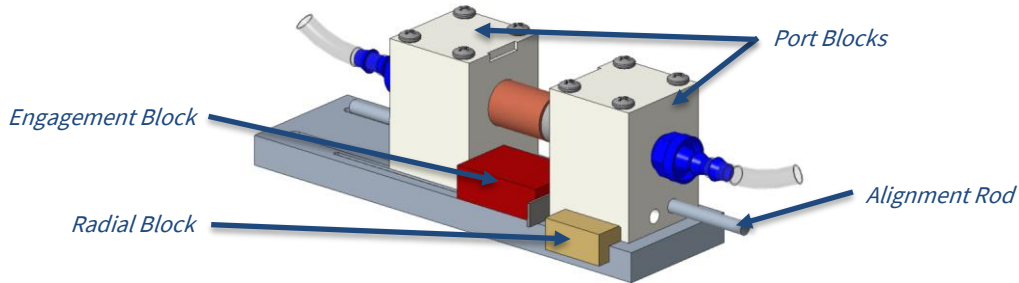


Figure 8 Test Fixture, Cv, Alignment Fixture

Post Process Method

Calculating performance of a given UQDB pair requires manipulating the definition of the flow rate coefficient, C_v . Assuming $SG \sim 1$ for water, Equation 1 and Equation 2 show how the equation can be arranged into a useful format. Note that Specific Gravity is defined by density of fluid over the density of water at 4 °C, so in Intel's lab the SG would be around 0.99823. Not only is this negligibly different than 1 but assuming $SG \sim 1$ results in slightly lower C_v values, so this is a conservative estimate. In the equations below Q is the fluid flow rate, SG is the specific gravity, and ΔP is the pressure drop.

$$C_v = Q \sqrt{\frac{SG}{\Delta P}}$$

Equation 1 Flow Rate Coefficient definition

$$Q = C_v \sqrt{\Delta P}$$

Equation 2 Cv Definition Rearranged to Calculate Cv Using Water

Once the raw flow and pressure data is collected, the pressure drop of the test system is subtracted from the raw data to determine the pressure drop over a UQDB pair (Figure 12). Once the pressure drop curve is determined for a given UQDB pair, it is straightforward to apply Equation 2 and solve for C_v as the slope of a linear fit to the data. An example of this is shown in Figure 10.

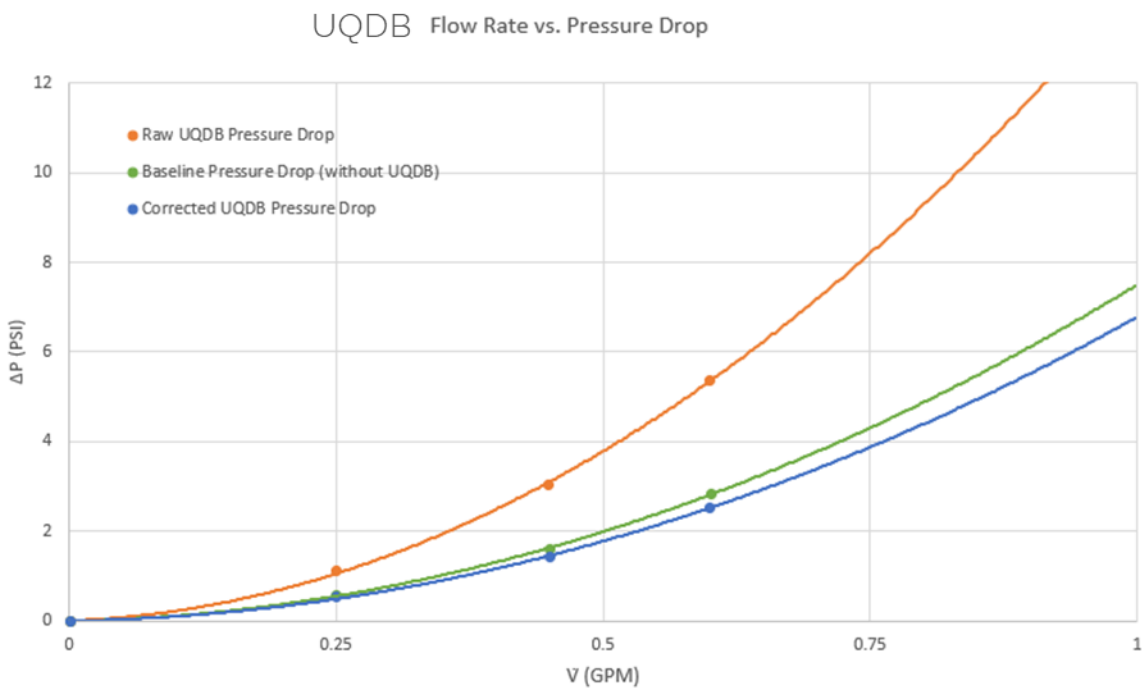
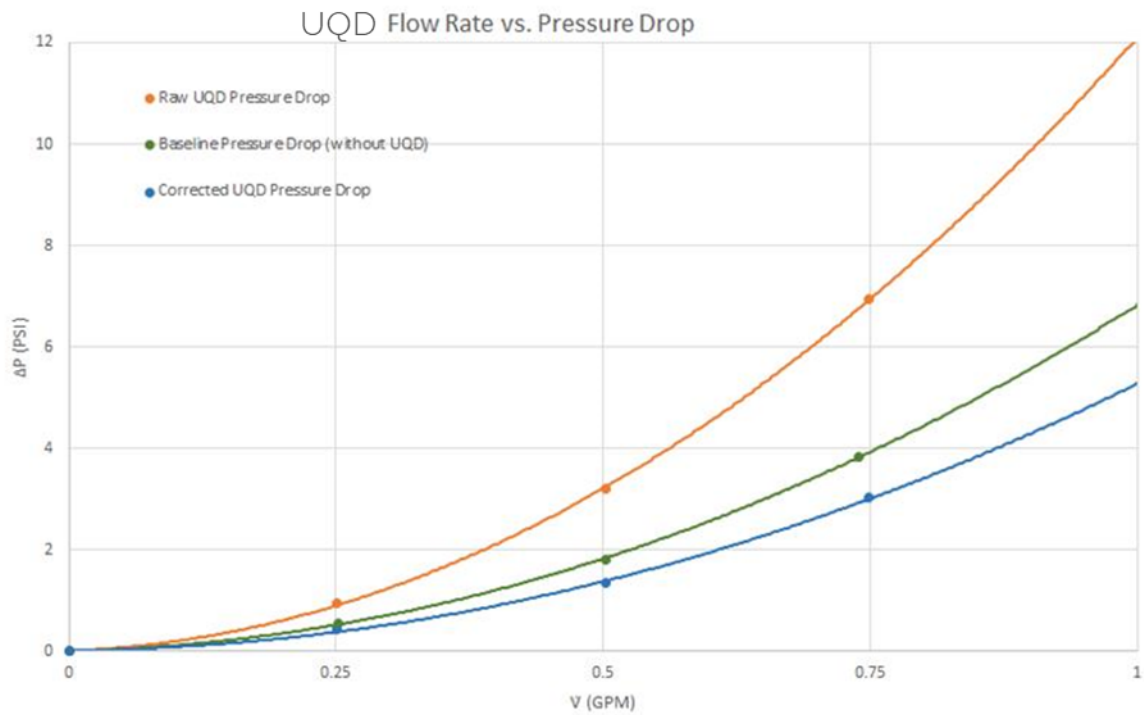


Figure 9 Pre-test Prediction Showing Effect of Subtracting Calibration Data, Comparison of UQD Hand Mate and UQDB

CV =
[0.37136629]
R_squared value =
0.9876543965995271

UQD Hand-Mate Example Cv = 0.37

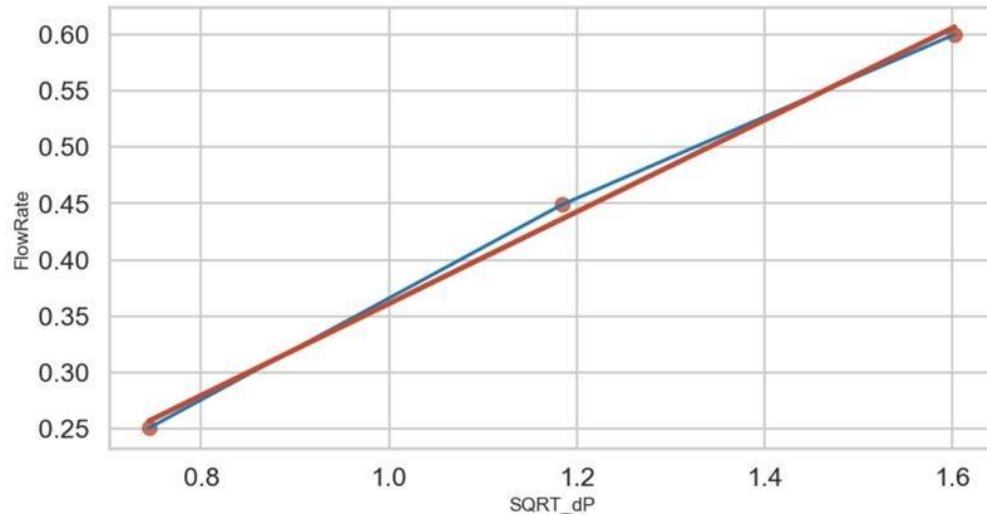


Figure 10 Example of Calculating Cv From Linear Fit

Pre-test Prediction

As mentioned above, it is expected that the pressure drop will be proportional to the square root of the pressure drop. The Cv value will be similar going from plug to socket or socket to plug, although slightly higher going from plug to socket. Since socket to plug was the limiting factor for hand mate UQDs, we believe this direction will be the worst case for meeting the requirements of the specification as shown below in Figure 11.

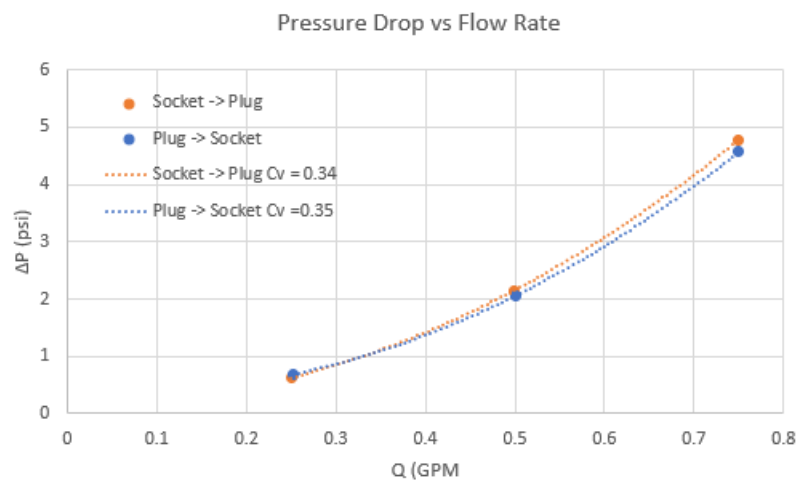


Figure 11 Pre-Test Prediction of Pressure Drop Versus Flow Direction

Example of Test Data

Figure 12 shows an example data set of pressure drop versus flow rates curves for 16 interchanged samples (4x4 plug and socket matrix). Figure 13 shows an example data set of a four-supplier interchange matrix. Row 1, column 1 would correspond to supplier A plug with supplier A socket. Row 1, column 2 would correspond to supplier A plug with supplier B socket.

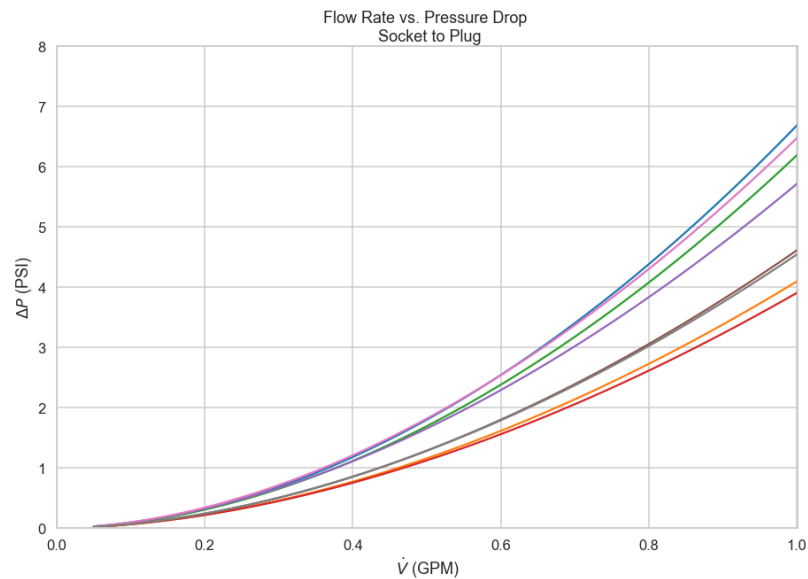


Figure 12 Pre-Test Example of Test Data Expected Pressure Drop Versus Flow

Plugs	Sockets			
	A	B	C	D
A	0.33	0.36	0.35	0.39
B	0.30	0.30	0.30	0.31
C	0.33	0.35	0.35	0.36
D	0.38	0.40	0.41	0.42

Figure 13 Example Interchanged Pair Cv Matrix four Suppliers

Visual Verification

The following verifications will be performed before testing and issues recorded along with the test results

- Verify that the UQD contains the required markings specified in UQDB Specification
 - Verify that the parts contain a visual identifier that corresponds to the associated size
 - Verify that minimum color options of red and blue are available
- Verify that the terminations of the part are in accordance with UQDB Specification

Fit Check

Cv testing will include a fit check of the pair combinations. Each supplier combination should couple smoothly and reach the nominal engagement specification.

Burst Test

The purpose of the burst test is to verify that combinations of supplier plugs and sockets will not rupture or leak at the specified burst pressure of 300 psi. During the test, supplier combinations will be pressurized using a hydraulic ram to 300 psi, and the pressure held for 30 seconds before being depressurized. The quick disconnects will be assessed for leaks before breaking and mating them to verify they still mate without added resistance.

Use of Data Collected

The purpose of collecting data on the pressure drop and burst pressure for combinations of suppliers is to verify that customers can rely on any combination of supplier plug and sockets to have the expected performance in accordance with the OCP Universal Quick Disconnect Blind-Mate (UQDB) Specification 1.0. This allows for customers to have larger flexibility in which supplier they purchase from and to have redundancy in their supply chain, a critically important feature for modern businesses. Additionally, by testing the plug and sockets to determine their Cv values and burst pressures, the results may highlight potential areas where the product could benefit from suppliers making modifications. If an outlier is found among the suppliers, the test data will be used to inform the supplier of their interchangeable performance. This provides suppliers with an option to redesign to improve the performance of their connector.

Further, as of this writing, there is not a clear understanding of a reasonable Cv value for blind mate connectors. UQDB testing will provide data to be used to determine a Cv specification for UQDB-02 and UQDB-04 connectors. Once Cv data for inter-supplier UQDB connections is on-hand, Intel will perform a sensitivity study to determine flow and pressure drop impacts of using UQDB pairs with low Cv values with UQDB pairs with high Cv values in a representative datacenter system. The data will then be reviewed with the suppliers before finalizing the performance specification.

Conclusion

Developing a Universal Quick Disconnect requires the input from industry experts in the areas of QD design (See acknowledgements below). Additionally, it requires an end-user centric focus to drive towards the needs of the

customer which is primarily focused on supply chain, reliability, scalability, ease of use and cost to name a few criteria. Development of the UQDB specification employs the following key strategies.

1. Maximize commonality with the OCP Universal Quick Disconnect (UQD) Specification 1.0 to maximize reuse of hand-mate design
2. Team with expert suppliers to provide early input to the dimensional and performance specification
3. Ensure partner suppliers are capable of covering global demand both in volume and proximity
4. Minimize prescribed requirements to maximize supplier differentiating IP
5. Minimize prescribed requirements to maximize innovation potential for UQD & UQDB supplier design

This strategy has prompted innovation within the consumer electronics liquid cooling industry with respect to Universal Quick Disconnects. The blind-mate (UQDB) is hoped to lead to similar innovative approaches within the industry.

Acknowledgments

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