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3W SFP Interface Development

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Abstract

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New technologies allow and demand increasing levels of data being transferred. Increasing levels of data being transferred, results increase of energy used in transferring devices. This leads to need for more efficient cooling systems.
3W SFP module design project was done in period of 1.2. -30.6. 2022, as part of new product platform development. When the thesis work started, 1.4. 2022, most of concepting and designing was already done.
The work started with small heat sink design adjustments. Thermal interface design deals with thermal boundary resistance between connected solid bodies. Main tools for cope this problem are interface materials and contact pressure.
Thesis work´s focus was on conducting thermal test of designed prototypes and TIMs. Efficiency of interface was calculated from measured temperature difference. Effect of contact pressure was studied by recording its effect on temperature difference. A special jig was designed for this.
Tests indicated that increased pressure is beneficial and interface with silicon-based TIM gain efficiency with moderate pressures.
Based on tests, two thermal interface concepts were selected for further development and productization.

Keywords: thermal design, cooling, product design, mechanical design

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Uudet teknologiat mahdollistavat ja vaativat yhä suurempien datamäärien siirtämistä. Siirrettävän datan määrän lisääntyminen johtaa siirtävien laitteiden käyttämän energian lisääntymiseen. Tämä johtaa tehokkaamman jäähdytyksen tarpeeseen.
3W SFP -moduulin suunnitteluprojekti tehtiin 1.2. - 30.6.2022, osana uuden tuotesukupolven kehitystä. Opinnäytetyön alkaessa 1.4.2022 suurin osa konseptoinnista ja suunnittelusta oli jo tehty.
Opinnäytetyö aloitettiin pienillä jäähdytyselementin geometriasäädöillä. Jäähdytyksen liityntärajapinnan suunnittelussa pyritään minimoimaan yhdistettyjen kiinteiden kappaleiden välistä lämpökontaktiresistanssia. Tärkeimmät keinot tämän ongelman ratkaisemiseksi ovat lämpöä johtavat materiaalit kappaleiden välissä (TIM) ja kontaktipaine.
Opinnäytetyö keskittyi suunniteltujen prototyyppien ja TIM:ien lämpötestaukseen. Lämpörajapinnan tehokkuus laskettiin mitatusta lämpötilaerosta. Kontaktipaineen vaikutusta tutkittiin kirjaamalla sen vaikutus lämpötilaeroon. Tätä varten suunniteltiin jigi.
Testit osoittivat, että korkeampi kontaktipaine parantaa jäähdytystä ja silikonipohjaisten TIM:ien kanssa riittää pienempikin paine.
Testien perusteella valittiin kaksi lämpörajapintakonseptia SFP -moduulin jatkokehitystä ja tuotteistamista varten.

Avainsanat: lämpösuunnittelu, jäähdytys, mekaniikkasuunnittelu

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List of Abbreviations

SFP:	Small Form-Factor Pluggable
TIM:	Thermal Interface Material
PCM:	Phase Change Material
PI:	Polyimide
EMI:	Electromagnetic Interference

1 Introduction

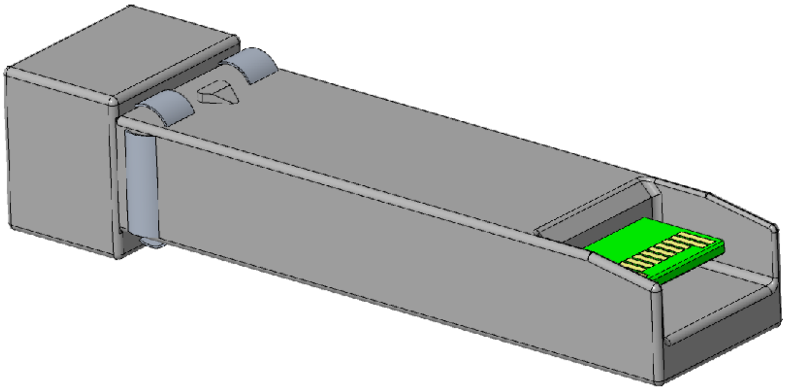
New technologies allow and demand increasing levels of data being transferred. Increasing levels of data being transferred, results increase of energy used in transferring devices. This leads to need for more efficient cooling systems.

Increase of excess heat of a SFP transceiver from 2W to 3W is in proportion quite significant. Purpose of this project was to ensure efficient cooling of SFP transceiver.

SFP generates excess heat, that must be transferred to heatsink, and dissipated to the ambient to avoid SFP overheating. Radio heatsink cannot be used to cool SFP, as its temperature is too high to efficiently cool SFP to desired level.

1.1 SFP transceiver

SFP transceiver is a device which converts optical signal to electrical and vice versa. This conversion process produces excess heat. SFP main dimensions are shown in fig1. Transceivers are manufactured by several companies. Dimensions and other features are defined and standardized by The Storage Networking Industry Association (SNIA) [1].



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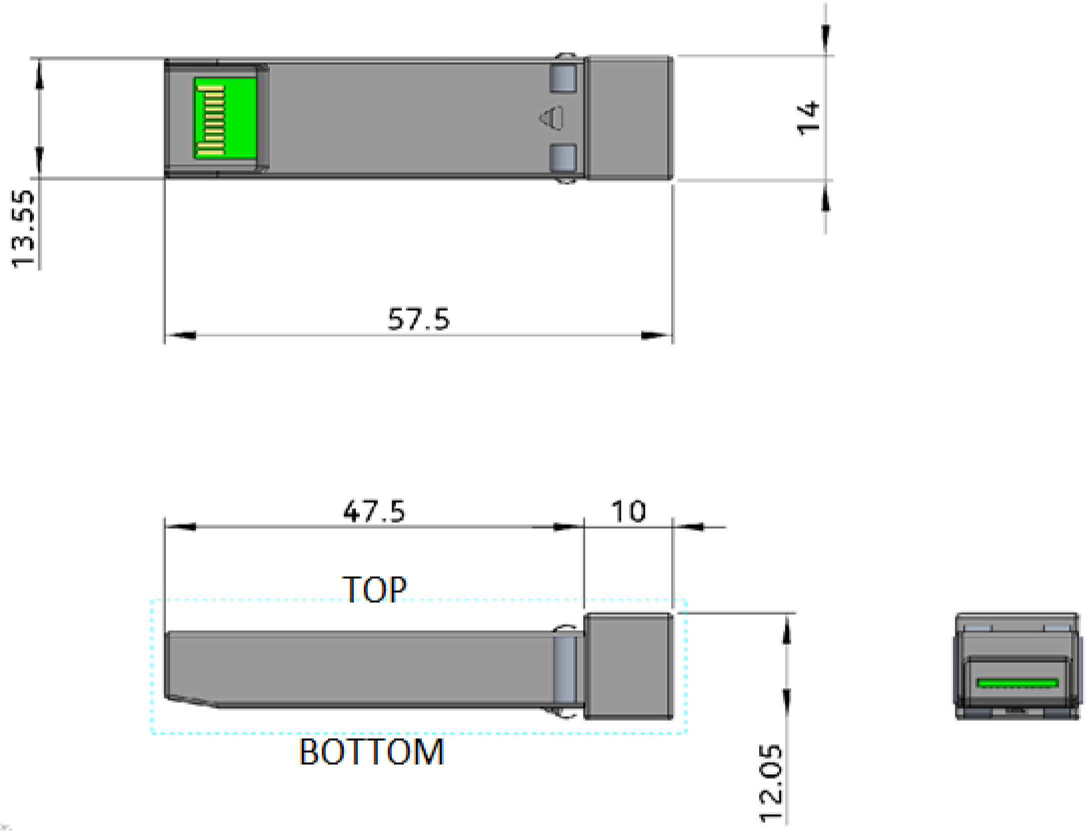

Figure 1 SFP main dimensions

some of manufacturers have a cavity and a label on transceivers top surface. This is very problematic from the thermal contact point of view. Surface edges take most of the contact pressure, leaving less pressure on the middle part, where it would be most needed. Feature works as thermal insulator.

From this project´s perspective SFP transceiver is just a hot component that must be cooled down, and the thermal connection must be designed in a way that allows the component to inserted and removed.

2 Thermal connection

Cooling efficiency of SFP module builds up from small details in the design. It can be described as a thermal chain where the heat transfer is limited by the weakest link.

2.1 Basic theory

Heat flow between two solid bodies according to Fourier´s law is [2]:

$$Q=-kA\frac{\Delta T}{\Delta x} \tag{1}$$

- Q= heat flow
- k= thermal conductivity
- A= cross section area
- T= temperature difference
- x= distance

here we can leave area and distance out. We have thermal contact resistance [3]:

$$R=\frac{\Delta T}{Q} \tag{2}$$

As we can measure the temperature difference and heating power is known, we can compare efficiency of different design solutions.

There are various approaches to analytically define a contact resistance between flat and rough surfaces.

Navni N. Verma &co. [4.] models surface contact interface as a zone where the contacting surface asperities and gas(air) consist of one homogenic material, witch thermal properties are resulting from proportions of materials in the contact zone, which are product of the asperities profiles, the material elasticity and the contact pressure (figure 2).

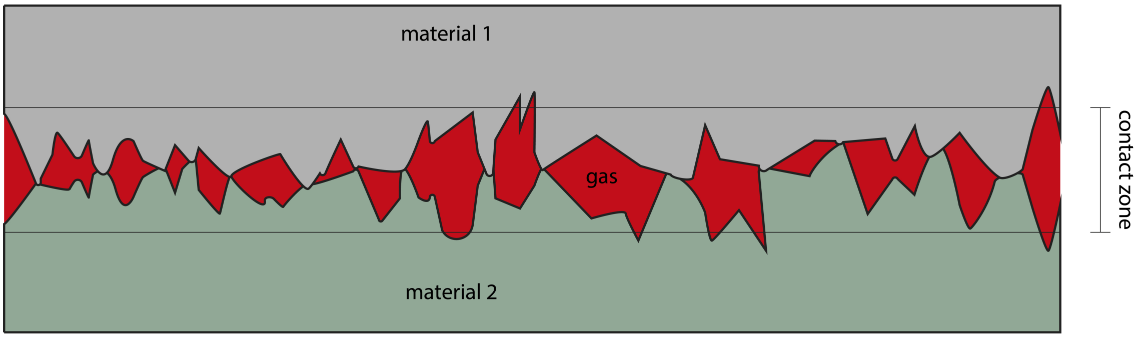

Figure 2 contact zone

The Hertz theory could help to define an estimation of actual contact area and pressure. But it models the surface contact only parallel to theoretical contact line, contacts only on asperity peaks. [5] This is said not be sufficient for modelling thermal connection [6 p.3].

Junfeng Peng & Jun Hong [6] models contact interface with parabolic asperities that can contact also in tangential, slope to slope. Number of different contacts are evaluated by the Gaussian distribution.

Preliminary calculations could be helpful for defining design specifications for thermal contacts. Accuracy of thermal contact resistance calculations require detailed microscopic information of the surface roughness profile. In addition, these models deal with a metal to metal contacts and could be beneficial in case of all metal system. Here TIMs are compounds silicone, plastic and metal components. This makes here, application of for example Navni &co and

Jungfen & Jun models questionable. Relatively simple empirical tests provide case specific data about efficiency of the contact under development.

2.2 Thermal chain

This thermal chain builds up basically of seven elements. The SFP, thermal contact, TIM, thermal contact, Pi-film, thermal contact, the heatsink. (figure3)

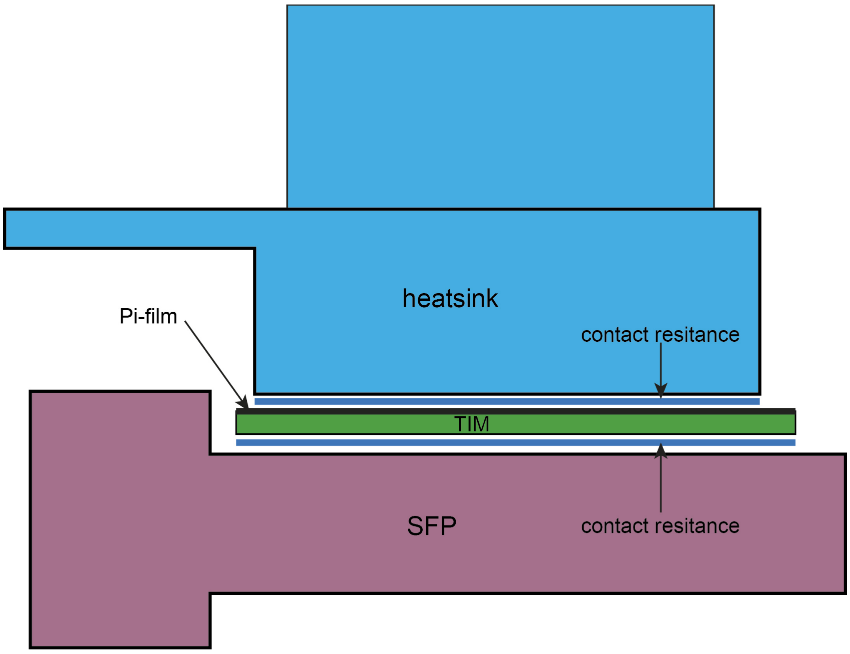

Figure 3 Thermal chain

Other effecting factors are, the contact pressure, the contact area, materials, microscopic surface structure (roughness) and the surface geometric shape (manufacturing tolerances).

By measuring the temperatures from the SFP surface and corresponding, nearest possible place on the heatsink surface, TI-material- and contact resistances can be described in one resistance figure.

Thermal resistances in the surface interfaces are bottlenecks here. Leaving a TIM pad out would shorten the chain to three elements. But then surface imperfections would reduce conductivity. Function of a TIM material is to tackle this problem.

SFP surface roughness is a result of manufacturing processes. Some are sheet metal parts, some casted parts with shot blasted surface. Heatsink inner surfaces result from diecasting process, machining is possible. But whether this would be any beneficial for the heat transfer point of view, remain uncertain. Overall, there aren´t that much to be done for the surface features.

Main factors with which efficiency of the thermal chain can be effected are, contact pressure, contact area and TIM material. The contact area here is mainly result of other dimensions of the product and can only be effected into certain extent. This leaves the heatsink outer geometry, TI -material and the contact pressure variables to be effected with design decisions.

2.3 TIM material

Thermal interface material types

- Pastes
- Adhesive
- Gap filler
- Pad 1,5-25 W/mK
- Tape 1-2 W/mK
- phase-change
- metals 8-429 W/mK

Because the thermal connection must allow SFP transceiver to be inserted and ejected when needed, applicable types here are tapes, pads (which can be either solid or phase-change -type) or metals.

Silicone-based pads allow desired elasticity to adapt surface imperfections. In contrast pads are relatively delicate to mechanical wear. To tackle this pad can be protected with a thin PI(Polyimide film). This basically makes these a compound of tape and pad.

Pads can also be made from PCMs. These changes, as temperature rises, to liquid phase. This helps to fill cavities between microscopic surface asperities and phase change binds some of heat energy. Also, these are coated with PI-film. Phase-change materials are particular good when rapid temperature changes occur [7].

Metals used as a TIM are often soft, thin plates or foils. Metals provide better conductivity but require greater contact pressures to adapt surface imperfections.

3 Design specifications

Reusing previous SFP concepts and components provides straight forward way to gain tested functionalities of design features.

3.1 Manufacturability

Nokia approved materials will be used.

The heat sink will be diecast aluminium. Some machining will be inevitable. Design must allow drafts for diecast mould, machining minimized.

3.2 Usability

SFP is slided trough heatsink to connect PCB. Simultaneously it displaces the spring that is pushing it against the heatsink to provide thermal connection. This causes resistance to the insertion force and cannot compromise usability. The Insertion force max 18N, ejection force max 12,5N [1 p.13]

3.3 Robustness

Materials must stand changing environment. Temperature range -40 to +85 °C. Especially TIM is a key part; thermal conduction must be kept in all cases.

Mechanics must stand the transceiver to be inserted and ejected. Tested for 100 insertions.

3.4 Thermal performance

Measurement point temperature must remain under 85 °C, in 55 °C ambient temperature, 0,2 m/s wind.

4 Previous SFP -module concepts

4.1 EF3 -concept (figure 4)

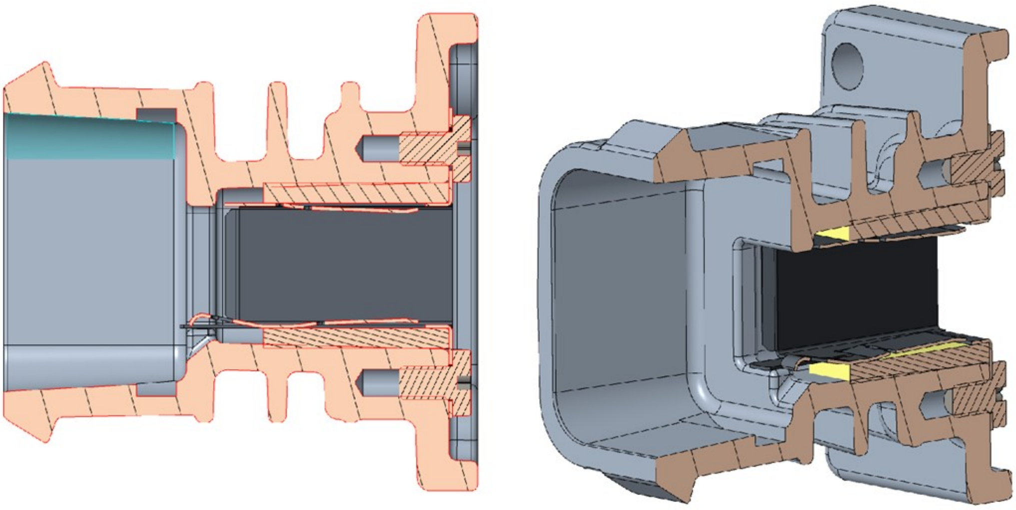

Figure 4 EF3´s SFP heatsink, TIM pads on top and bottom sides.

In this concept there are 1.5mm TIM pads on both sides of the SFP. Between them and the SFP is sheet metal cage that protects relatively delicate TIM pads from wear when the SFP is inserted. The cage functions also as a Spring element to maintain the contact pressure between components.

The cage (figure5) brings on more element of thermal connection and -resistance to the thermal chain. Contact pressure between the cage, the TIM-pad and the heatsink seems to be very moderate.

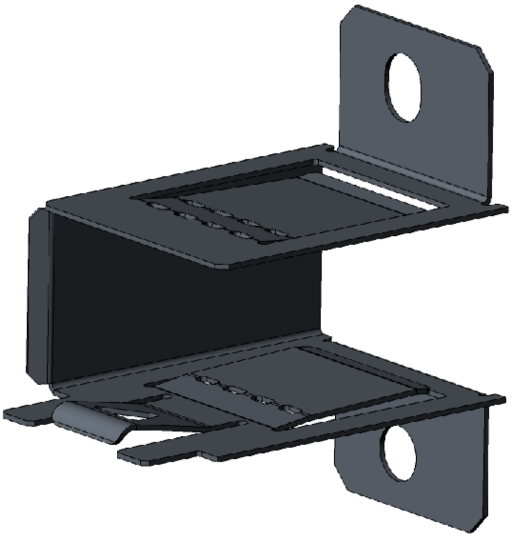

Figure 5 The cage protects TIM pads and functions as spring to provide contact pressure.

The spring applies some pressure between the metal parts (cage & SFP). There must be some gap between to allow module insertion. Thus, seems that the spring and the SFP surfaces are not parallel and actual thermal contact area remains small.

4.2 AB1 -concept

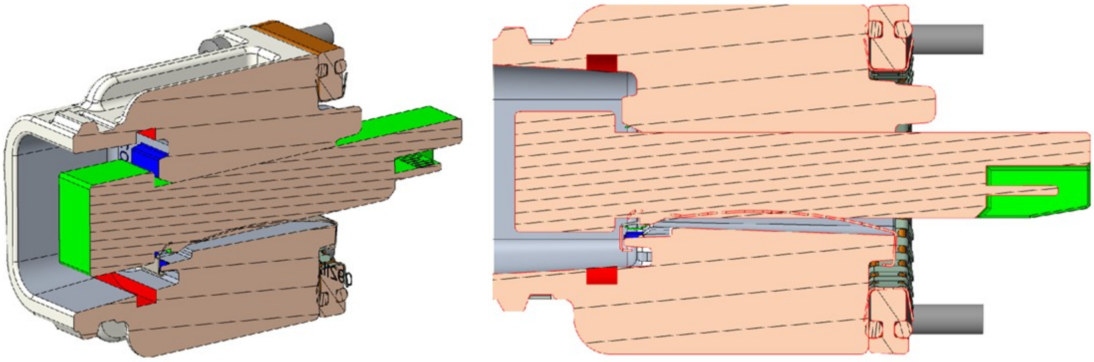

Figure 6 The original AB1 -concept, direct contact between SFP and heatsink

Original AB1 -concept uses direct contact between the SFP and the heat sink. Thermal chain remains short. Sheet metal spring provides pressure between surfaces. It remains very moderate. Thermal contact is very prone to surface imperfections caused by manufacturing technology. Bakelite plate isolates the SFP heatsink from radio main heatsink. It functions also as IP- and EMI-isolator.

5 Tested SFP -modules

5.1 AB1 -concept

This concept is basically same with original AB1. Spring clip is same and isolation plate have just minor changes in dimension. In addition to AB1 - concept, this one has a TIM pad between the heat sink and the SFP top surface. Cooling fins are enlarged compared to original AB1.

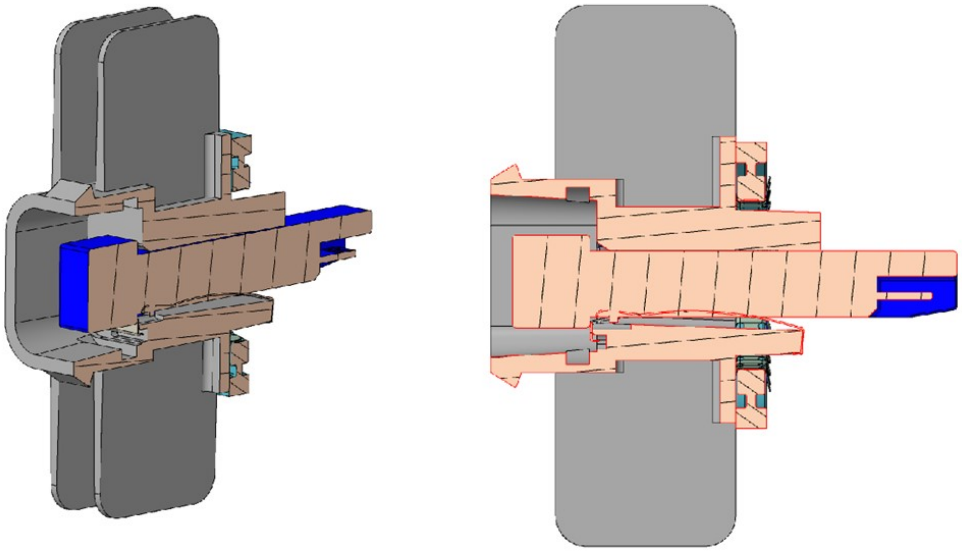

Figure 7 AB1 -concept

5.1.1 SFP heatsink

The SFP heatsink has enlarged cooling fins compared to previous concepts. There are no draft on SFP hole top surface, which functions as thermal contact surface.

5.1.2 Spring

Spring clip design is re-used from AB1. It uses sus301 stainless steel (equivalent European standard EN 1.4310 steel). This alloy is commonly used in stainless springs due its high work hardening capacity (here ¾). [8] Thickness is 0,2mm.

Spring constant / force is not known. It has not been defined in previous designs. A rough estimation made with a handheld instrument is approximate 3-5 N

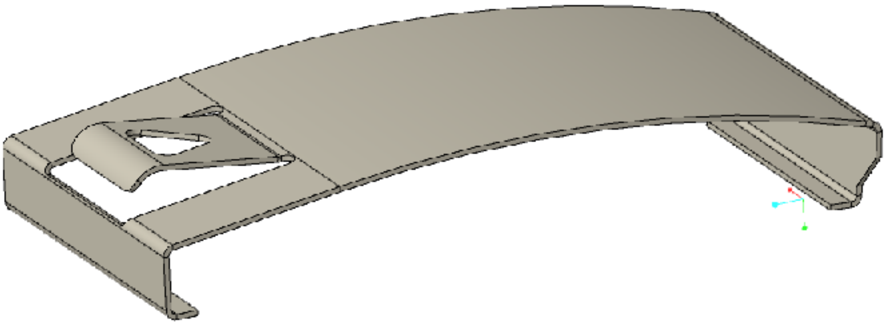

Figure 8 spring clip

5.1.3 TIM

TIM -pads tested for the cooling solution are:

- Nolato

  Compatherm pad 9430, 0,25 + 0,045mm polyimide liner

  Thermal conductivity: 3 W/mK
- Laird

  Opti-tim 0,16mm, polyimide liner, phase-change

  Thermal conductivity: 1,6 W/mK
- Allied
  - TPCM-300P, TIM solution 3#, 0,2mm phase-change, polyimide film

    Thermal conductivity: 3 W/mK
  - TPCM-300P, TIM solution 4#, 0,23mm phase-change, aluminum foil

    Thermal conductivity: 3 W/mK

5.1.4 Isolation plate

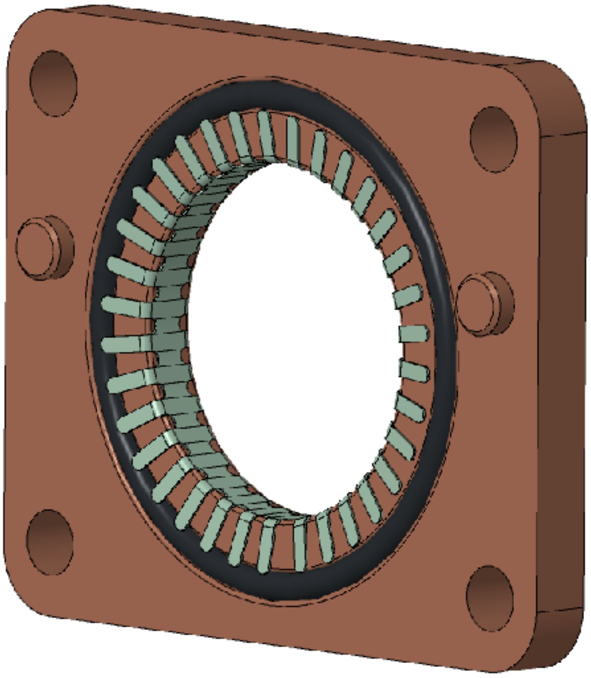

Figure 9 isolation plate with O-rings and sheet metal EMI -seal.

An isolation plate is assembled between the SFP heatsink and the radio main heatsink. The isolation plate functions as a thermal isolator, and it includes IP- and EMI -seals. EMI -sealing is done with a sheet metal part, IP-sealing by O-rings on both sides of the plate. In case of this new lead variant, the main heatsink temperature can be high as 90 °C, direct thermal contact between heat sinks would make impossible to cool SFP to desired level.

Material used previously for these plates are PM 9820 Phenolic or Phenolic DUREZ 153 BK. It has low thermal conductivity 0,2W/mK.

For thermal tests material being used is nylon 12, due to availability in inhouse printers. It has little higher conductivity (0,24-0,3 W/mK) than DUREZ 153 BK, but not in significantly for thermal tests point of view. For the test EMI and IP - seals are stripped away, and supporting features removed from plate.

5.2 AB1 -concept #2

Alternative version of AB1 -concept was made. Thermal contact surface was made narrower to match cavities on some of SFP top surfaces.

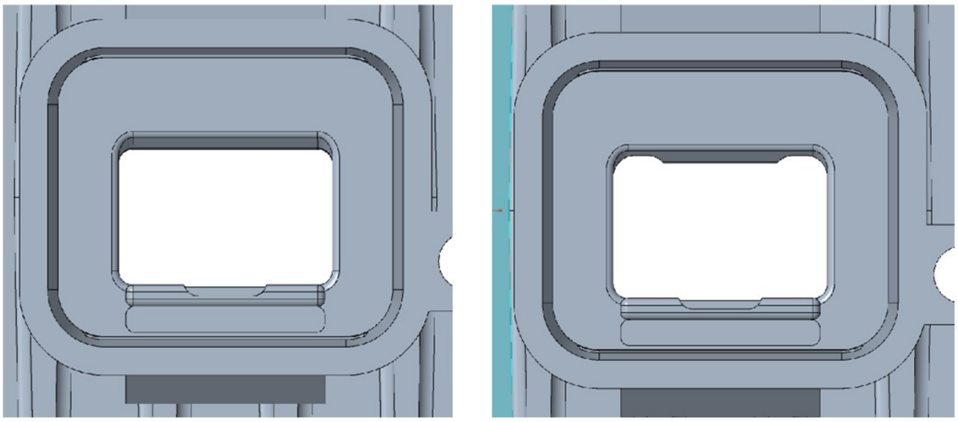

Figure 10 left AB1, right AB1 #2

5.3 EF3 -concept

Design concept represents EF3 inner parts (TIM, cage, springs) with same heat sink outer geometry as this version of AB1 concept. This makes it possible to compare thermal connections performance.

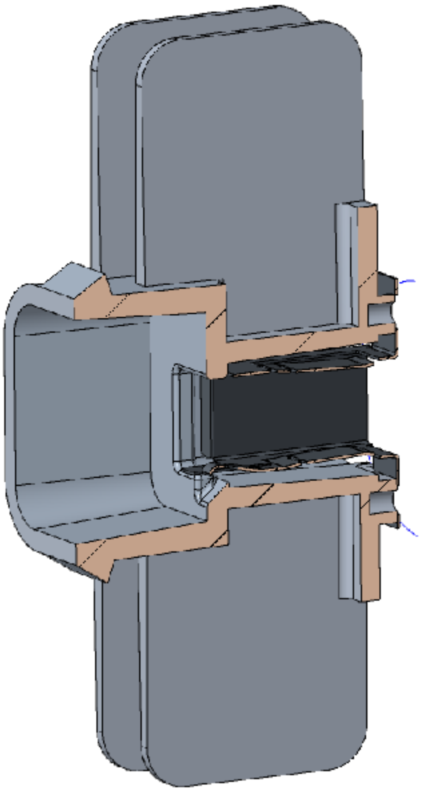

Figure 11 SFP heatsink with EF3 -type thermal connections

5.4 CD2 R&D solution E

Concept does not use TIM pads. Thermal contact is done with finger springs. It is all metal system, which has better conductivity values.

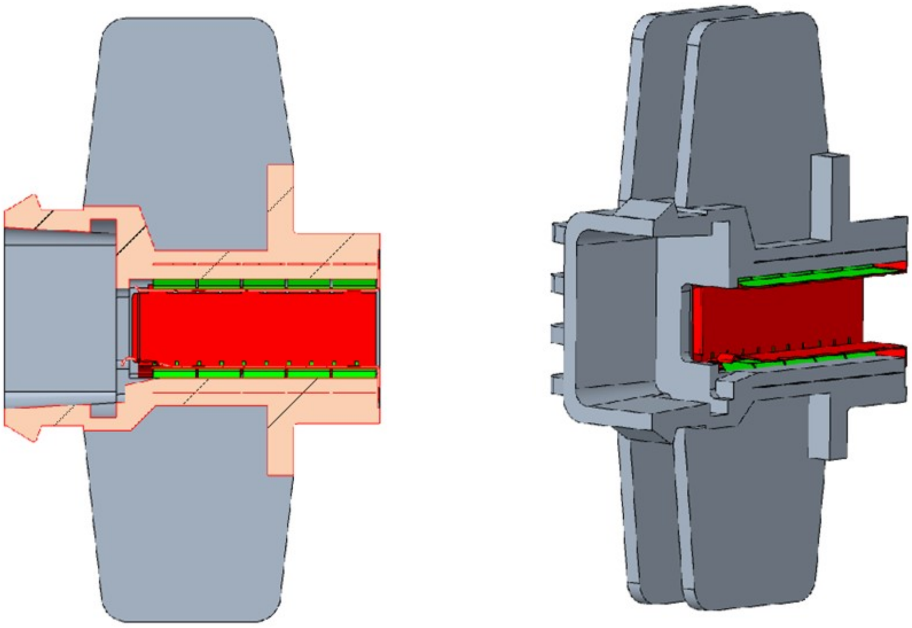

Figure 12 CD2 solution E

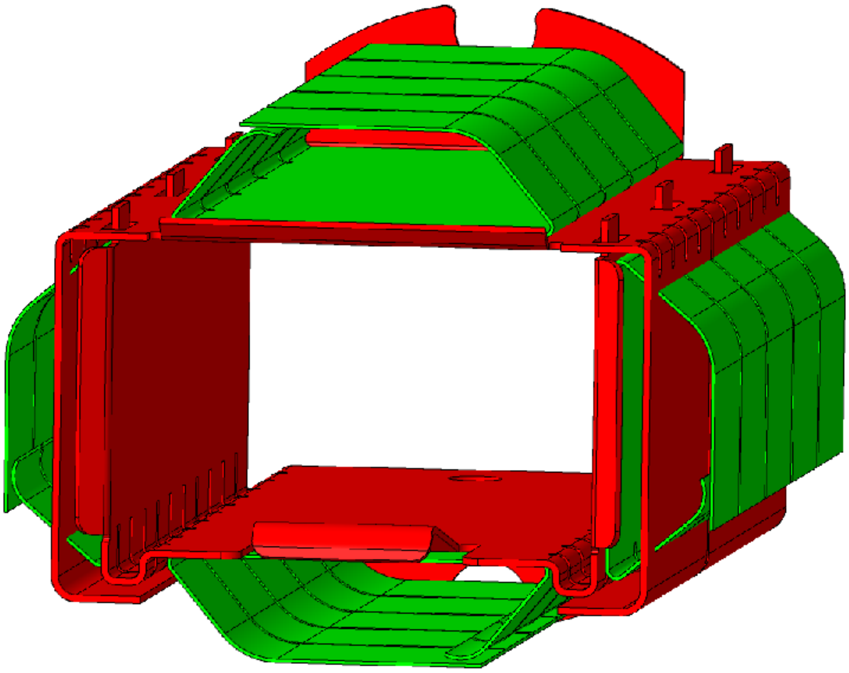

Figure 13 CD2 solution E, finger springs and cage

5.5 GH4 -concept

GH4 -concept has a sheet metal cage and TIM pads on top and bottom sides of SFP, these function also as a spring applying the contact force. Separated sheet metal plates between SFP and pads protects TIM material from wear and enables transceiver sliding in an out. How the elasticity of the pads keeps time and heat cycling, and thus also holds the pressure, remain questionable.

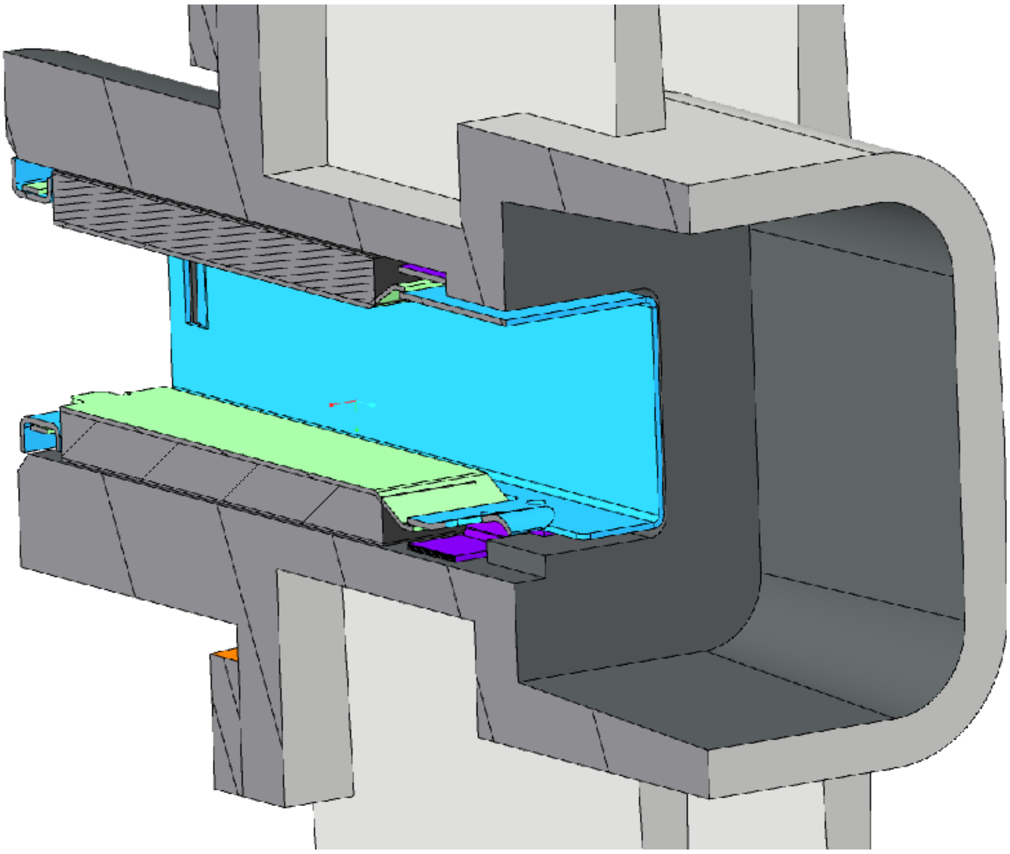

Figure 14 GH4 -concept

6 Thermal simulation results

Simulation uses 1,9 W/mK TIM pads, this includes contact resistances. It has been planned to use 3 W/mK TIMs in thermal test.

Environment settings in simulations are not completely aligned with new requirements (55 °C, 0,2 m/s wind). First Simulation uses 45 °C ambient temperature.

Also simulating with 55 °C ambient temperature + 3 m/s side wind, the measurement point temperature remains below limiting 85 C°.

Scenario with 50 °C ambient temperature and 0,2m/s side wind makes the SFP temperature rise to 89,4 °C. Compared to new, more harsh requirements, this indicates that thermal performance could remain below desired.[8]

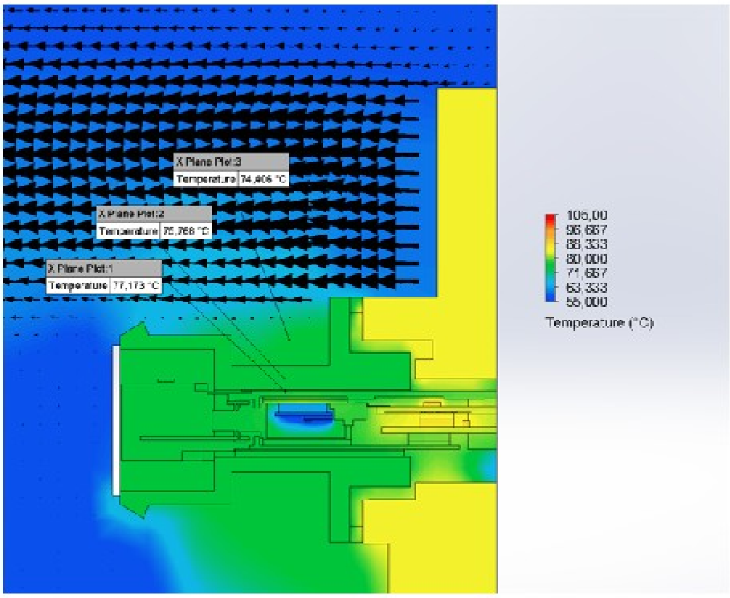

Figure 15 simulation results, SFP in 55°C, 0,2m/s, 3,5m/s, 60 °C HS outlet air, 86°C heatsink

Changing new lead variant to fan cooling, helped the SFP cooling by increasing air flow. Simulating with 55c ambient temperature, air flow from fans, dropped measurement point temperature to 77 °C. (figure 15)

Difference between 2 & 4mm isolation plates remain marginal.[9]

7 Thermal tests

7.1 Testing setup and environment

All test were conducted in room temperature.

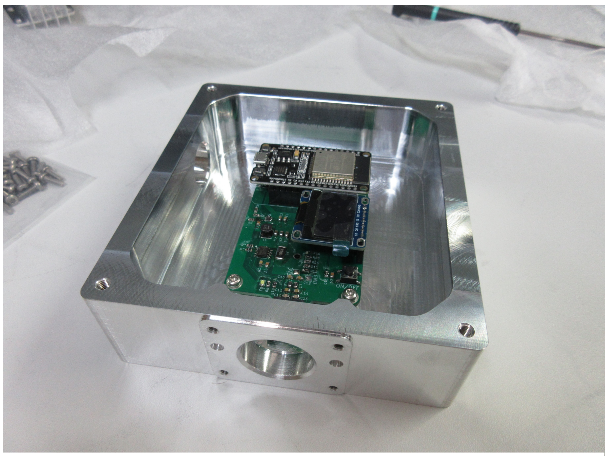

Figure 16 PCB and housing for testing

Figure 17 thermo couple on SFP

The test setup consists of a special PCB to which the SFP is connected, housing for the board, (figure 16), the SFP heat sink. External thermo couples are connected on the SFP top surface and on heat sink(figure17), nearest possible location to other thermo sensor. System monitors the SFP power levels and the SFP inner temperature (inner heat sensor). The SFP transceiver type that was planned to be used here is special "loop back" type that is designed only for test cases.

The PCB -board turned out to be mostly useless. Data output was problematic, controlling the SFP -power levels would have required configuring loopback SFPs settings, which knowledge were not available at that moment. It was decided to use SFP transceiver which internal parts was replaced with heat resistors. This solution allowed to freely adjust heating power with external power supply.

At the first test phase four different TIM samples were tested with the same SFP heat sink. Test steps were:

1. Insert SFP and measure insertion force
2. Test with 3W
3. Insert 100 times
4. Test with 3W
5. Test to 80 °C

On the second phase the AB1-type#2 was tested with Allied #3 TIM.

The CD2 solution E tested with loopback SFP power level 1,7W and with the heat resistor equipped SFP, 3W and 12,6W.

The EF3 -type tested briefly with 3W to give comparison to performance of thermal connection concepts, already in use.

The GH4 -concept tested with foam TIM and 3W TIM pads, both also after hundred insertions.

Testing included also experimenting with placing 1,5mm TIM pad under the spring clip, and double spring. Purpose of this was to find solutions to enhance thermal performance.

Sensor readings were monitored with Agilent Bechlink DataLogger -software. Measurements were written in .csv format, so data analysing with spreadsheet program was easy.

7.2 Contact pressure test

As the contact pressure is important variable in the contact resistance, jig for testing, how variation in the pressure effects the thermal performance in this case, was made. (Figure 18) This test requires drilling hole through the SFP heat sink. Forces used where 35, 87, 170 and 350 N, (corresponding pressures of approx. 0,1; 0,25; 0,5; 1 MPa). Used heatsink and TIM type were AB1 -type and Allied #3.

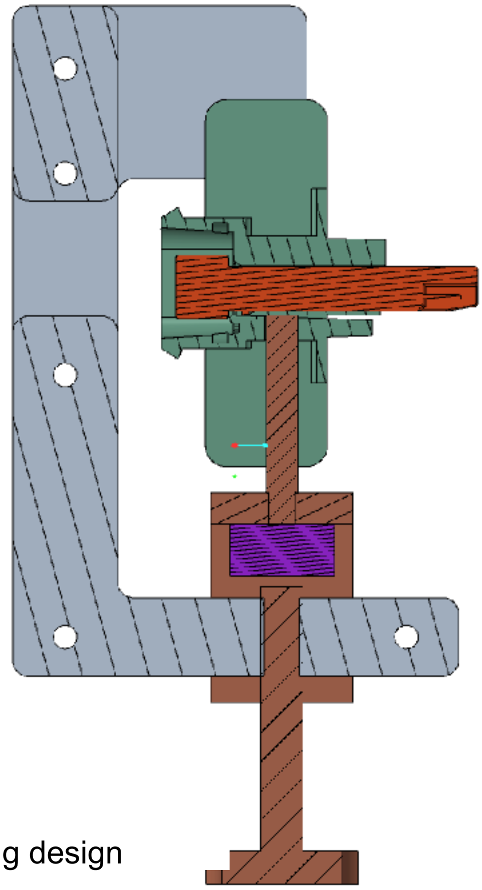

Figure 18 cross section of pressure testing jig design

Research data shows that contact pressure has strong impact on contact resistance with metal-to-metal surfaces, in pressure range up to 2 MPa [4. p.29]. On the other hand, with PCM type TIM pads, pressure doesn’t seem to have such a strong effect. Manufacturer´s data uses pressure range up to 0,3 - 0,7 Mpa. (50-100 psi) [10], [11]

8 Test results

8.1 TIM

There were some differences between tested TI pads (Tests 1-14 &18). Minor value variations in size, thickness and thermal conductivity made comparison possible only in sample level, not as TI material.

Nolatos TIM had slightly better results than Allied #3. Problem with the Nolato pad was that Pi-film did not hold as well as Allieds, which in turn appeared robust and finalised product. Removing Allied pad did require scraping it off with a knife. The TIM pad did hold its place after removing PI-film. Reliability would stand on Allieds side.

8.2 Thermal connection concept

The EF3 -concept worked as ground level for cooling performance (test 27). It remains much lower than AB1 -concepts.

The CD2 solution E (test 15-17, 28, 37) had very good results due high contact pressure. Thermal contacts are on all 4 surfaces. Insertion and extraction forces were extremely high (50N). This made the concept impossible to use. Reducing spring/contact forces would probably better the usability issue, but how it would then perform in thermal perspective remain to be clarified.

The GH4 prototype had resistance values around 2 K/W, which is more than best AB1 -concept values around 1,2 K/W. This concept had quite significant insertion forces(10N-20N). Seems that higher contact pressures here do not lead to better conductivity. Usability feeling was the best. [appendix 2 p.9-10]

AB1 -concept had good thermal performance and usability. Sideway guiding SFP to connector could be better. It is easy to miss the connector.

8.3 Manufacturability

The AB1 -concept has cast bulkhead, but TIM assembly on the bulkhead inner surface requires custom tool design.

The CD2 solution includes various sheet metal parts and tools for those. Assembly of the spring-cage system is not clear.

The GH4 concept has machining on the bulkhead opening.

8.4 Contact pressure

Effect of the pressure remain smaller than expected. TIM pads functions best at moderate pressures. Higher pressures would displace soft silicon-based TI-materials from interface. Metal to metal contacts benefit more from very high pressure values.

The testing left marks on the TIM pad. The Marks were on same area where the contact force was applied. The other end of pad remains intact. This rises question that whether the pressure distribution was even. (tests 29-36)

Figure 19, pressure marks on TIM after testing with elevated pressure

Experimenting with placing another TIM pad under the spring and double spring gave better values (tests19-26). It is probable that the effect of TIM pad under the spring was mainly because it gave support to the spring force, not as increase of the thermal conduction from downside. The increase in insert forces did not reach the significant level that would effect on usability. This indicates that increase to spring force is beneficial and can be done, at least to approx. 10-15N insertion force is met.

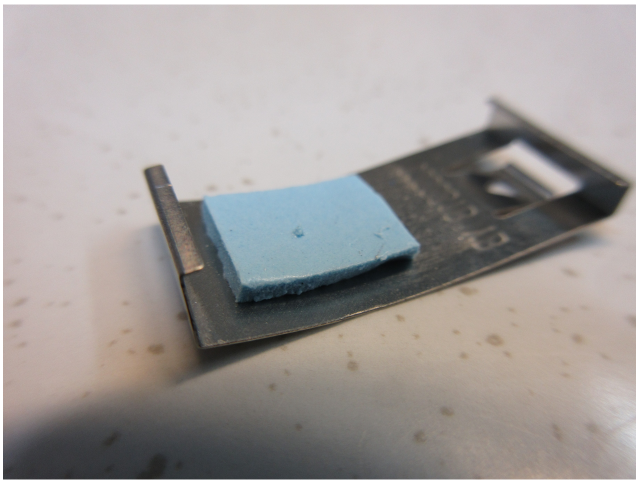

Figure 21, TIM also under the spring

Figure 20, double spring

9 Conclusions

The GH4 concept with foam TIM and the AB1 concept were selected to further development and productization. The CD2 concept failed to pass the usability test due to too high insertion force. Tests showed clearly that EF3 type solution does not have sufficient thermal performance.

The GH4 solution needs investigation on foam material durability to ensure the thermal contact. Machining cost of opening on bulkhead needs to be clarified, too.

The AB1 concept needs further studies for thicker spring clip and tooling for the TIM assembly. In addition the durability of the TIM adhesion needs to be verified.

Recess and label on some of the transceivers top surface works as thermal insulator. Need for efficient thermal interface basically excludes usage of this type of SFP housing. Each vendor SFP must be separately tested and qualified for the 3W SFP application.

Simulations with fan cooled new lead variant indicates that selected designs could be efficient enough. Simulations with passively cooled radio shows that reference point temperature would not remain below 85 °C with passively cooled variants.

TIM material manufacturers provide product specific data of how contact pressure effects on their products. With metal-to-metal contacts, suitable approximation of surface properties could lead to sufficient accuracy of preliminary estimation of desired pressure. Defining level of detail in the initial data and suitable calculation models were out of this thesis works scope.

Thermal interface design could benefit from defining desired contact pressure range in advance. This would probably straighten the way to desired results and allow to concentrate effort to develop design further, and thus lead to better solutions.

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		TIM		heat			max temp C			thermal resistace
est no	FP heatsin	manufact	model	A	V	P(W)	T1(SFP)	heatsink t	**dT**	**dT/P**
1	AB1 type	none		0,4	7	2,8	61,4	38,5	**22,88**	**8,170**
2	AB1 type	nolato	19431025	0,45	7,1	3,195	50,4	40,6	**9,81**	**3,071**
3	AB1 type	nolato +1	19431025	0,45	7,1	3,195	47,8	42,0	**5,80**	**1,815**
4	AB1 type	nolato +1	19431025	0,8	12,1	9,68	82,2	68,9	**13,29**	**1,373**
5	AB1 type	allied	tim soluti	0,45	7,1	3,195	50,2	43,7	**6,50**	**2,035**
6	AB1 type	allied +10	tim soluti	0,45	7,1	3,195	49,3	42,2	**7,07**	**2,213**
7	AB1 type	allied +10	tim soluti	0,8	11,9	9,52	84,6	67,9	**16,70**	**1,754**
8	AB1 type	Laird	optiTIM,	0,45	7,1	3,195	54,6	38,4	**16,21**	**5,073**
9	AB1 type	Laird +10(	optiTIM,	0,45	7,1	3,195	54,5	39,2	**15,26**	**4,775**
10	AB1 type	Laird +10(	optiTIM,	0,8	12,1	9,68	83,3	43,8	**39,58**	**4,089**
11	AB1 type	allied	tim soluti	0,45	7,1	3,195	52,0	41,2	**10,82**	**3,387**
12	AB1 type	allied +10	tim soluti	0,45	7,1	3,195	50,4	42,2	**8,22**	**2,572**
13	AB1 type	allied +10	tim soluti	0,8	12,1	9,68	82,5	65,0	**17,46**	**1,804**
14	AB1 type	allied +10	tim soluti	0,45	7,1	3,195	46,1	39,8	**6,34**	**1,983**
15	CD2 sol. E	none/ as assembled				1,7	32,0	31,2	**0,85**	**0,499**
16	CD2 sol. E	none/ as assembled		0,45	7,1	3,195	42,3	37,8	**4,53**	**1,418**
17	CD2 sol. E	none/ as assembled		0,9	14	12,6	82,1	66,4	**15,66**	**1,243**
18	AB1 type	nolato	19431025	0,45	7,1	3,195	44,9	39,0	**5,87**	**1,838**
19	AB1 type	nolato + allied tpa		0,45	7,1	3,195	44,8	40,7	**4,08**	**1,276**
20	AB1 type	nolato + allied tpa		0,45	7,1	3,195	45,6	41,2	**4,37**	**1,368**
21	AB1 type	none	allied tp	0,45	7,1	3,195	52,7	39,9	**12,75**	**3,992**
22	AB1 type	allied	tim soluti	0,45	7,1	3,195	43,1	39,0	**4,06**	**1,271**
23	B1 type #	allied	tim soluti	0,45	7,1	3,195	46,9	41,4	**5,55**	**1,736**
24	B1 type #	allied + a	tim soluti	0,45	7,1	3,195	45,3	42,1	**3,19**	**0,998**
25	B1 type #	none	allied tp	0,45	7,1	3,195	51,1	42,0	**9,16**	**2,867**
26	B1 type #	none	allied tp	0,45	7,1	3,195	47,0	39,7	**7,30**	**2,285**
27	EF3 -type	cage + TIMs		0,45	7,1	3,195	57,8	40,0	**17,73**	**5,548**
28	D2 sol. E #	allied tpad-so30-1		0,45	7,1	3,195	43,8	37,3	**6,47**	**2,025**
29	AB1 type	none	none	0,45	7,1	3,195	45,7	35,0	**10,68**	**3,342**
30	AB1 type	none	none	0,45	7,1	3,195	42,2	34,9	**7,26**	**2,273**
31	AB1 type	none	none	0,45	7,1	3,195	42,6	36,4	**6,21**	**1,945**
32	AB1 type	none	none	0,45	7,1	3,195	42,0	36,2	**5,80**	**1,816**
33	AB1 type	allied	tim soluti	0,45	7,1	3,195	40,3	35,5	**4,77**	**1,494**
34	AB1 type	allied	tim soluti	0,45	7,1	3,195	38,7	34,6	**4,10**	**1,283**
35	AB1 type	allied	tim soluti	0,45	7,1	3,195	39,8	36,3	**3,49**	**1,091**
36	AB1 type	allied	tim soluti	0,45	7,1	3,195	40,1	37,2	**2,97**	**0,930**
37	CD2 sol. E	none/ as assembled				1,7	31,5	29,3	**2,17**	**1,278**
38	GH4 foam	as assemt	as assemb	0,45	7,1	3,195	42,9	35,9	**6,93**	**2,169**
39	GH4 foam	as assemt	as assemb	0,45	7,1	3,195	43,0	36,0	**7,03**	**2,200**
40	H4 3W pa	as assemt	as assemb	0,45	7,1	3,195	42,2	36,3	**5,82**	**1,822**
41	H4 3W pa	as assemt	as assemb	0,45	7,1	3,195	42,0	36,2	**5,78**	**1,809**
42	AB1 type	allied	tim soluti	0,45	7,1	3,195	46,4	39,6	**6,80**	**2,128**
43	AB1 type	allied	tim soluti	0,45	7,1	3,195	46,6	38,0	**8,60**	**2,692**

thermal resistace	contact pressure			force (N)		
dT/P	area (	force (	pressure	insert	retent	notes
8,170	354,9	**5**	**0,014**		177	heating current dificult to define
3,071	273	**5**	**0,018**	2	204	side ways movement makes possible to miss sfp conne
1,815	273	**5**	**0,018**			same TIM as test run 2. but after 100 insertions
1,373	273	**5**	**0,018**			same TIM as test run 2. power rise to match 80c temp
2,035	273	**5**	**0,018**	1,8		
2,213	273	**5**	**0,018**			same TIM as test run 5. but after 100 insertions
1,754	273	**5**	**0,018**			same TIM as test run 5. power rise to mach 80c temp
5,073	72	**5**	**0,069**	1,8		TIM size???
4,775	72	**5**	**0,069**			same TIM as test run 8. but after 100 insertions
4,089	72	**5**	**0,069**			same TIM as test run 8. power rise to match 80c temp
3,387	218,4	**5**	**0,023**	1,8		metal foil instead of PI-film
2,572	218,4	**5**	**0,023**			same TIM as test run 11. but after 100 insertions
1,804	218,4	**5**	**0,023**			same TIM as test run 11. power rise to match 80c temp
1,983	218,4	**5**	**0,023**			retest test 13 with 3W after +80c temp
0,499				50		heat power from loop back sfp
1,418				~50		heat power from power source
1,243				~50		heat power from power source
1,838	273	**5**	**0,018**			retest test no.2
1,276	273		**0,000**	12		TIM pad also under the spring
1,368	273		**0,000**	5		smaler TIM under the spring
3,992	273		**0,000**	2		same as test 20. but no TIM on top
1,271	273	**8**	**0,029**	6		double spring
1,736	273	**5**	**0,018**	2		
0,998	273		**0,000**	5		TIM under the spring/ 2 TIM solution
2,867	273		**0,000**	2		TIM only under the spring
2,285	273		**0,000**	3,4		TIM only under the spring
5,548				8		
2,025						TIM between cage and heatsink, insetead of spring
3,342	349	**35**	**0,100**			pressure test
2,273	349	**87**	**0,249**			
1,945	349	**170**	**0,487**			
1,816	349	**350**	**1,003**			
1,494	273	**35**	**0,128**			
1,283	273	**87**	**0,319**			
1,091	273	**170**	**0,623**			
0,930	273	**350**	**1,282**			some deformation on SFP after testing
1,278				50		retest test no. 15.
2,169				10...13		the test was stopped when 10s increment was less tha
2,200				9...11		the test was stopped when 10s increment was less tha
1,822				17.5...19.5		the test was stopped when 10s increment was less tha
1,809				17		the test was stopped when 10s increment was less tha
2,128				6		repeat the test 5
2,692						TIM pasted on SFP bulkhead instead of SFP transceiver
2,473						TIM pasted on SFP bulkhead, +double spring