Implementation Agreement for Thermal Interface Specification for Pluggable Optics Modules

IA # OIF-Thermal-01.0

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ABSTRACT:

This document provides a summary of information to be transferred between pluggable optical module suppliers and system thermal designers to facilitate integration of the modules into challenging thermal environments. The information applies specifically to modules that will utilize sliding heatsinks but much of it will apply to those that don't require heatsinks, in particular, the need to identify monitor point locations, plug power classes, operating temperature limits and module dissipation.

The concepts of a thermal interface area for the contact region between heatsinks and the module, power density class and a thermal interface resistance based on the temperature difference between the monitor point on the module surface and the average heatsink base temperature are introduced. A method for measuring the interface resistance between the module and a cold plate with an "ideal" i.e. extremely flat with small surface roughness, heatsink surface is outlined. The remaining surfaces of the module and the board on which the module is being tested are insulated to eliminate extraneous heat paths.

Factors affecting the thermal interface resistance are discussed and recommendations for limits for surface finish, flatness and spreading resistance are given.

In some cases, detailed thermal models of the modules are required by system designers and the thermal information requirements for such models are listed.

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4 Document Revision History

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OIF2015.017.00	Jan. 13, 2015	Initial Baseline Text following Straw Ballot #210
OIF2015.017.01	Jan. 20, 2015	Additional editor's reference updates and text proposals for Q115 TC PLUG session.
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5 Introduction

This implementation agreement (IA) defines the requirements of, and method of implementing and testing a thermal interface between a pluggable optical module and the host-system heatsink. It also specifies the information to be provided by module suppliers to facilitate thermal integration of the module within the host system.

Background for this project was defined in reference 1, OIF-PLUG-Thermal-01.0 Thermal Management at the Faceplate White Paper. In that document, various methods that could be employed by system designers to reduce the temperatures of modules in air-cooled systems were described. These methods included the direction of airflow over the modules, internal system baffling to direct airflow, placement of the modules and other heat dissipating devices on the blade, optimizing fin layout on the heatsink, and increasing the thermal conductivity of the heatsink. Also discussed, was the importance of thermal contact resistance between the module and the heatsink.

It was noted in the white paper that several interface parameters that are included in vendor specific or multi-source agreements (MSAs) affect this resistance and are not consistently defined or controlled. These include: surface roughness, surface flatness, normal force pushing the faces together, heat flux across the interface, and thermal spreading in the module interface surface. In addition to these parameters, the thermal conductivity of the module lid and heatsink materials and the surface hardness of both the module and heatsink affect performance of the thermal interface. Guidelines for the effects of changing these parameters within typical ranges are given here.

When heatsinks are mated with optical modules, the goal is to remove over 90% of the heat through the interface area to the fluid via the heatsink. Nominal ranges of heat flux are defined as Power Density classes. The agreement will define acceptable thermal impedances for the contact area for various pluggable module types and a method of measuring this impedance.

Specifications are given in terms of generic interfaces properties but will include specific examples. Types of modules now covered include, CFP, CFP2, CFP4, XFP, SFP, SFP+, QSFP, QSFP+, CDFP etc. Of primary concern are interfaces where the pluggable module slides through the faceplate and under a spring-loaded heatsink. This type of interface has limited contact force because the insertion and extraction force and force from the heatsink on the connectors are limited.

The specification is intended to apply to pluggable optical modules that require a heatsink to be adequately cooled with available air flow when inserted in a MSA design-compliant cage, connector and printed circuit board assembly.

Appendix B describes the typical thermal environment for pluggable optical modules. It shows that, in practice, the boundary between when a heatsink is required for a given design of module, and when it is not required, cannot be easily determined without performing an application-specific thermal analysis. This is because, in addition to the design of the module, it depends on factors such as: temperature of the local incoming air, airspeed and direction relative to the cage/module, device power dissipation, local board temperature, cage design, and the absolute and gauge pressures of the air within the system.

6 Thermal Parameters for Pluggable Optical Modules

6.1 Thermal Interface Power Density Classes

The first 6 thermal power density classes are defined, see table 1, to provide a basis for system designers to estimate the thermal losses from the module to the heatsink and compare thermal performance of various module designs. Power density classes for power densities above 0.6 W/cm^2 are defined similarly at 0.1 W/cm^2 increase per class. To define power density class, only the thermal interface area is considered and this is usually a subset of the upper surface. Table 2 gives the thermal interface and module top areas for various module form factors, references 2 through 8, 14, 16 and 17.

Power Density Class	pd01	pd02	pd03	pd04	pd05	pd06
Power Density [W/cm^2]	≤0.1	≤0.2	≤0.3	≤0.4	≤0.5	≤0.6

Table 1: Power Density Class Definitions

Form Factor	Top of Module Width [mm]	Top of Module Depth [mm]	Top of Module Area [cm^2]	Heat Sink Interface Width [mm]	Heat Sink Interface Depth [mm]	Heat Sink Interface Area [cm^2]
SFP+	13.55	47.5	6.44	9.55	34.5	3.29
CXP	21.2	28.45	6.03	21.2	16.0	3.39
QSFP+	18.35	52.4	9.62	12.5	30.0	3.75
XFP	18.35	69	12.66	13.8	48.9	6.62
CFP4	21.5	76	16.34	16.6	66.7	11.07
CFP2	41.5	91.5	37.97	37.8	71.0	26.84
CFP	75	130.25	97.69	73.6	96.4	70.95
CDFP Style 1	27.06	26.0	7.04	26.3	14.47	3.81
CDFP Style 2/3	27.06	42.81	11.58	25.5	25.91	6.61

Table 2: Thermal Interface and Module Top Dimensions

Current module Power Classes are given in Table 3. Power Density Classes are to be contrasted with the current MSA-defined Power Classes which are defined for each module type and of more direct relevance to system power supply designers, references 2 through 7 and 14. These are based on the power supplied to the module and generally correspond to different internal processing levels for the module and travel distances for the optical signal, e.g. Short Reach, Intermediate Reach, Long Reach, etc. Note that in the case of SFP+ modules, the power classes are referred to as power levels.

Form Factor	Power Class 1 [W]	Power Class 2 [W]	Power Class 3 [W]	Power Class 4 [W]	Power Class 5 [W]
SFP+	1.0	1.5	2.0		
QSFP+	1.5	2.0	2.5	3.5	
XFP	1.5	2.5	3.5	> 3.5	
CFP4	1.5	3.0	4.5	6.0	
CFP2	3.0	6.0	9.0	12.0	
CFP	8.0	16.0	24.0	32.0	
CDFP	3.0	4.0	5.0	6.0	> 6

Table 3: Pluggable Optical Module Power Classes

Table 4 gives the power density and power density class for modules dissipating the maximum power of their power class. When a module power density has an undefined upper limit, the corresponding power density class shall be defined as ≥pdxx where pdxx is the power density class of the last defined power class for the module form factor. Note that the small thermal interface area of the QSFP+ and CDFP result in a much higher power density classes than the similarly powered modules of similar overall size.

	Power Density [W/cm²] **and Power Density Class**									
Form Factor	Power Class 1		Power Class 2		Power Class 3		Power Class 4		Power Class 5	
	[W/cm²]		[W/cm²]		[W/cm²]		[W/cm²]		[W/cm²]	
SFP+	0.30	*pd03*	0.46	*pd05*	0.61	*pd07*				
QSFP+	0.40	*pd04*	0.53	*pd06*	0.67	*pd07*	0.93	*pd10*		
XFP	0.23	*pd03*	0.38	*pd04*	0.53	*pd06*	>0.53 *	*≥pd06*		
CFP4	0.14	*pd02*	0.27	*pd03*	0.41	*pd05*	0.54	*pd06*		
CFP2	0.11	*pd02*	0.22	*pd03*	0.34	*pd04*	0.45	*pd05*		
CFP	0.11	*pd02*	0.23	*pd03*	0.34	*pd04*	0.45	*pd05*		
CDFP Style 1	0.85	*pd09*	1.14	*pd12*	1.43	*pd15*	1.71	*pd18*	*>1.71*	*≥pd18*
CDFP Style 2/3	0.45	*pd05*	0.61	*pd07*	0.75	*pd08*	0.91	*pd10*	*>0.91*	*≥pd10*

Table 4: Power Density and Power Density Class at Maximum Power Class Module Dissipation

* Power Class 4 power density for XFPs and Power Class 5 for CDFPs have no upper limit defined, hence the power density class ≥pdxx applies.

Multiplying the power density by the thermal resistance, defined below, gives a reasonable estimate of the temperature drop between module and the heatsink base. This facilities calculation of the heatsink resistance required for modules at different locations on the circuit board without knowing all the internal details of the module.

6.2 Thermal Interface Area

For any thermal interface, the size and location of the heat transfer area must be defined. For example, figure 1 shows the size of the cage opening as defined in the MSA for QSFPs, references 7 and 8. The thermal interface area is a subset of this opening and can be at most 0.5 mm smaller in width, and 2 mm less in depth than the opening to allow the heatsink to easily fit into the opening, and incorporate a ramp feature to ease insertion of the module. Table 2 gives examples the shapes of thermal interface areas for various modules. Drawings showing details of the cage opening available for heatsink interface area are contained in the relevant MSA for the module. Where the MSA has no part of a cage or module guide rail covering any portion of the module's top surface, it can be assumed that the entire nominally-flat portion of the top surface is available for a heatsink excluding any portion lying outward of 1 mm inside the inside surface of the faceplate.

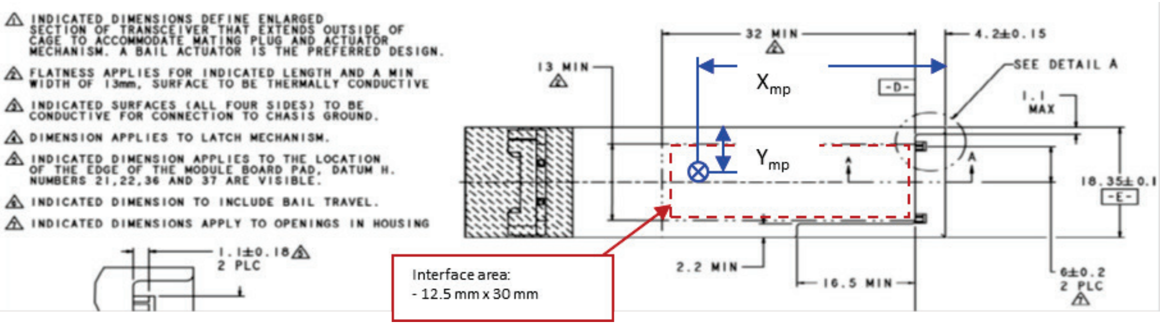

Figure 1: QSFP Thermal Interface Area Definition.

Any thermal interface area where a heatsink will contact should be kept free of labels or other impediments to heat transfer. It is strongly recommended that labels are applied to surfaces not required for heat transfer. If a label must be placed in this area, it must be of a design that will not be removed or damaged by sliding contact with the heatsink and through design shall minimize any increase in the thermal interface resistance. Additionally, if a label must be applied to the heatsink contact surface area, this label must be in place for any measurement of the thermal interface resistance.

6.3 Thermal Monitor Point Definition

Module suppliers must provide the co-ordinates, X_{mp}, Y_{mp} of a point in an accessible location on the exterior surface of the module where case temperature is to be monitored; this location is defined as the Monitor Point and is depicted in figure 1. It is expected that the Monitor Point will be on the top surface of the module within or near the heat sink interface area. Modifications to the pcb on which the module and cage are mounted, or warranty-voiding modifications to the module must not be required to permit instrumentation at the monitor point. It is not required that the monitor point is located at the hottest point on the surface which is often referred to as the "hot spot".

Module manufacturers must also provide the maximum monitor-point temperature compatible with long-term operation of the module, and the maximum monitor-point temperature for short term operation without appreciable loss in performance, permanent damage to the module or significant impact on long-term reliability.

The monitor point location is required so that system designers can measure the case temperature to verify the performance of the heat sink design under all operating conditions and also so that module designers can monitor the location while measuring the thermal resistance of the module and calibrating internal temperature sensors. Module designers may alternatively monitor the temperature on the inside of the case at the same in-plane coordinates as the exterior monitor point if it gives substantively the same temperature as an exterior probe.

Calibration of the internal sensor shall provide a temperature output within ± 3°C of the monitor point temperature with the module operating at maximum power with heat removed through the interface area by the cold plate method of section 9 or an equivalent method. Cold plate temperature is controlled to vary the case monitor point temperature over the full operating range for the calibration.

6.4 Definition of Interface Thermal Resistance

For any module to heatsink thermal interface, a thermal resistance can be defined as the temperature difference between the Monitor Point on the module surface and the average temperature of a mating heatsink surface that is located centrally on the module interface area, divided by the heat flux across the interface. The area used to define the heat flux will be that of the heatsink contact surface. As discussed in section 7.2, this area will be smaller than the module interface area which is limited by the area of the top surface of the module, or by the size of the opening in the cage as defined in the MSA for the module. For purposes of this specification, the magnitude of the heat flow will be assumed to be equal to the total power dissipated by the module. Consequently, it is required that the resistance will be measured with other heat paths to ambient insulated so that > 95% of the heat is removed across the interface between the module and the heat sink. A procedure for measuring the interface resistance is given in the section 9.

The thermal resistance obtained by this method includes the cumulative effects of surface flatness, surface roughness, spreading resistance, surface materials, and normal force applied by the heatsink on the module.

6.5 Thermal Interface Resistance Classes

For any thermal interface, a thermal resistance can be defined as a function of heat flux and the temperature difference between the Monitor Point on the module surface, and the average temperature of the base of the heatsink. This thermal resistance is given units of °C-cm^2/W. To be acceptable for a high power density module, the overall temperature rise from Monitor Point to the heatsink needs to be less than ≤~15% of the difference between the incoming air temperature and the maximum monitor point temperature. This thermal interface resistance includes all contributing factors, e.g. contact resistance, out-of flatness effects, and heat spreading, etc. to interface resistance resulting from the module and system designs. Standard -Ambient resistance is based on 40°C ambient air typical of networking equipment designed to ETSI or ASHRAE standards, references 10, 11 and 12, and a maximum monitor point temperature of 70°C. The High-Temperature Ambient resistance derives from a 70°C monitor point maximum, and 55°C ambient air for shelf level products as defined by Telcordia NEBS requirements, reference 13.

Power Density Class	**Power Density** [W/cm²]	**Standard-Ambient Resistance** [°C-cm²/W]	**High-Temperature-Ambient Resistance** [°C-cm²/W]
		4 °C total dT	**2 °C total dT**
pd01	≤ 0.1	40	20
pd02	≤ 0.2	20	10
pd03	≤ 0.3	13	6.7
pd04	≤ 0.4	10	5.0
pd05	≤ 0.5	8.0	4.0
pd06	≤ 0.6	6.7	3.3
pd07	≤ 0.7	5.7	2.9
pd08	≤ 0.8	5.0	2.5
pd09	≤ 0.9	4.4	2.2
pd10	≤ 1.0	4.0	2.0

Table 5: Thermal Interface Resistance Classes

Using the standard ambient temperature as an example, the allowable temperature rise across the thermal interface is calculated as 15% of the available temperature difference with truncating , e.g. 0.15 x (70 – 40) = 4.5 which is truncated to 4. Using this with a power density of 0.5 gives a resistance of 4/0.5 = 8.0 C-cm^2/W.

6.6 Normal Forces for Heatsinks

As discussed in Appendix C section 1, the normal force can affect the thermal resistance of the interface. The normal force acting between the module and heatsink during the measurement of thermal interface resistance should therefore be reported. This normal force must be compatible with long term operation of the module, and with other force restrictions such as insertion force.

6.7 Information Relevant to Using Thermal Interface Materials

Appendix C section 2 discusses the use of thermal interface materials with pluggable optical modules. Results reported for this specification are obtained without using these materials, however, interface parameters relevant to the performance of an interface that uses such materials are reported. These include the normal force, surface roughness and the flatness of the interface area.

6.8 Multiple Thermal Interface Areas on a Module.

This specification does not preclude the use of multiple thermal interface areas on a module. Data must be supplied for each interface area and performance measurements are done separately for each interface area as though it is the only one available for use.

6.9 Thermal Modelling Information

The complex thermal environment of pluggable optical modules described in Appendix B and reference 1 often leads to a requirement for detailed thermal models to be used at some locations in the thermal model of the host blade/system. The required information for this includes:

- Geometry of the case and lid. This can be simplified, but needs details of any surface that has heat dissipating or temperature critical components connected.
- Material(s) of the case and lid or the thermal conductivity of the material(s).
- Location and size (contact area on the surface) of any components connected to the case/lid.
- PCB component location, size, and heat dissipation. PCB thermal conductivity in- and through-plane.
- Heat dissipation of all components at nominal voltage at the long term and short-term maximum case temperatures.
- Thermal conductivity and thickness of interface materials used to thermally connect components to the lid. If no interface material is used, the details of the interface between the component and case are required, i.e. attachment points, contact force (e.g. per screw or screw torque), flatness and surface finish in the contact area so that thermal resistance may be estimated.

This information can be transferred from the supplier’s thermal model if commercial thermal analysis software was used, or via detailed CAD models and additional information that specifies the thermal parameters of the design as listed above.

6.10 Other Thermal Related Information

The power dissipated under various conditions is required to evaluate thermal model performance against measured system data. This information is normally required as part of the electrical specifications, but is included here for completeness.

- Standby power level if applicable.
- Beginning of Life (BOL) power dissipation at minimum operating temperature,
- End of Life (EOL) power dissipation at maximum long-term monitor point temperature,
- EOL power dissipation at maximum short-term monitor point temperature.

6.11 Data Sheet Information for Pluggable Optical Modules

The following table summarizes the thermally relevant information to be provided for each module design.

	Reportable Item	**Description**
a	Power Density Class	pdnn where nn is as defined in section 7.1 and based on the EOL power.
b	Thermal Interface Area [cm^2]	Figure showing the area size and location on the module or a reference to the relevant MSA or other accessible document with the information.
c	Thermal Monitor Point	Figure showing the location of the thermal Monitor Point. May be combined with item b.
d	Thermal Interface Resistance [°C-cm^2/W]	Average and range of test results for the module
e	T_{mp} Max Long-Term [°C]	Maximum Long-Term operating temperature[1] at the monitor point
f	T_{mp} Max Short-Term [°C]	Maximum Short-Term[2] operating temperature at the monitor point
g	T_{mp} Min [°C]	Minimum operating temperature at the monitor point
h	Pmax BOL [W]	Design maximum power dissipation at BOL at Tmp Max Long-Term
i	Pmax EOL [W]	Design maximum power dissipation at EOL at Tmp Max Short-Term
j	Pmin BOL [W]	Minimum power dissipation at BOL at T_{mp} Min
k	$dT_{\text{module interface}}$ [°C]	The maximum difference between any two temperatures measured at the monitor point and in the interface area of the module surface. Per section 9.1.3
l	Surface Roughness [µm]	Surface roughness measured in the interface area, Ra_x, and Ra_y
m	Surface Flatness [mm]	Flatness of the thermal interface area

Table 6: Data Required on Pluggable Optical Module Data Sheet

1) By operating temperature it is implied that the module operates within normal electrical and optical specifications.
2) Short-term is as defined in Section 4.1 of reference 13. The equipment is expected to operate within specification but may incur a reliability penalty.

7 Bounds for Design Factors Affecting Thermal Interface Resistance Between Pluggable Modules and Their Heatsink

7.1 Surface Flatness

An interface of nominally-flat or highly-compression-loaded surfaces will have solid material contact generally spread across the entire interface area. For interfaces between modules and heat sinks, the applied forces are not large enough to significantly alter the shape of mating pieces so that there is not general contact over the surface. When a surface isn't flat, there are larger areas where no contact occurs and air gaps form significant resistance to heat flow across the gap so heat will flow through the hot surface to an area where surface asperity contact occurs to be conducted to the cold surface. Simplified analyses of a CFP2 module have shown that above a certain net flatness, the temperature difference across the lid of the module does not change, while below that the lid spreading loss is reduced due to improving conduction from the lid to the heatsink through the smaller air gaps. This occurs at a net flatness of approximately 0.002 cm/cm corresponding to ~0.15 mm net flatness based on the length of the interface area between lid of a CFP2 and its mating heatsink.

This suggests an upper bound on surface flatness of 0.001 cm/cm for both the module and heatsink.

7.2 Surface Finish

The much smaller scale asperities that are part of an imperfect surface finish will create a mesh of voids and contact points across that surface which results in a resistance to heat flow due to the effective mechanical and thermal properties of the materials comprising the interface. As discussed in references 1, 9 and 15, reducing the roughness of the contact surfaces has been shown to reduce the thermal resistance of an interface. Test data for CXPs dissipating 4.5 W was presented showing that surface roughness >0.8 µm Ra had increased resistance giving ~1°C more temperature rise compared to CXPs with surface roughness <0.6 µm Ra.

Surface roughness of less than 0.8 µm Ra on the interface surface is readily achievable in all directions by casting, forging and machining so a manufacturing method that gives this surface roughness or better is required for both surfaces.

7.3 Spreading Resistance

The spreading component of the resistance is due to conduction in the lid of the module and is mainly controlled at the module design stage. Spreading resistance is reduced by increasing the thickness of the module lid (case), increasing the thermal conductivity of the lid material and by layout of the heat dissipating devices within the module. It will be less significant in smaller modules where lid thickness is similar but distances are smaller and in modules where the monitor point is closer to the centre of the thermal interface area.

Analysis presented in reference 1, showed that for high powered (5 W) QSFP's ~1.5 to 2°C of the temperature drop between the module monitor point (at the hot spot) and the base of the heatsink was attributable to spreading in the lid of the module. In these modules, the major heat dissipating devices are located outside of the heat sink interface area. This is very significant for high temperature ambient systems where the overall interface temperature drop is desired to be ≤2°C.

Design should limit the in-module spreading component of thermal resistance to <50% of the total thermal interface resistance.

7.4 Normal Force of Contact Between Module and Heat Sink Surfaces.

Resistance of contact areas decreases as the normal force is increased. This works by deforming the surface asperities to increase the solid contact area and reducing the overall height of the air gaps. Gains in thermal performance over the force range compatible with sliding contact heatsinks are small since the contact pressure is low relative to the material surface hardness.

Increasing the force also offers the potential to make some gains by reducing the net flatness between the module and heatsink, or by reducing air gaps if a very compliant interface material is used. The maximum contact force normal to the thermal interface area may be explicitly defined in the MSA or otherwise restricted by insertion force or contact with the pcb.

8 Thermal Interface Performance Verification for Modules

8.1 Cold Plate Method

This test method is intended to verify that the design of the optical module meets the requirements of this IA. The intent of the design is to remove all heat dissipated in the module through the thermal interface between the module case, and the module interface piece. The basic layout of components is shown in figure 2.

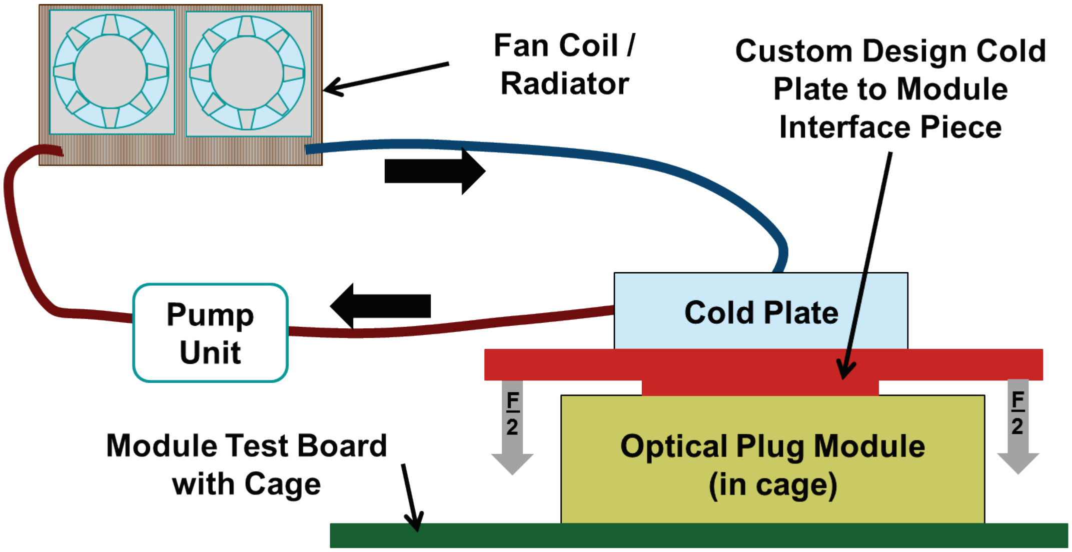

Figure 2: Cold Plate Test Fixture Components.

8.1.1 Instrumentation and Layout on Module and Cold Plate

Thermocouples, Resistance Temperature Detectors (RTDs) or other thermal instrumentation used for internal sensor calibration is located on, or within the module near the interface surface, within 2 mm of the defined Monitor Point(s) within 2 mm of the corners and centre of the interface area and at other locations such that the maximum spacing along any grid axis does not exceed the larger of 15 mm or 1/3 of the length or width of the interface area. Note that the Monitor Point may lie outside of the thermal interface area. Instrumentation may be attached to the inner surface of the module, or contact the outer surface through holes in the interface piece.

A thermal sensor is also required on the board top surface 5 mm from the back of the cage along the centerline of the module. This sensor is used to verify that the board is not significantly different in temperature from the interface surface and that the board has reached an equilibrium temperature during test.

A design for an interface piece and pump/cold-plate unit for a CFP2 is shown in figure 3. Note the instrument locations and slots for connecting wires.

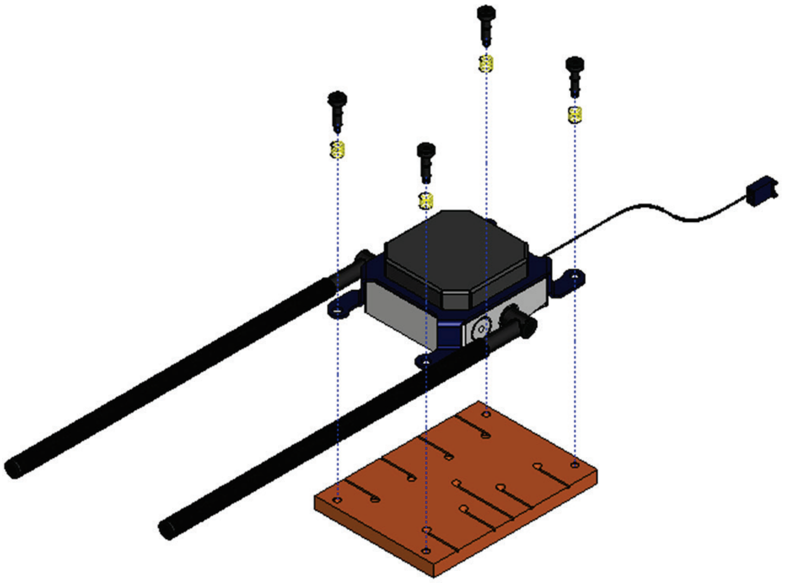

Figure 3: Exploded View of Pump Cold-Plate Unit and Interface Piece for CFP2

8.1.2 Test Method

a) Instrumentation temperature offset measurements are made at the maximum module monitor point temperature for the cold plate board and module instrumentation.
b) Offsets are calculated relative to the average of all readings.
c) Install module on a test board with board connector and cage.
d) Bring cold plate interface assembly into contact with the module and apply the maximum allowable normal force consistent with plug insertion.
e) Insulate the assembly comprising the test board, module and interface piece. Insulation should extend to the top of the interface piece and have resistance equivalent to a minimum 2 cm of still air except over the top of the module. Instrumentation, power leads and plumbing extending outside the insulation need not be insulated. Avoid any forced air cooling of the assembly.
f) Turn on the cold plate cooling and control temperature so that the module monitor point temperature is at the module design maximum when the module is operating at its maximum power dissipation.
g) Maintain temperature so that steady-state is reached.
h) Record all temperatures at steady state.

8.1.3 Thermal Interface Test Results Reporting

The test report must contain the following results:

a) The maximum allowable long-term steady-state operating temperature at, and the location of, the monitor point;
b) The steady-state power dissipation of the module with the monitor point at the maximum operating temperature reported in 9.3.1 a);
c) The nominal heat flux across the interface, i.e. power dissipation from 9.1.3 b) divided by the heatsink interface area;
d) The maximum difference between any two temperatures measured on the surface of the module. If the monitor point lies outside of the interface area it is to be included.;
e) The difference between the monitor point temperature and the average temperature of the cold plate interface surface;
f) The thermal resistance of the interface in °C-cm^2/W, i.e. the temperature difference measured in 9.1.3 e) divided by the nominal heat flux from 9.1.3 c); and
g) The thermal resistance class determined from the measurement.

The temperature difference across the interface piece is also reported for the cold plate interface piece assembly.

8.1.4 Thermal Resistance Measurement Interface Piece Details

The interface piece contact area is to be congruent with the maximum heatsink interface area for the type of module being tested. Design of the cold plate must ensure that the temperature variation across the surface is less than 0.25°C. Figure 4 shows the locations of temperature probes located within the interface piece to measure the cold plate temperature and the location of a hole through the cold plate for measuring the temperature of the module surface at the monitor point location. The interface piece temperature sensing elements are located within the interface piece 0.75 mm from the interface surface. Note that the figure is representative of an XFP and that the monitor point location is module supplier specific.

The cold plate contact surface is finished to provide an “ideal” heat-sink surface so that module performance is evaluated for a “best possible” metal-to-metal system interface. The contact surface (shown in pale blue in figure 4) requirements are:

- Flatness:	1.4 µm
- Surface Roughness:	0.1 µm Ra in any direction

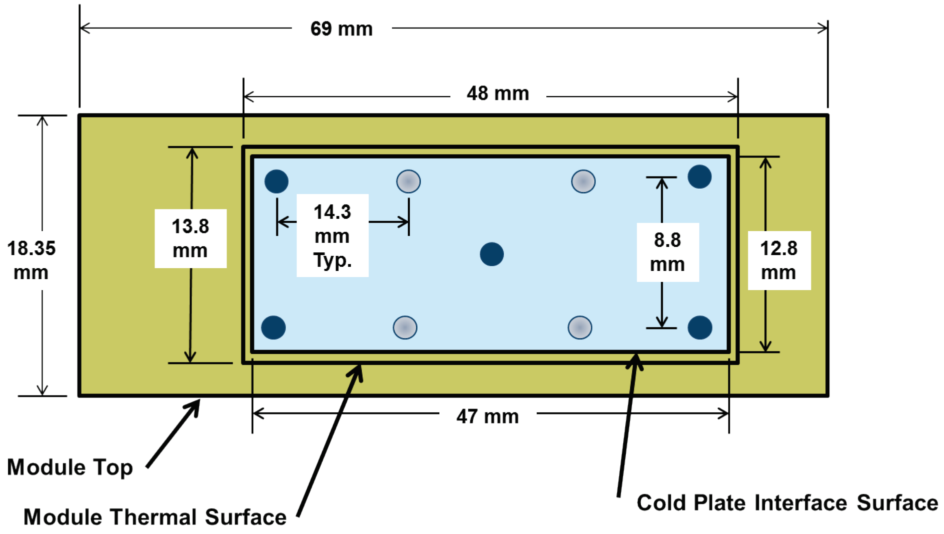

Figure 4: XFP Interface Piece Internal and Monitor Point Probe Locations.

8.1.5 Pluggable Module Interface Area Details

Module surface or interior thermocouples (or other temperature probes) are to be located within 2 mm of the planform location of the interface piece temperature probes shown in figure 4. The probes may contact either the outside of the module or the inside surface of the module lid in the heatsink area of the module. The load can be applied by either, supporting the insulated test board in a horizontal position and adding weight to the upper surface of the cold plate (weight must be centred on the cold plate) or applied using springs compressed (or stretched) to provide the normal contact force.

8.2 Data Included on Module Data Sheet

The following test data is to be included on the module data sheet:
a) The maximum temperature difference across the interface area,
b) The thermal resistance of the interface piece-to-module interface.

This data must be the average of at least 5 modules from production, and be verified when significant design changes are made. In particular, this will include change in material, surface specification or production method of the module case, thermal interface materials, or internal dissipating components.

8.3 Module Internal Temperature Sensor Calibration

Pluggable optical modules may include an internal temperature sensor (or sensors) that can be monitored and used for alarms and warnings. The sensor is generally intended to report the module case temperature within a given error. These sensors shall be calibrated in a fixture similar to that used for measuring the thermal interface resistance in that all or almost all of the heat flow is outward across the thermal interface area.

Ideally, the sensor will be located near the monitor point and have its lowest thermal resistance to the monitor point to best capture that temperature. However, mounting the sensor close to the monitor point inside the module may not be possible. In that case, the thermal connection to the module case will likely have a larger resistance and the temperature at the sensor will be more strongly influenced by the direction and quantity of the heat flow from the dissipating components to (and from) the outside of the module case.

Refer to appendix B for applicable heat flow directions and consider a sensor connected to the module surfaces and PCB by a resistance network. In all cases, the temperature difference between the sensor location and a monitor point on the top surface of the module increases as the amount of heat removed through the thermal interface increases. Therefore, a module sensor calibrated with a significant proportion of the heat removed from other surfaces will increasingly overestimate the monitor point temperature as the amount of heat removed through the thermal interface increases. In essence, the better the heatsink performs, the more the error between the internal sensor and the case temperature.

9 Summary

This document outlines requirements for the thermal interface between pluggable optics modules and the host systems that use such modules. Systems that utilize spring-loaded heatsinks that slide into place over the module as it is inserted are the main focus. The document also defines basic terms such as thermal resistance, thermal interface resistance, interface area and power density.

Requirements include physical and performance information about the pluggable module. Required information from vendors to be used by system designers for initial assessments, basic design calculations, and for detailed modelling of pluggable modules in complex thermal environment is defined. In addition, monitor point location and temperature limits allow system designers to verify the adequacy of their thermal design. Sections on the physical contact area between the pluggable module and the heatsink list and describe and suggest which module design factors can be manipulated to reduce the thermal resistance between the module and the heatsink. A test designed to measure the overall resistance between the module and an ideal heatsink is proposed, and a method provided so that a best-case thermal resistance between a pluggable module and a heatsink can be measured and provided by vendors.

Thermal interface resistance objectives for different power densities and system environments are given.

10 Reference Documents

10.1 Normative references

[2] INF-8077i 10 Gigabit Small Form Factor Pluggable Module XFP MSA R4.5, August 2005

[3] INF-8074i Specification for SFP (Small Formfactor Pluggable) Transceiver, Rev. 1.0, May 2001

[4] Traverso, M. Editor, CFP MSA Hardware Specification, Revision 1.4, June 2010, www.cfp-msa.org

[5] Hiramoto, K. Hardware Technical Editor, CFP MSA CFP2 Hardware Specification, Revision 1.0, July 2013, www.cfp-msa.org

[6] Oomori, H. Hardware Technical Editor, C FP MSA CFP4 Hardware Specification, Revision 1.0, August, 2014, www.cfp-msa.org

[7] SFF Committee, SFF-8663 Specification for QSFP+ 28 Gb/s Cage (Style A), Rev 1.5 April 2014, ftp://ftp.seagate.com/sff

[8] SFF Committee, SFF-8661 Specification for QSFP+ 28 Gb/s 4x Pluggable Module, Revision 2.0, February 2014, ftp://ftp.seagate.com/sff

[10] ETSI European Telecommunication Standard ETS 300 019-2-3, May 1994

[13] Telcordia NEBS™ Requirements: Physical Protection, Telcordia Technologies Generic Requirements, GR-63-CORE Issue 3, March 2006

[14] Palkert, T. Technical Editor, CDFP MSA for 400 Gb/s (16x 25 Gb/s) Pluggable Transceiver Rev 2.0 September 18, 2014. http://cdfp-msa.org/CDFPrev2-0published-Sept18.pdf

[16] http://cfp-msa.org/Documents/CFP2-BASELINE-REV-1L-20130806.pdf

[17] http://cfp-msa.org/Documents/CFP4-BASELINE-DRAWING-REV-R.pdf

10.2 Informative references

[1] OIF-PLUG-Thermal-01.0 Thermal Management at the Faceplate White Paper, March 2012

[9] Yovanovitch, M.M: Four Decades of Research on thermal Contact, Gap, and Joint Resistance in Microelectronics, IEEE Transactions on Components and Packaging Technologies, Vol. 28, No. 2, June 2005[11] ASHRAE TC9.9 Data Center Networking Equipment – Issues and Best Practices, Whitepaper prepared by ASHRAE Technical Committee (TC) 9.9

[12] Steinbrecher, R.A. and Schmidt, R., Data Center Environments ASHRAE's Evolving Thermal Guidelines, ASHRAE Journal, ashrae.org December 2011

[15] Yovanovitch, M.M., Culham, J.R., and Teerstra, P., Calculating Interface Resistance, Electronics Cooling, May 1997, http://www.electronics-cooling.com/Resources/EC_Articles/May97/article3.htm

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11 Appendix A: Glossary

BOL – Beginning of Life

CAD – Computer Aided Design

EMC- ElectroMagnetic Control

EOL – End of Life

MSA – multi-source agreement

net flatness – the maximum gap between 2 mating surfaces. For example, with identical surfaces, this equals twice the flatness of either part while for two surfaces where one is convex of radius R and one is concave of radius R, the net flatness would be zero.

pcb – printed circuit board

surface asperity – surface unevenness, the holes and bumps that make up the surface of a material. The detailed geometry of the asperities and hardness of the materials in contact are important factors influencing deformation of surfaces that are pressed together.

surface finish – is defined by surface roughness, waviness, and by the lay of surface features. Surface finish is highly dependent on the fabrication method.

surface roughness – is the measure of the height deviations normal to the shape of the surface being measured. Average height =, Ra, and root mean square – Rms height are common measures obtained from linear traces. Sa roughness values are obtained in all directions over a surface. Roughness is usually measured in micrometers or microinches.

12 Appendix B: The Thermal Environment for Pluggable Optical Modules

The typical thermal environment for a pluggable optical module is shown in figures B.1 and B.2.

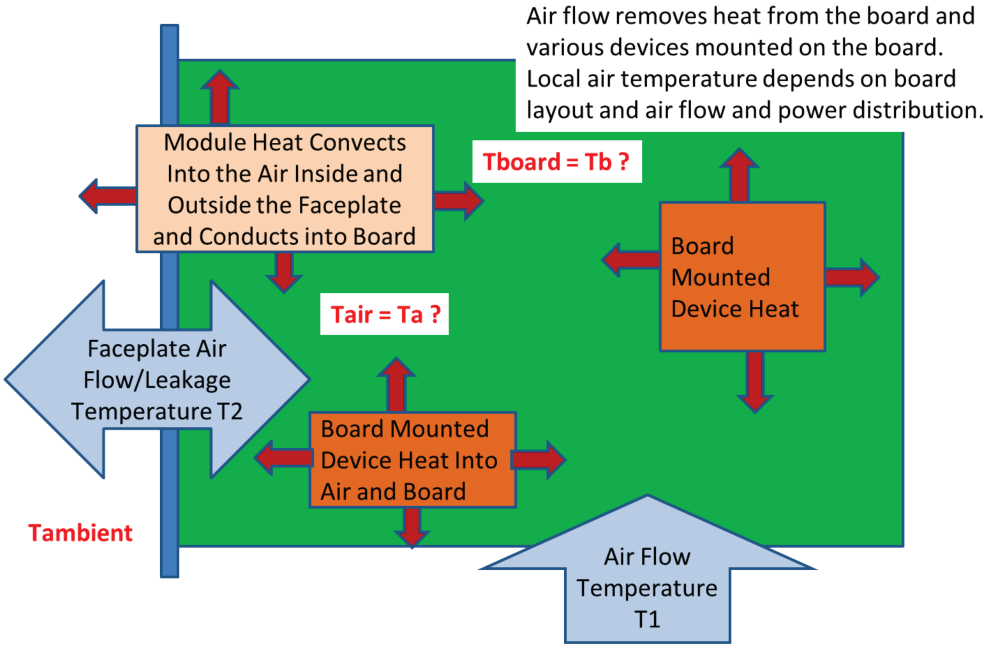

Figure B1: Typical Thermal Environment for a Module – Plan View

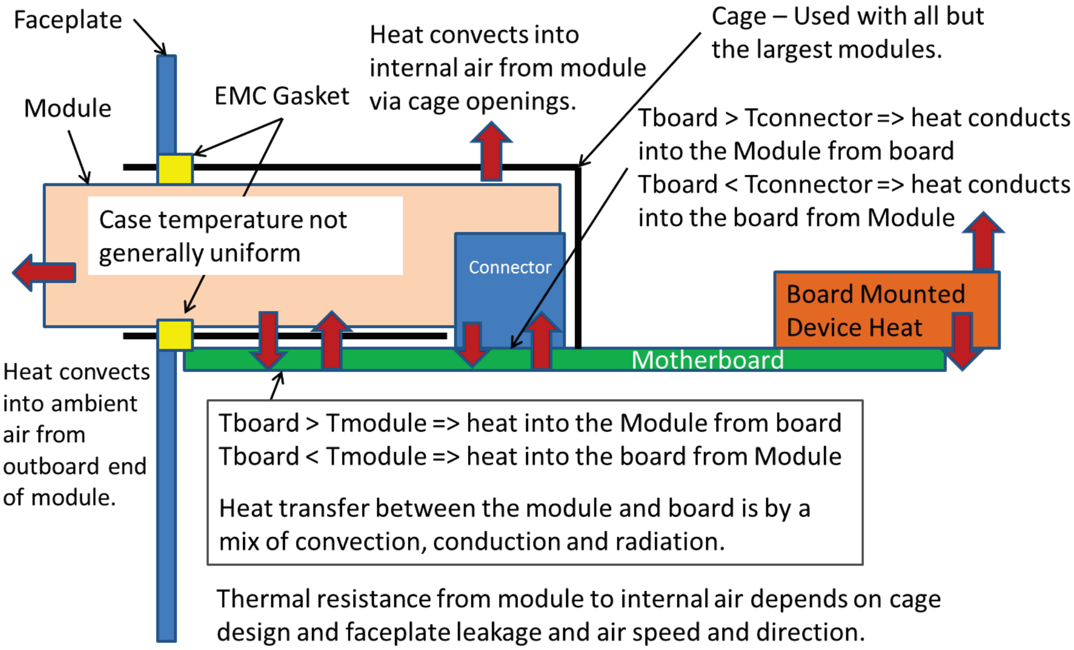

Figure B2: Typical Thermal Environment for a Module - Side View

In these figures, the blue arrows depict the direction of air flow and the red arrows show the direction of heat flow. The direction of air flow at the faceplate through designed openings or leakage paths depends on the pressure within the system relative to ambient pressure. Thus the temperature, T2, of this flow can be either the temperature of internal air, if air flows out, or ambient temperature if air flows in. The temperature of air flowing over the module, Ta, is a result of the mixing of the flow over the board that is heated by devices upstream of the module and flow through intentional and leakage paths through the faceplate. The other relevant temperatures for heat transfer from the module are the board temperatures at the connector and under the module; these temperatures are determined by the balance between heat flow from the various devices and modules on the board and heat convected from the devices and board to the air. Cage design also affects the heat transfer since it can prevent air flow from impinging directly on the module resulting in an insulating layer of air around the sides of the module. Parts of the cage may also contact the module and conduct heat from the module into the board or provide additional surfaces for convection to air. The thermal resistance thus depends on many factors that require detailed knowledge of the system board, the connector, the cage and its EMC design, system faceplate and EMC design in addition to the details of heat generation, system air flow, and conduction paths within the module. The last of these would be provided via detailed or simplified models containing the important thermal elements of the module design as provided by the module supplier. The others are provided by the system designer.

Modules are often placed in gang cages, 2x1, 4x1, 6x1 etc. to maximize faceplate optical connections. The internal modules in these cages have a much different thermal environment due to heat generated by adjacent modules and the restriction of air flow at the sides of the module.

For modules cooled without a heatsink, the surface designed to accommodate a heatsink may only transfer a small amount of heat out of the module. For example, power density can be used to estimate the amount of heat that can be removed from a module via the heatsink interface area when the available temperature difference is known. (The heat transfer coefficients suggested below are rough estimates for airflow rates in the 2 to 4 m/s range and are flow speed and geometry dependent. I.e. Estimate values for the system being evaluated.)

- For example, a Power Class 1 SFP dissipates 0.3 W/cm^2 maximum via interface area of 3.3 cm^2 for a total of 1.0 W. Typical heat transfer coefficients for air flowing over the surface of the module range from 40 to 80 W/m^2-°C (0.004 to 0.008 W/cm^2-°C) which at best gives 3.3 x 0.008 = 0.0264 W/°C so that at best ~38°C temperature difference is required to cool the 1 W dissipation. I.e. 32°C air is required to cool a 70°C case.

- Alternatively, a Power Class 1 CFP2 dissipates 1.12 W/cm^2 over an interface area of 26.8 cm^2 for a total of 3W. With a typical heat transfer coefficient of ~ 0.008 W/cm^2-°C x 26.8 cm^2 = 0.21 W/°C of a requirement for ~14°C to cool the 3W dissipation. I.e. 56°C ambient for a 70°C average case.

Note the wide range in required temperature differences predicted and that many systems would likely cool the SFP+ with much less temperature difference. Estimating the heat that could be removed from a module without a heatsink in an insulated environment could lead to underestimating the cooling capabilities particularly for smaller modules.

13 Appendix C: Factors Affecting Thermal Interface Resistance

13.1 Normal Forces for Heatsinks on Various Modules

In some MSA's, e.g. CFP MSA, reference 4, the normal force that may be applied to the module through the heatsink to the module is limited to 60 N but this remains undefined in most module MSA's. Increasing the force between the heatsink and the module has been advanced as a way of decreasing the interface resistance, references 1, 9 and 15. In sliding heatsink designs, system designers must limit friction to a level that permits easy installation and removal of the module and causes only minimal wear to the contact surfaces over the required number of insertions.

In other designs where the heatsink is mechanically lifted out of contact with the module for insertion and removal, contact forces must not deform the pcb significantly. If a thermal gap pad or other compliant interface material is used, suppliers of such materials typically recommend from 70 to 350 kPa pressure at the interface for optimal thermal resistance at the joint. This would put from 23 to 113 N on an SFP, and from 185 to 925 N (42 to 210 lbf) on a CFP2 and 490 to 2440 N on a CFP. No criteria for limiting the load from the heat sink to the module have been provided with respect to connector side force or module deformation.

Displacement normal to, and towards, the pcb is ultimately limited by contact between the module case and the pcb, or in some cases by contact with the cage bottom which in turn contacts the pcb. It has been advanced that geometric tolerances of the connector and module limit this motion to an acceptable level.

13.2 Interface Materials for Thermal Interface Areas.

The default interface is a contact between the heatsink base material or its plated coating and the module case/coating material where air fills any gaps or voids caused by asperities. Thermal interface materials whose purpose is to replace the air with a higher thermal conductivity material may be used at the discretion of the system designer. Desirable features for a thermal interface material for a sliding heatsink design, include: tough and tear resistant, thermally conductive, compliant, wear resistant, and resilient. Suitable materials have proven difficult to obtain since many of the properties are incompatible with others, for example, highly compliant materials are often neither tough nor tear resistant. Designs where the heatsink is mechanically lifted from the surface have less stringent wear and toughness requirements so that some conductive and compliant gap pad materials typically used with stationary components may be useful. As noted earlier such designs have fewer restrictions on interface contact forces.

13.3 Multiple Thermal Interface Areas on a Module.

At present, no MSA covers modules with multiple heatsink contact areas. However, in such a design, requirements for a single interface would apply to each contact area individually. Locations for labels may be restricted as a result of adding thermal contact areas on different surfaces. If forces oppose each other, net side forces on the module would be reduced. Contact forces in total would also be limited by module insertion/removal requirements, and any restrictions on connector and pcb forces or deformation.

14 Appendix D: List of companies belonging to OIF when document is approved

Acacia Communications
ADVA Optical Networking
Alcatel-Lucent
Altera
AMCC
Amphenol Corp.
Analog Devices
Anritsu
Applied Communication Sciences
Avago Technologies Inc.
Broadcom
Brocade
BRPhotonics
BTI Systems
China Telecom
Ciena Corporation
Cisco Systems
ClariPhy Communications
Coriant R&G GmbH
CPqD
Deutsche Telekom
Dove Networking Solutions
EMC Corporation
Emcore
Ericsson
ETRI
FCI USA LLC
Fiberhome Technologies Group
Finisar Corporation
Fujikura
Fujitsu
Furukawa Electric Japan
Google
Hewlett Packard
Hitachi
Huawei Technologies
IBM Corporation
Infinera
Inphi
Intel
Ixia
JDSU
Juniper Networks
Kaiam
Kandou
KDDI R&D Laboratories
Keysight Technologies, Inc.
LeCroy
Luxtera
M/A-COM Technology Solutions
Mellanox Technologies
Microsemi Inc.
Microsoft Corporation
Mitsubishi Electric Corporation
Molex
MoSys, Inc.
MultiPhy Ltd
NEC
NeoPhotonics
NTT Corporation
O-Net Communications (HK) Ltd
Oclaro
Orange
PETRA
Picometrix
PMC Sierra
QLogic Corporation
Qorvo
Ranovus
Rockley Photonics
Samtec Inc.
Semtech
Socionext Inc.
Spirent Communications
Sumitomo Electric Industries
Sumitomo Osaka Cement
TE Connectivity
Tektronix
TELUS Communications, Inc.
TeraXion
Texas Instruments
Time Warner Cable
US Conec
Verizon
Xilinx
Yamaichi Electronics Ltd.
ZTE Corporation