TrueTile modules & 4SBC
Status & plans

Ringberg, 13.3.2019

J. Treis, L. Andricek, J. Ninkovic, R. Richter, F. Schopper
MPG Semiconductor Laboratory

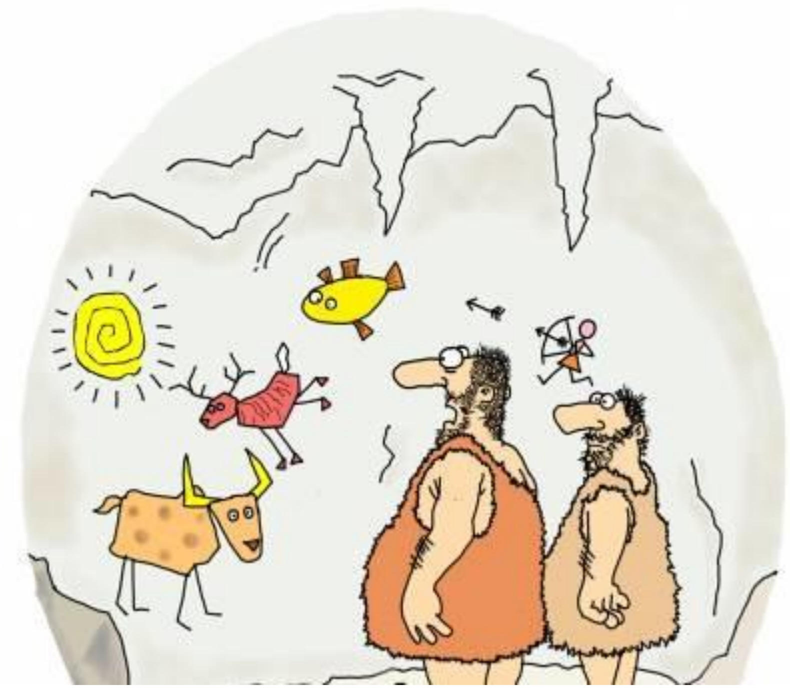
Contents

Introduction

Project target:

- 4-side buttability allows for composite focal planes w/ large sensor area mosaic
- Design "platform/concept" for 4-side buttable integration of sensor devices
- Low sensitivity gap between modules
- Large composite focal planes
- Maximum degree of modularity
- Large power contingency
- Device independent / device tolerant

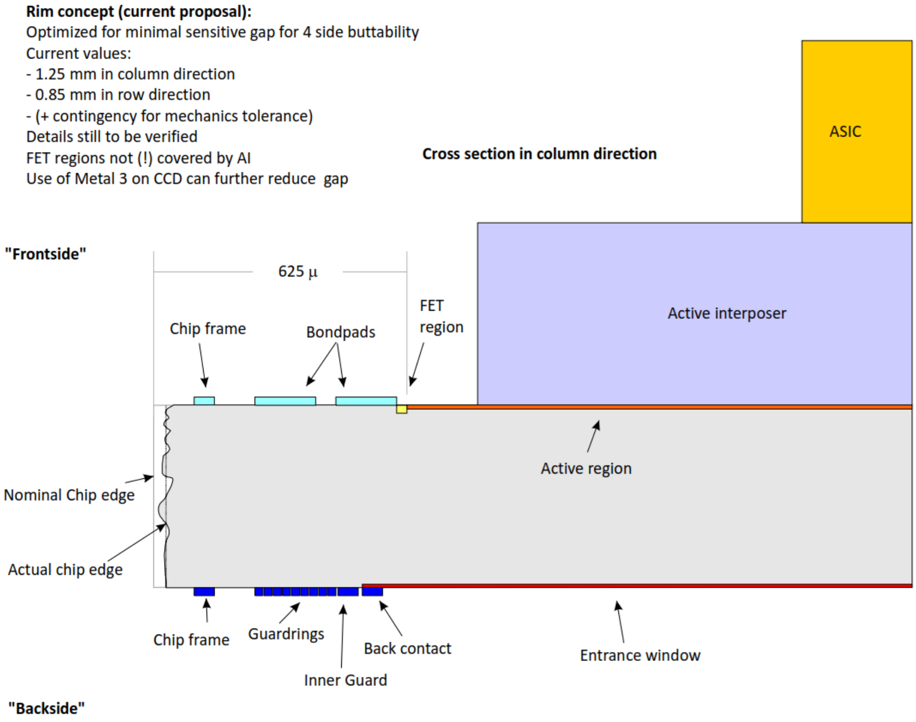
⇨ **TrueTile concept**



"I can't believe the pace of modern technology Ralph. A few--years ago, all these pictures would have been in black and white!"

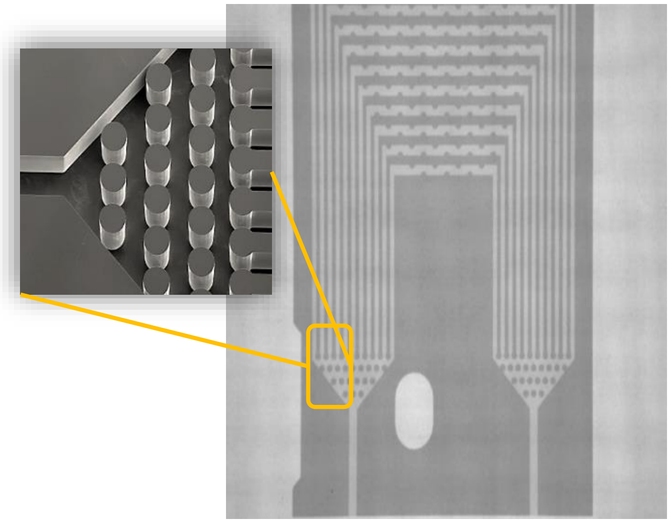
TrueTile concept

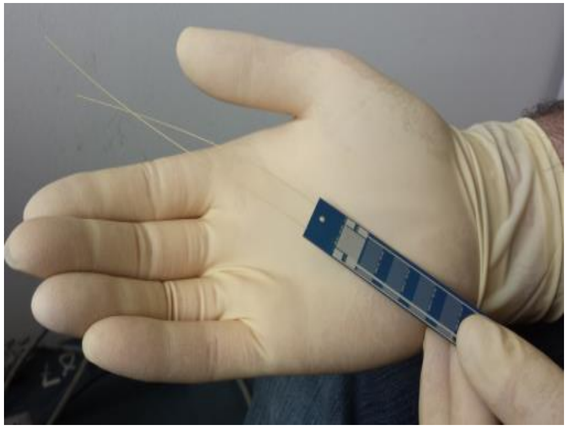
- 4-side buttable sensor modules with minimal sensitivity gap
- 4 main "ingredients":
  - Make guardring structures as narrow as possible for small sensitivity gap
  - Use Active Interposer (AI) unit to host
    - MCC
    - Sensor
    - ASM"ish" structure with
      - ASICs
      - Supplementary drivers (BARD)
      - Passive circuitry
  - Accommodate all biasing and backend circuits within AI / Sensor envelope
  - Maximally modular approach

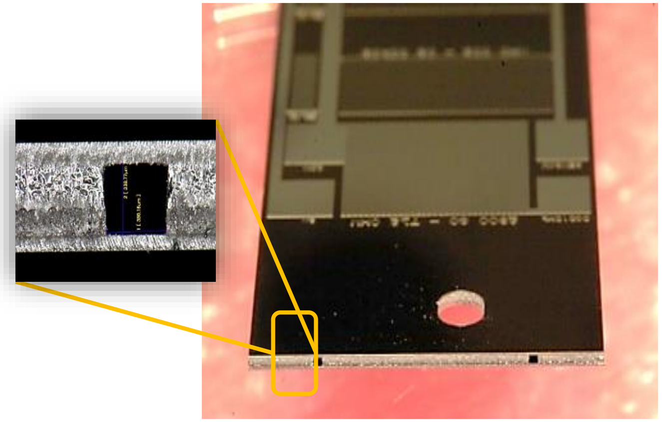


TrueTile concept

- **Microchannel cooler (MCC):**
  - Investigated as cooling concept for ATLAS / ILC
  - Plasma-etched channels in silicon wafer
  - Wafer bonded to lid wafer to hermetically seal channels
  - Channel design according to expected heat load distribution
  - Wafer can be processed like a normal wafer / lithography steps
  - Access to channels exposed during dicing



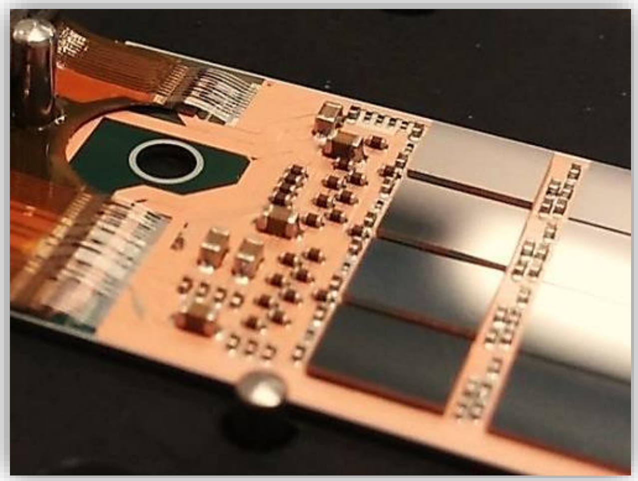




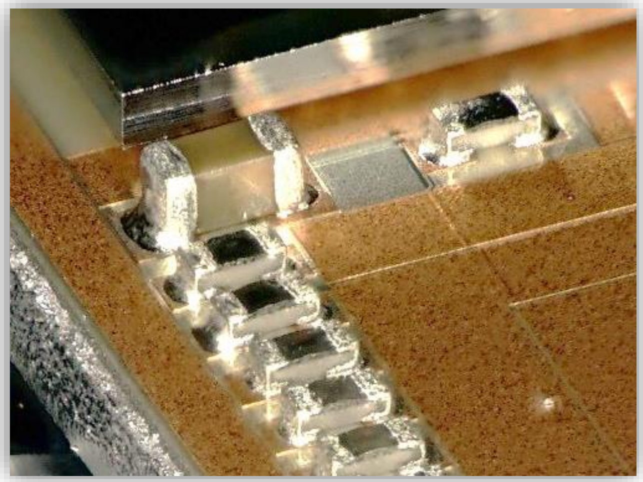
C. Marinas, Micro Channel Cooling for Tracking Detectors, Forum on Tracking Detector Mechanics, Bonn 2016

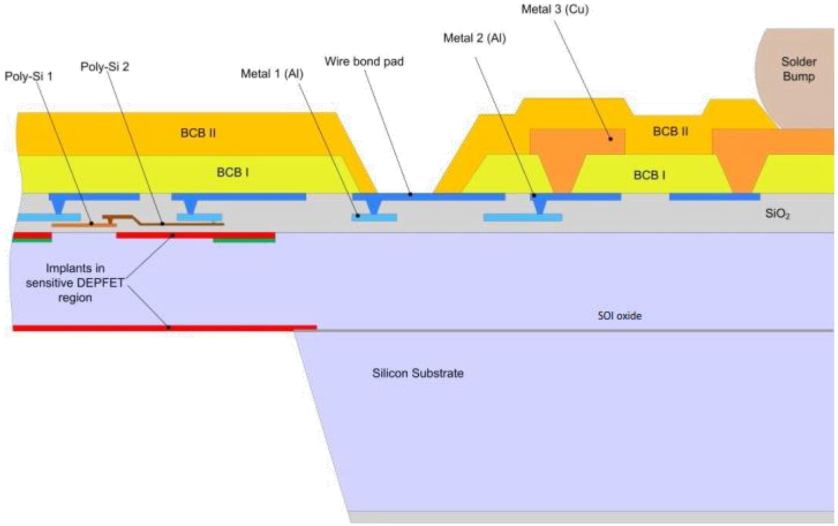
TrueTile concept

- **All-Silicon-Module (ASM):**
  - Sensor die includes regions for
    - Front-End-Electronics & Passives
    - Signal / Power traces
    - Bond-/Solderpads to periphery
  - "Passive" balcony regions, but no additional support structure



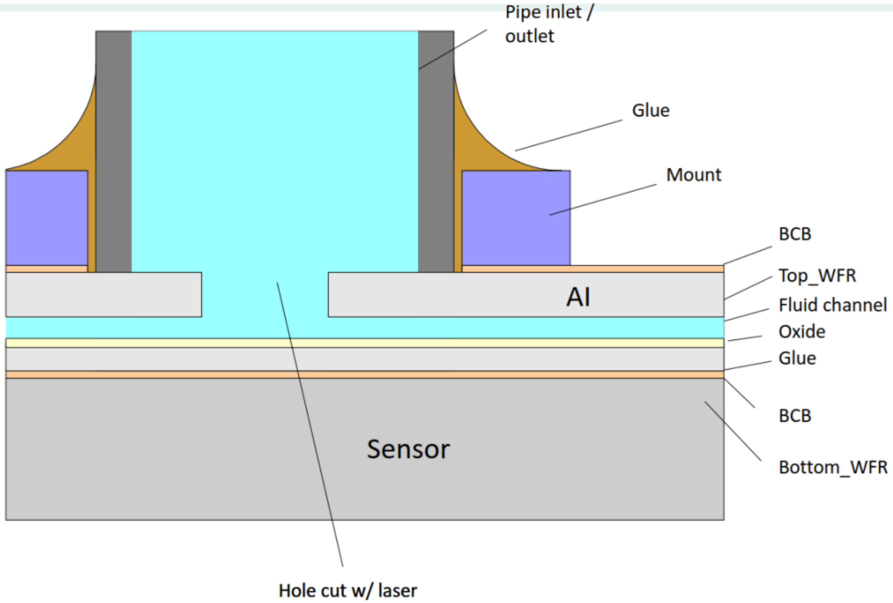
SuperBelle ASM on SOI wafer
w/ thinned sensor region

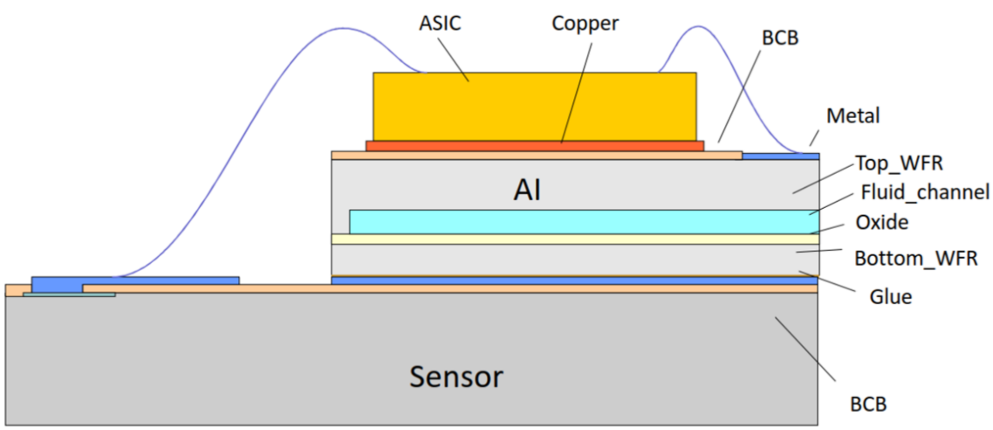




TrueTile concept

- **Active Interposer (AI):**
  - Silicon interposer based on SOI:
    - Matchmaker / Pitchadapter to sensor die
    - Carrier for FE ASICs and passives
    - Carrier for peripheral connector
    - Substrate for power / signal trace system
    - Container for SOI based MCC
  - Separated from sensor substrate
  - Interface to support mechanics
  - Fine-pitch 3-4 metal layer trace system
  - µBump bond pads for FEE
  - Optimum CTE match to sensor





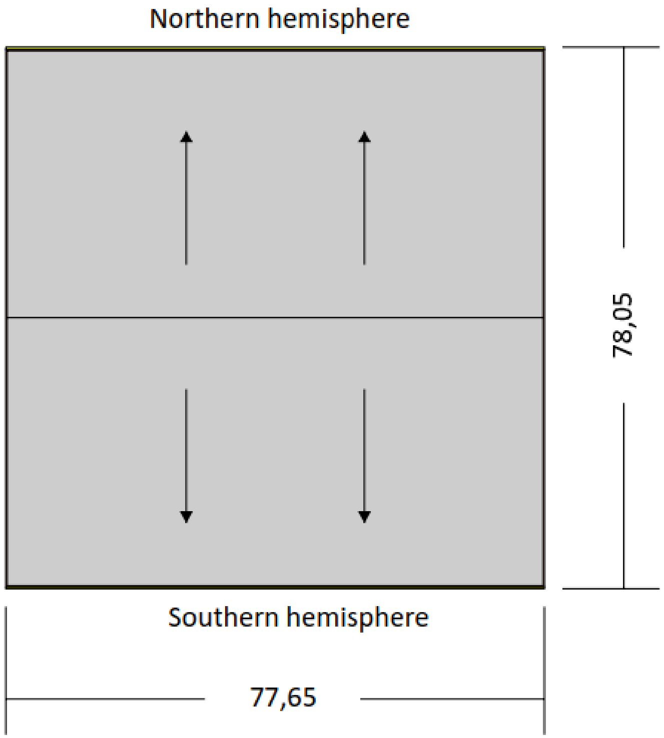
Active Interposer (AI) approach

4SBC as TrueTile Pathfinder

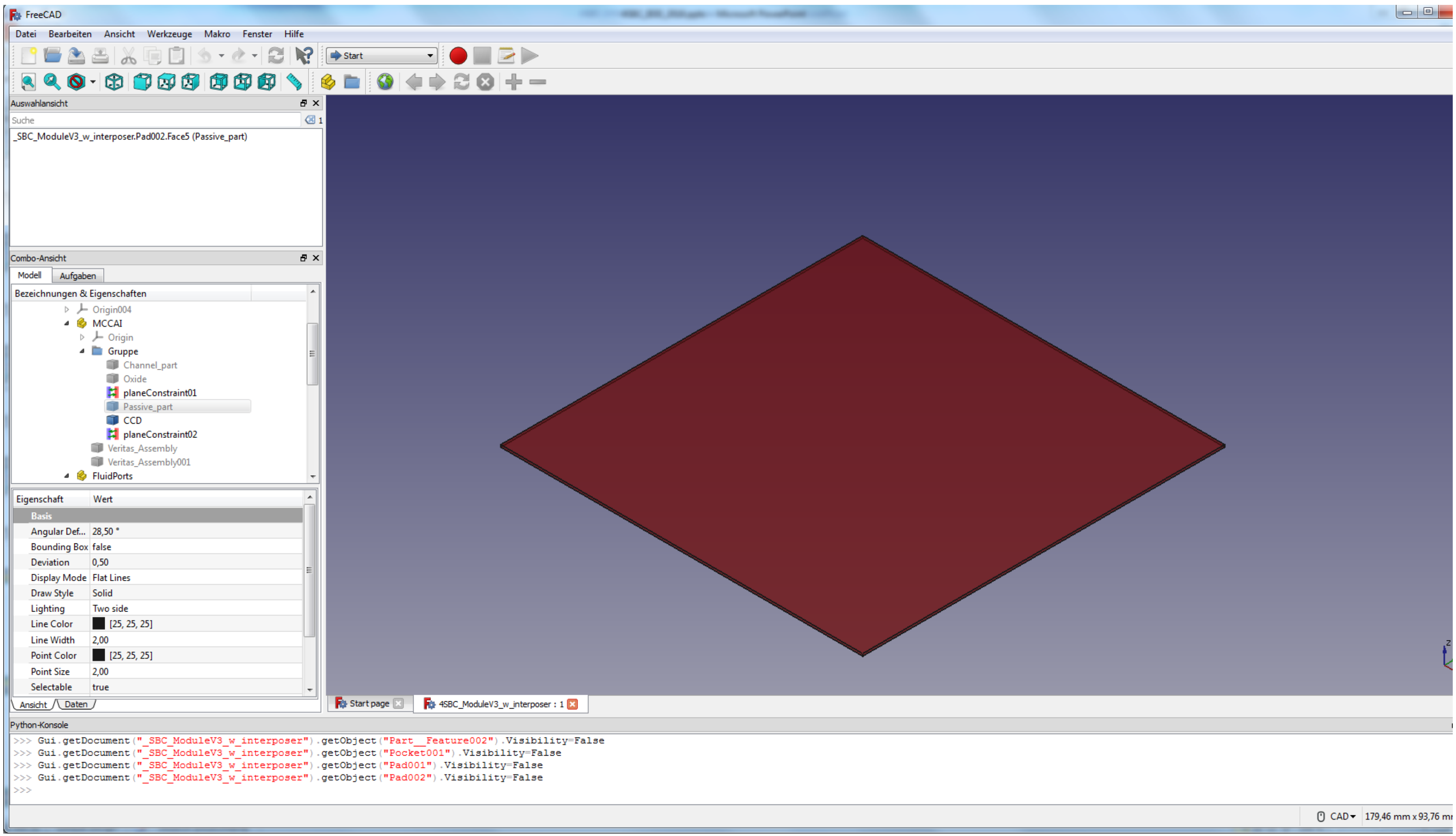
Pathfinder device architecture:

- "Conventional" pnCCD
- Standard mode (no frame store) suitable for synchronous operation
- Split frame / column parallel readout for optimized framerate
- 1 MPixel array with 75 x 75 μm^2 pixels, sensitive area 76.8 x 76.8 mm^2
- 2 x 1024 JFET (north edge and south edge) readout nodes read in parallel
- Readout: 2 x 16 x 64 channels
- Low complexity, low turnaround time
- Manufacturing in progress

1024 x 1024 pixels
75 x 75 μm^2
Sensitive area 76.8 x 76.8 mm^2
Standard mode, split frame, column-parallel pnCCD



CCD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Bezeichnungen & Eigenschaften
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Origin
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planeConstraint01
Passive_part
CCD
planeConstraint02
Veritas_Assembly
Veritas_Assembly001
FluidPorts
Eigenschaft Wert
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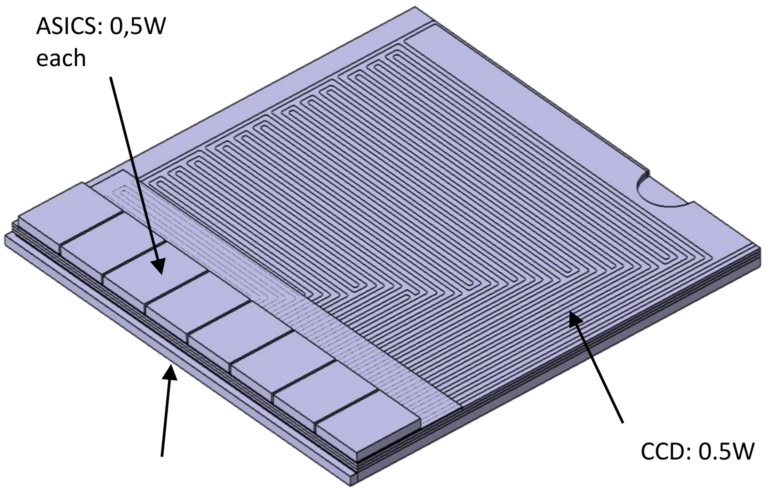
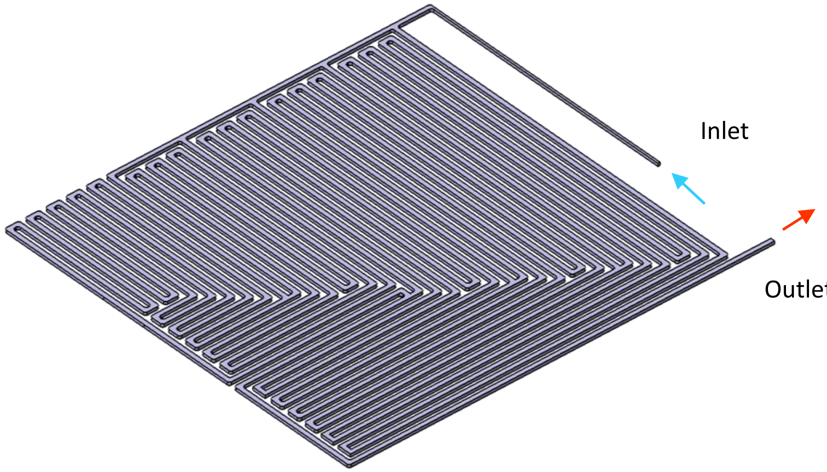
CAD
179,46 mm x 93,76 mm

4SBC Pathfinder: MCC



Expected power dissipation



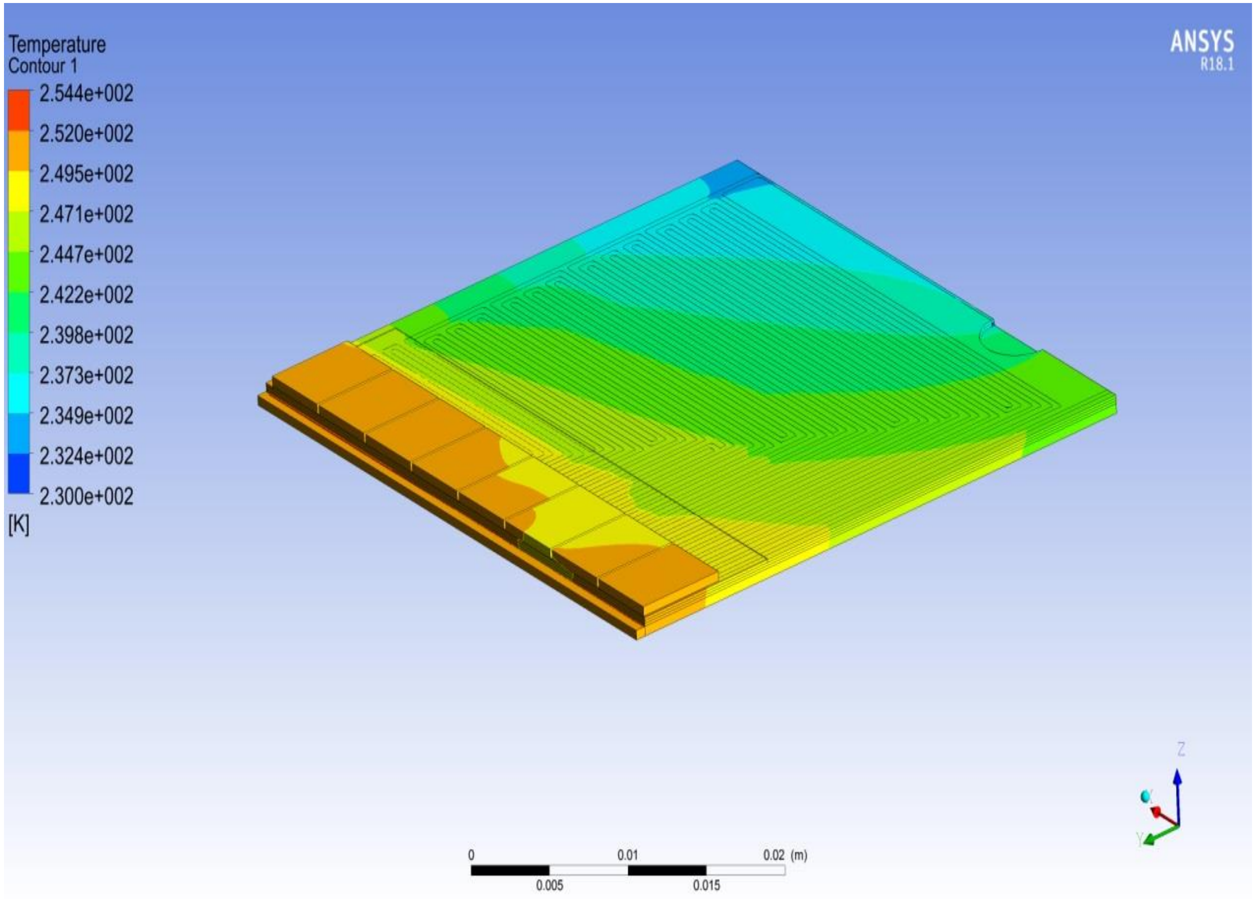
MCC channel design

Design and simulations:

M. Angel Villarejo, IFIC valencia

- 1 Quadrant of CCD
- Expected power dissipation
- Including parasitics (radiaton, conductive contributions)

4SBC Pathfinder: MCC



P = cp*m*ΔT → 7W=1348 x 2 x 0,0002 x 0,00015 x 4077 x (Tout-230) → 251K

Cooling fluid:

- PGW 80/20
- ρ = 1.348 kg / l
- η= 1.95 mPa s
- c_p = 4077 J / kg K

T_{out} of fluid= 246K
ΔP=3 bar

Channel geometry
200 x 150 μm^2

Power dissipation
@ MCC ~ 6 W
@ Module ~ 25 W

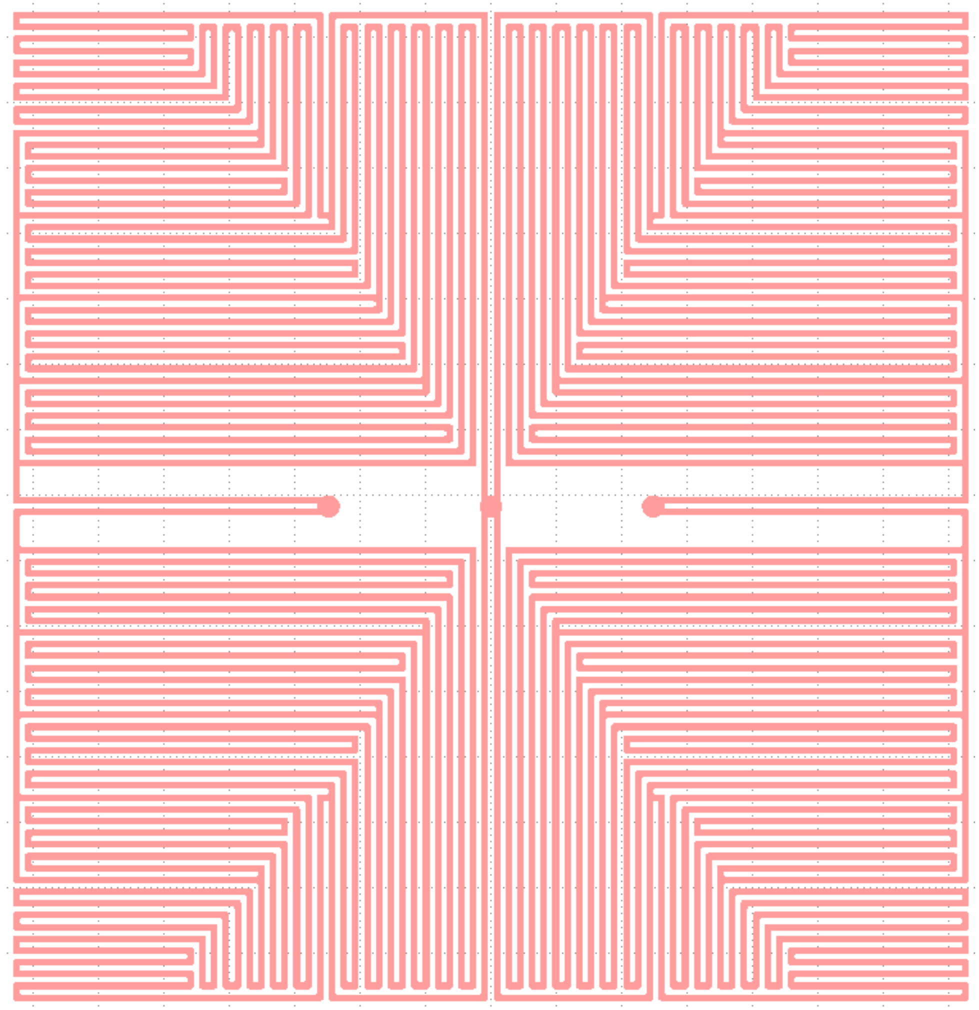
Temperature gradient
on device ~ 15°

New channel geometry (300 µm)
Adapted mass flow
Temperature gradient
on device < 5 ° C

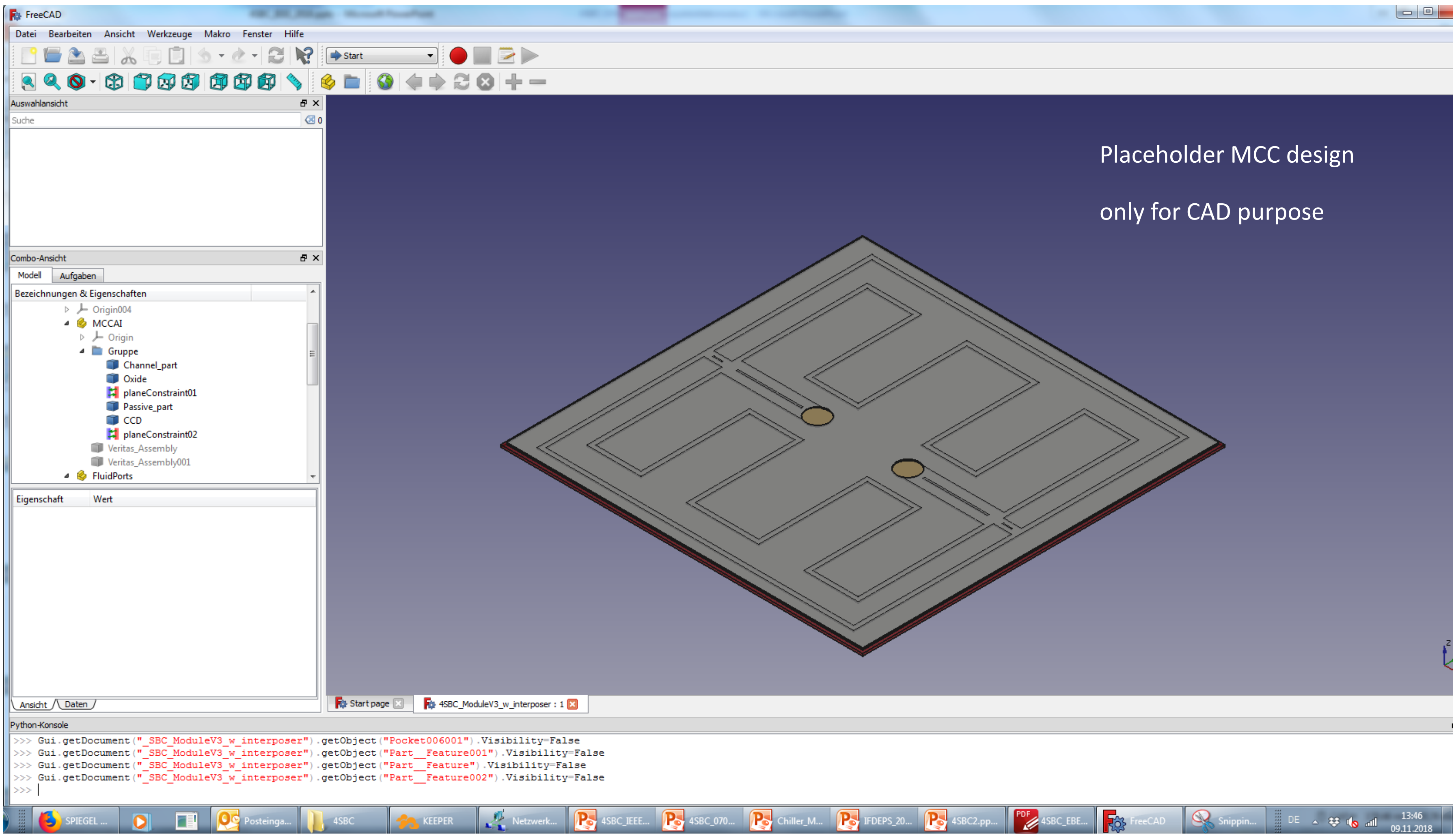
4SBC Pathfinder: MCC

MCC design:

- Large die area (~ 8 x 8 cm^2) structure as base for 4SBC AI
- Used to furnish first 4SBC prototype systems
- Confirm thermal simulations
- 4 quadrants
- 2 inlets
- 1 central outlet



MCC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only for CAD purpose
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4SBC Pathfinder: Pipes & Tubing

Silicon Terminal:

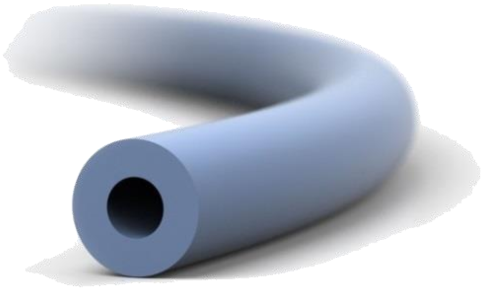
- IDEX NanoPort assembly
- Material: PEEK, Pressure rating: 70 bar
- Special glueing "groove" to avoid contamination of fluid path

Pipe Terminal:

- IDEX One-Piece finger-tight fitting
- Material: PEEK, pressure rating 340 bar
- For 1.6 mm tube

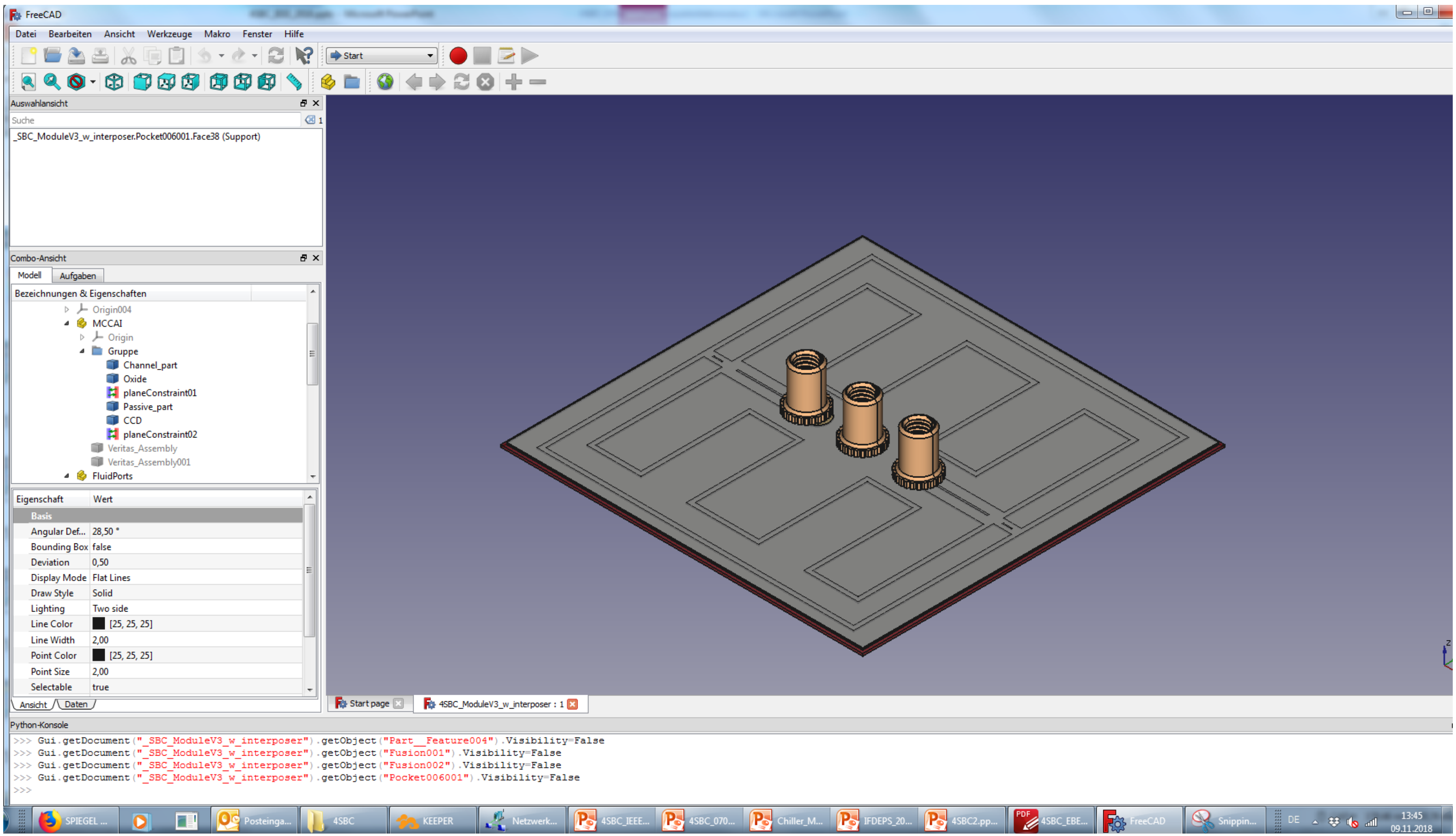
Tube:

- OD 1.6 mm, ID 0.25 – 1 mm
- Material: PEEK
- Pressure rating 480 bar
- Terminated on backend by standard (e.g. Swagelok) fittings



http://www.vici.com/index.php
http://www.idex-hs.com/

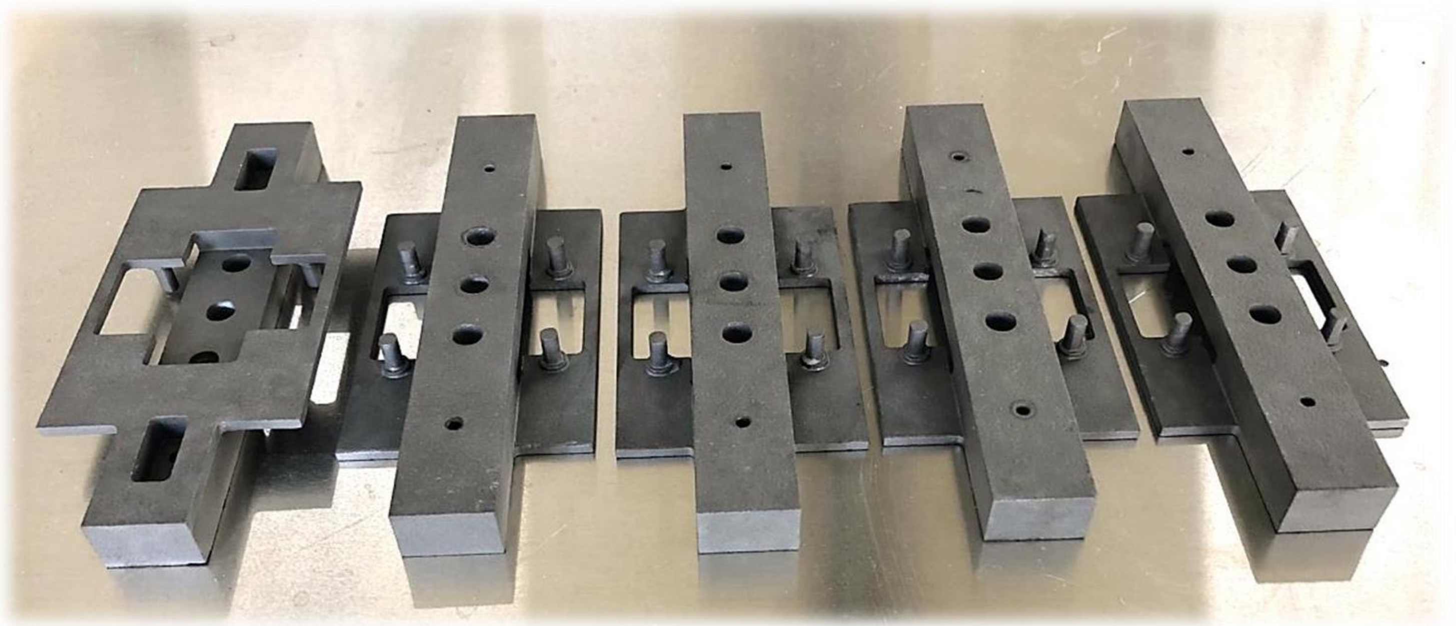
Pipes & Tubing



4SBC Pathfinder: Brackets

Support / mechanical interface:

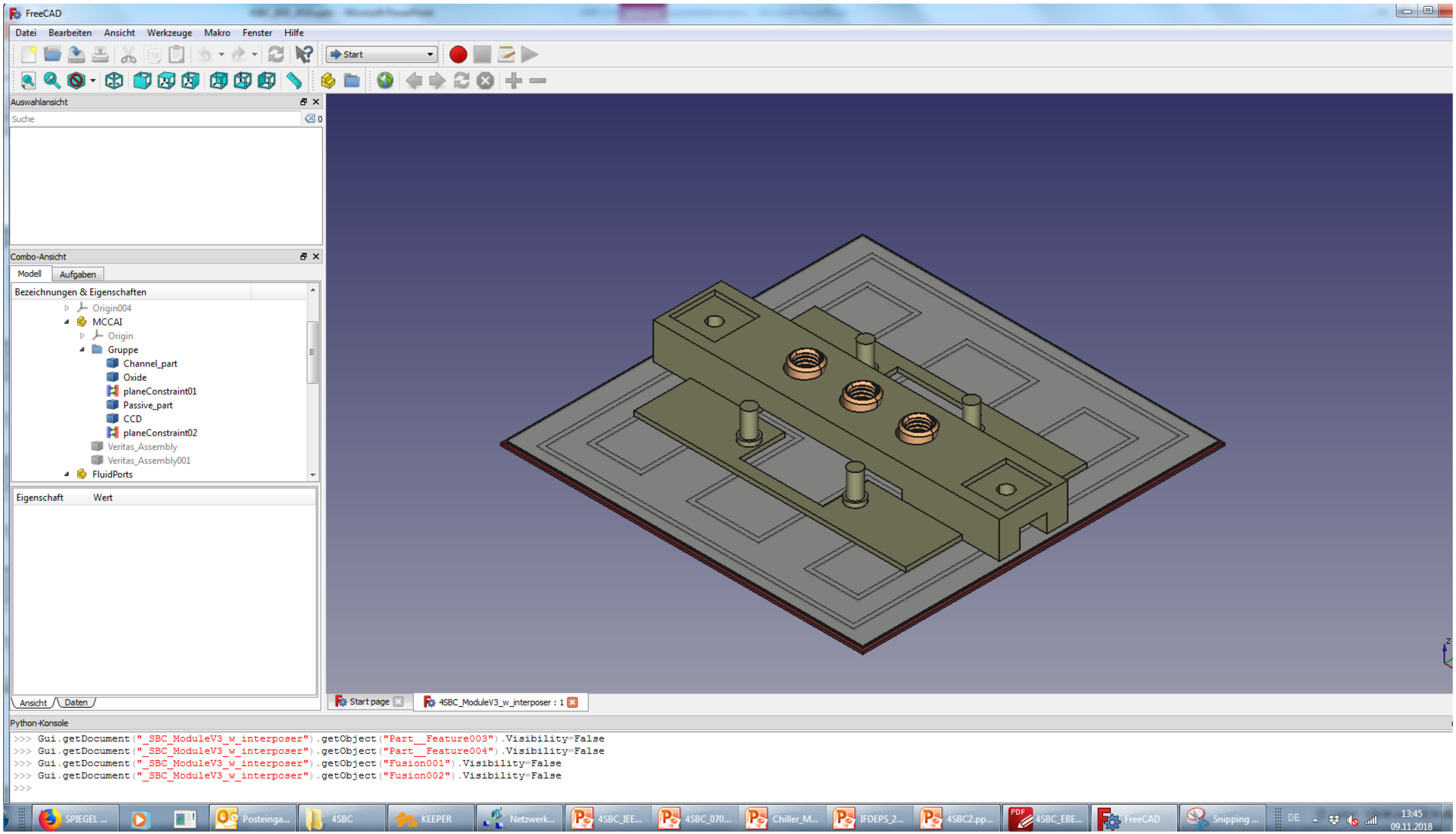
- Large-area glueing on silicon surface w/ BCB demands very good CTE match
- Here: CESIC (Carbon-Enhanced Silicon Carbide) material was selected due to
    - "Ideal" CTE match
- Good machining properties (polishing / spark erosion of small threads…)
- Ductility compared to Si / AlOx
- Low thermal capacitance



CESIC sensor bracket prototypes as fired

Courtesy: M. Krödel, ECM

Bracket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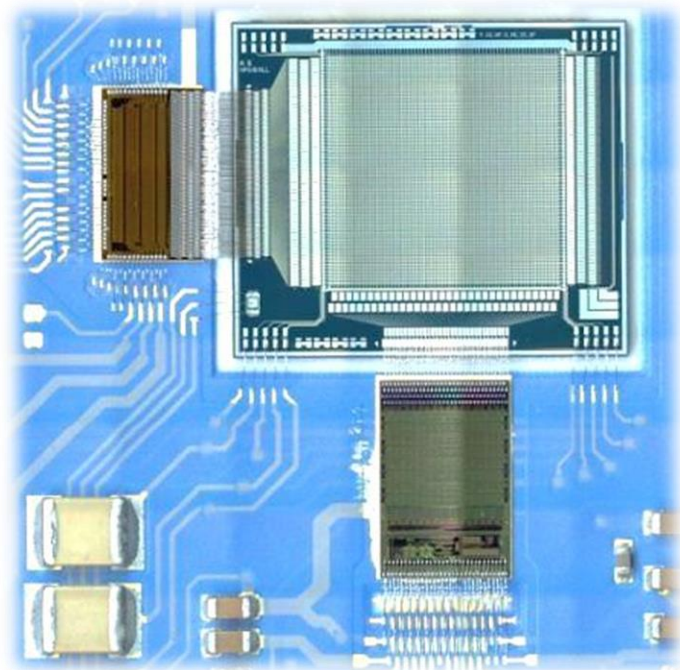
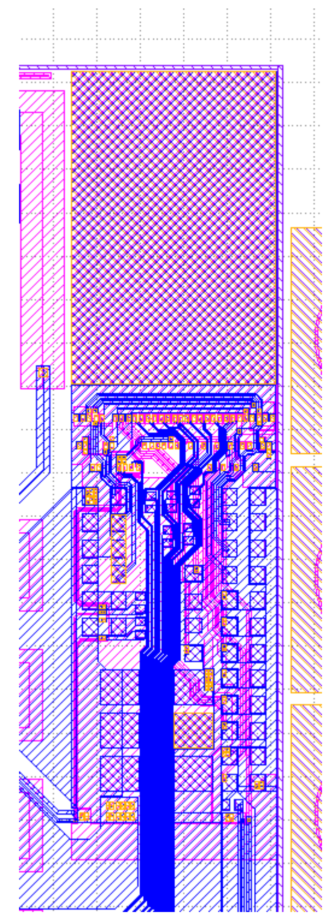
DE 13:45 09.11.2018

4SBC Pathfinder: ASICs

Readout IC: VERITAS II

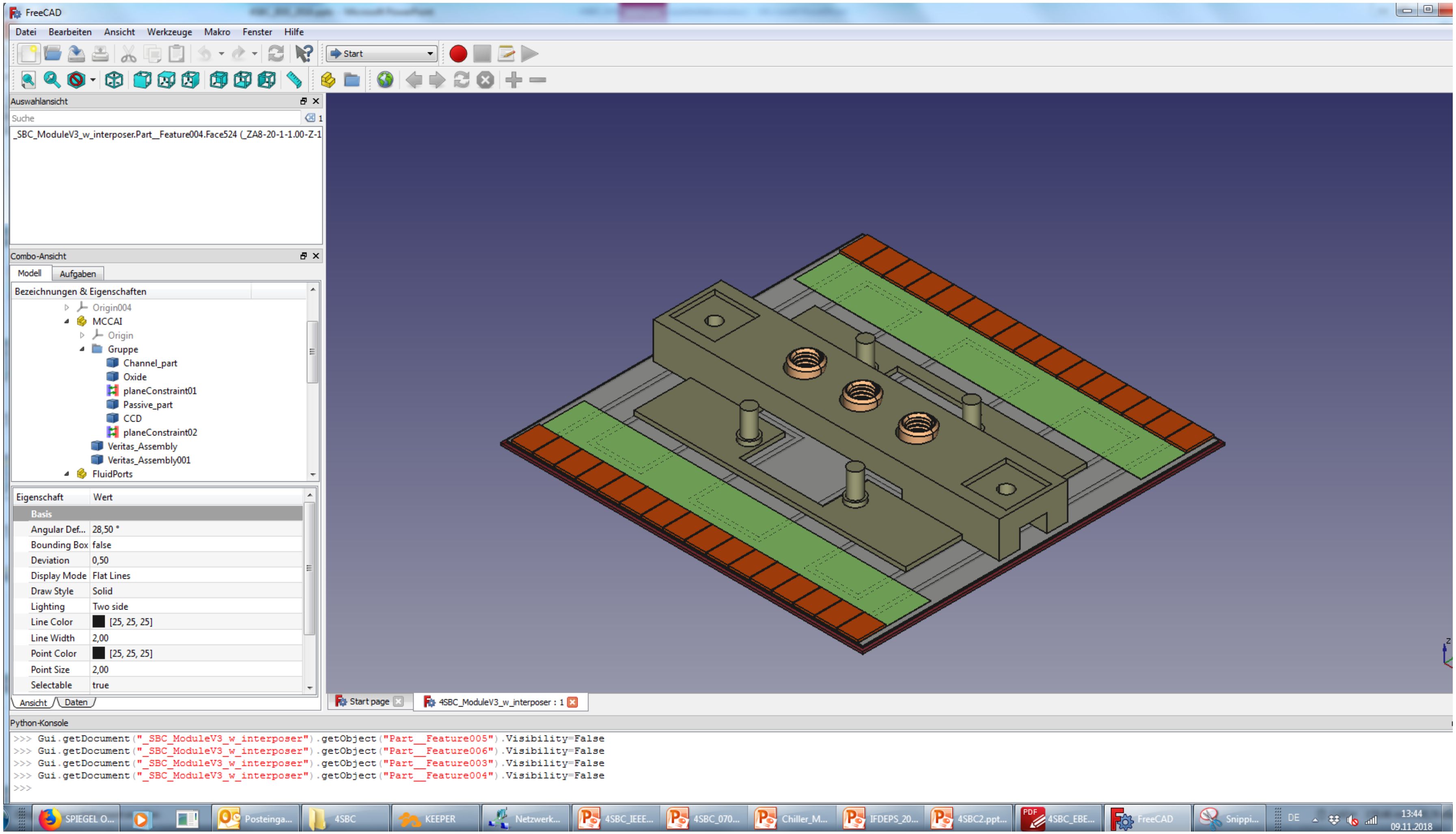
- AMS 0.35µ technology
- 64 channels
- Trapezoidal filter
- Fully differential architecture, CCD & DEPFET compatible
- Integrated sequencer, analog serialization (ν_{max} = 25 – 30 MHz)
- Min. shaping time ~ 0.5 µs
- Noise > 1 e- ENC
- Space required for passives ~ 9.5 mm
- Targeted readout: 2.5 µs / row
- Framerate: 800 Hz





M. Porro et al., Proc. of SPIE Vol. 9144 91445N-1 (2014)

ASICs



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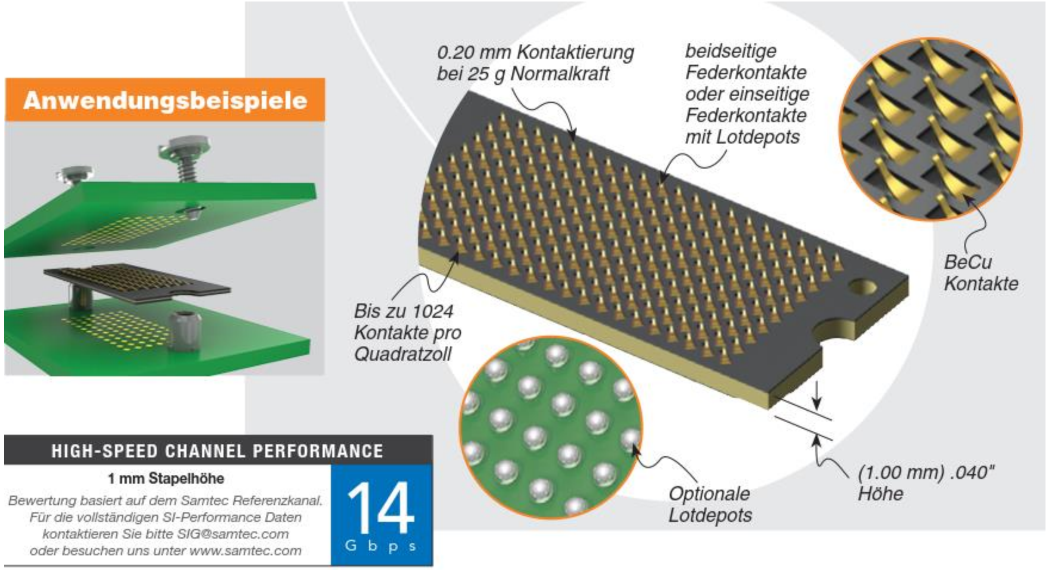
4SBC Pathfinder: Interposer

SAMTEC Z-ray interposer

- Compression-type interface
- BGA and Spring contacts
- Spring contacts for periphery
- 1 A current rating per pin
- 200 pins in total
- Tolerant against xy-displacement
- No shear forces on silicon

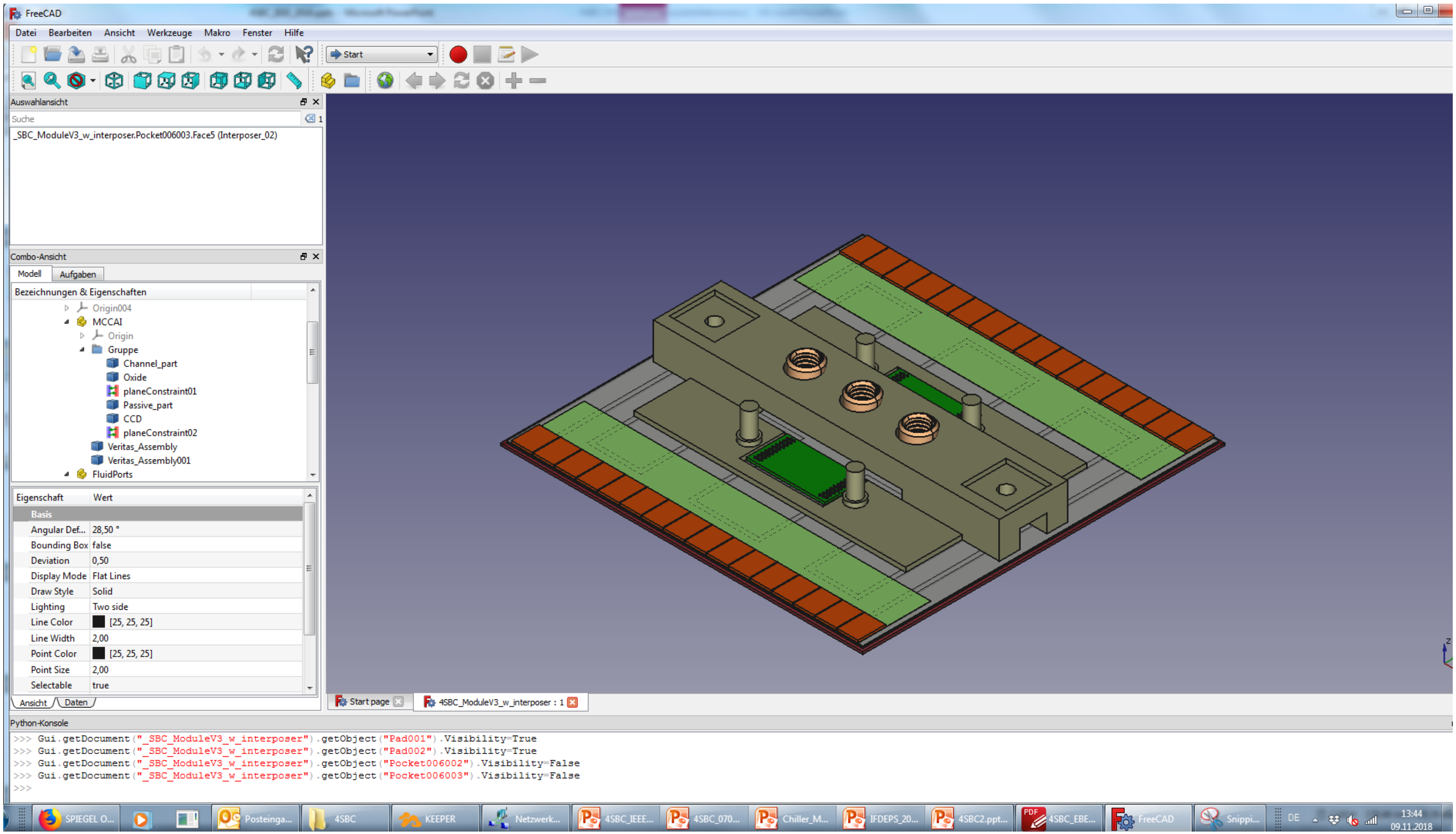
"Passive" Interposer PCB:

- Matchmaker / custom connector to backend readout electronics



Courtesy: SAMTEC

Interposer



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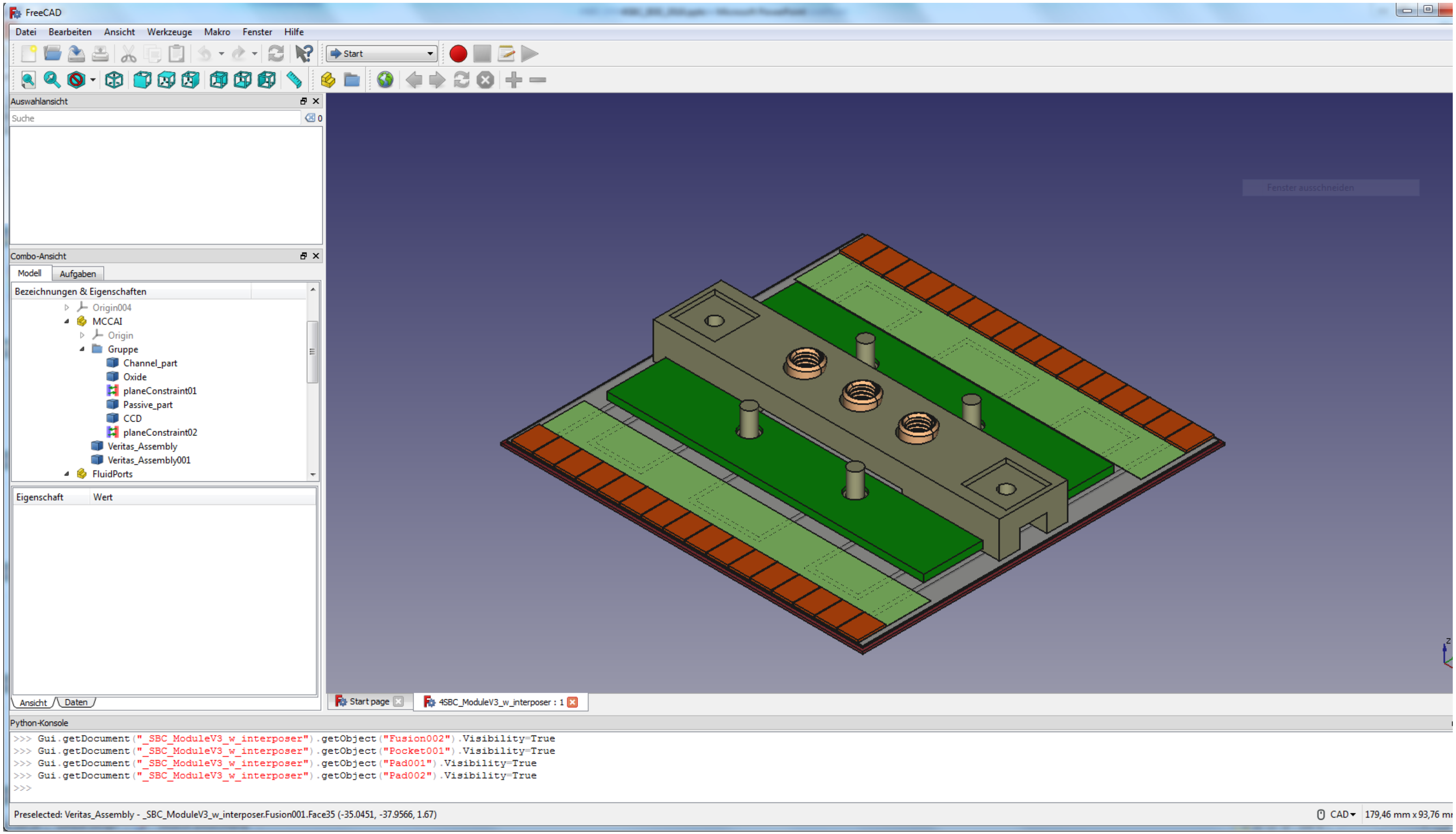
Interposer



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CAD
179,46 mm x 93,76 mm

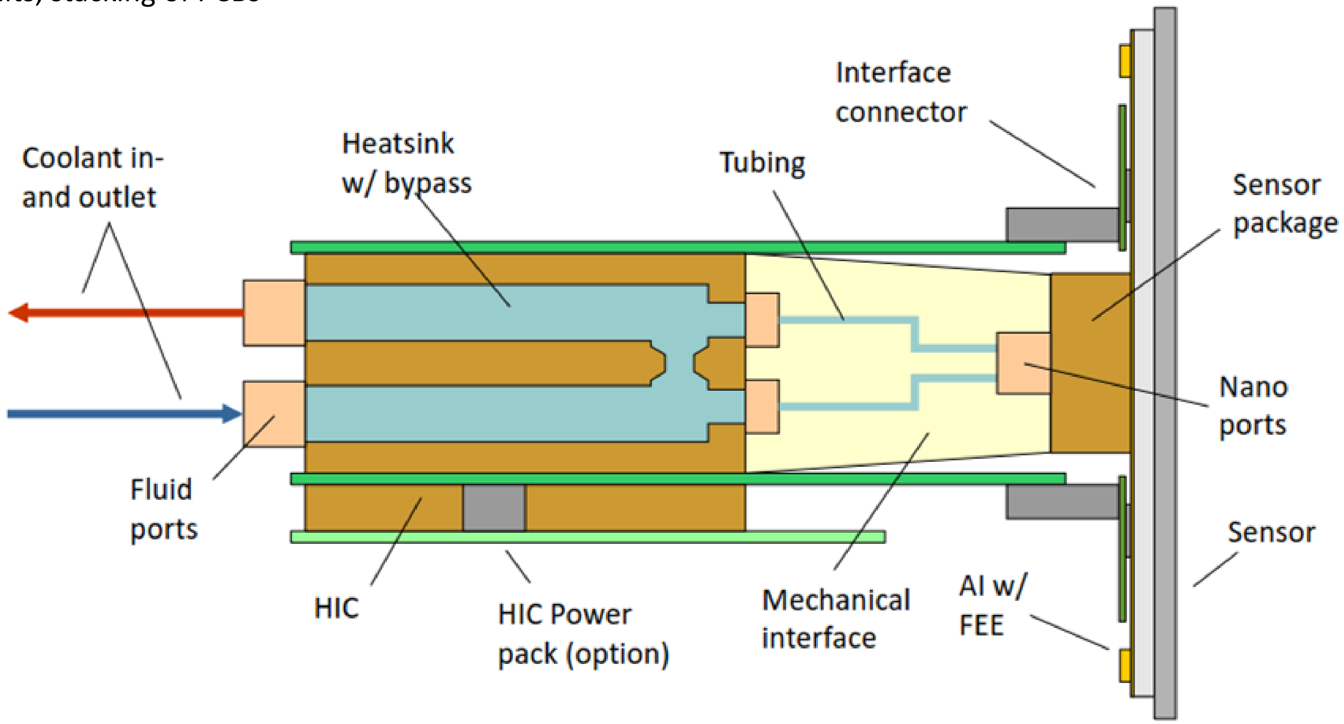
4SBC Pathfinder: Backend integration

Mechanical support

- Standard Multipin connector between interposer and Hemisphere Interface Card
- CCD connected w/ heatsink by interface parts
- Heatsink can act as pump bypass if required
- In case of PCB space limits, stacking of PCBs can be implemented
- Design in progress

Compact, flat package:

- Can easily fit in suitable vacuum compatible casing
- Low mass
- Transportable



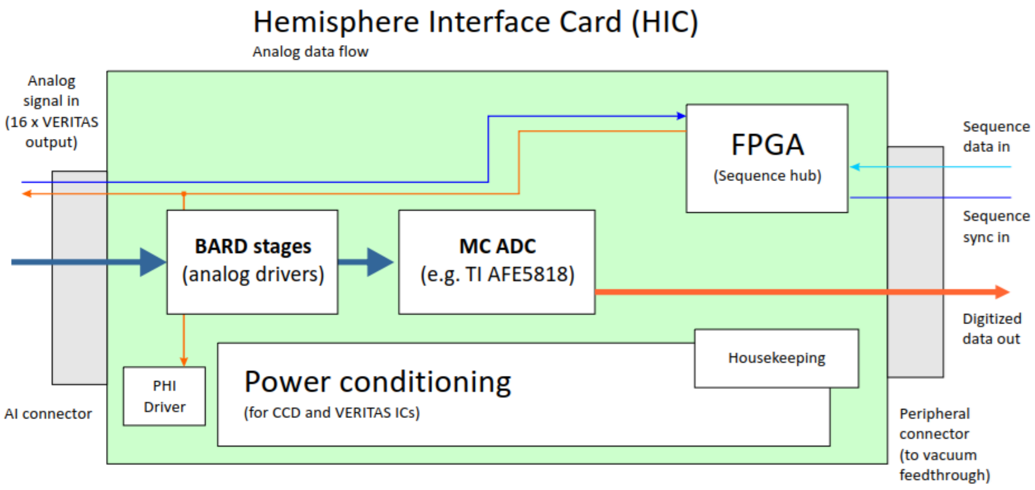
4SBC Pathfinder: Backend electronics

Hemisphere interface card

- BARD driver stages (digitally tunable)
- Multichannel ADC
- Power conditioning & housekeeping
- moved to piggy back PCB (PowerPack) if applicable
- small & simple FPGA as sequence hub

Vacuum interface:

- Only small number of voltages and digital signals to be trransferred to the outside
- Required for wire length contingency



4SBC Pathfinder: System

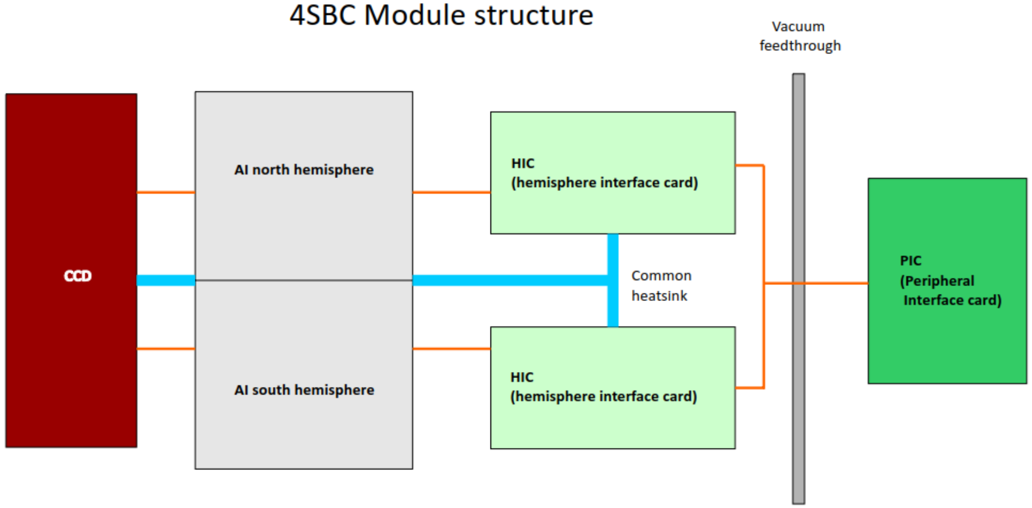
Digital backend module

- "Brain" layer (Xilinx Zynq SoC based solution)
- Sequence generation
- Data synchronization and metadata generation
- Zero suppression & clustering
- 10 GBit Ethernet interface for data transmission to file server

Power layer:

- Prereg board to generate LDO intput voltages

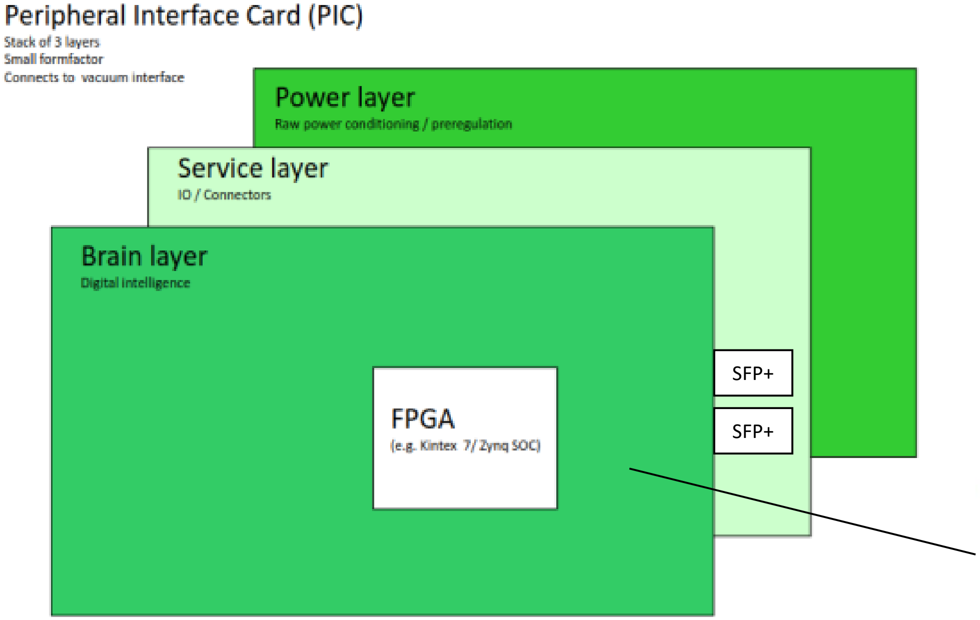
4SBC Module structure



Stand-alone capability

Easy to connect to larger systems

4SBC electrical backend

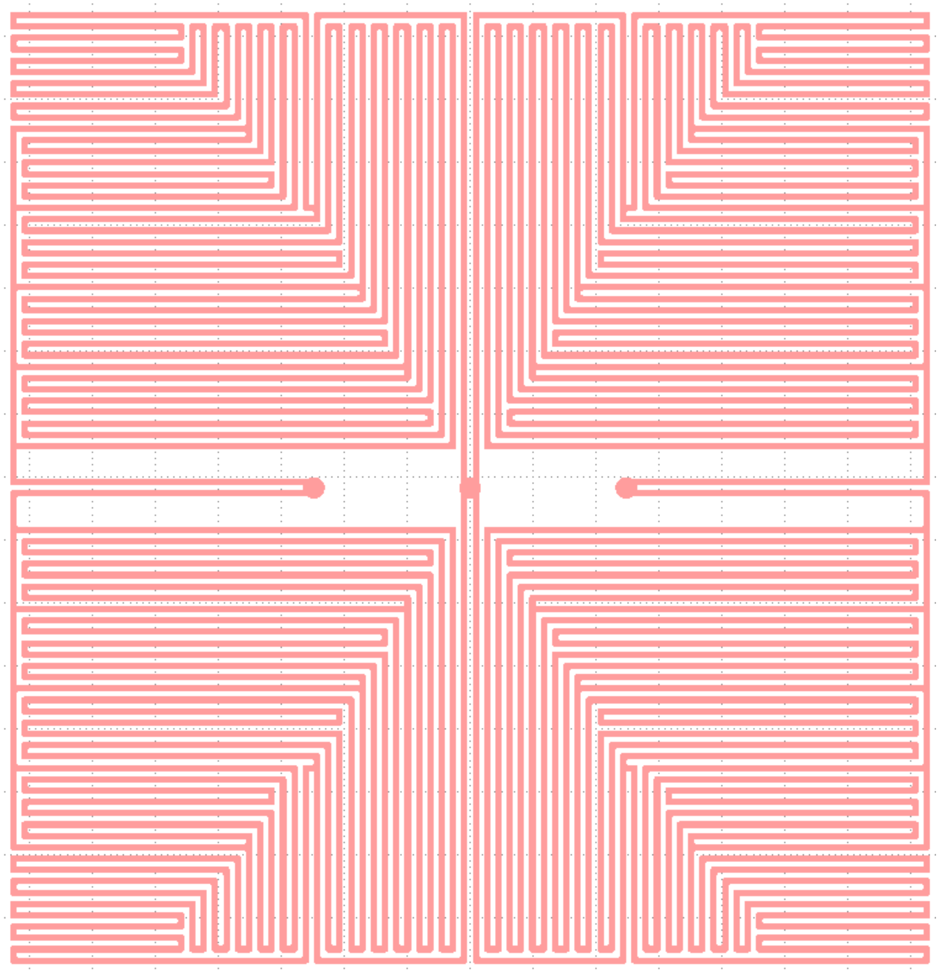


- Commercially avaliable Mercury XU1+
- Xilinx® Zynq Ultrascale+™ MPSoC
- 4GB DDR4 ECC SDRAM
- 16 × 6/8/12.5 Gbit/sec MGT
- 2 × Gigabit Ethernet
- Up to 747,000 LUT4-eq
- Small form factor (74 × 54 mm)

"Kids today with all their technology."

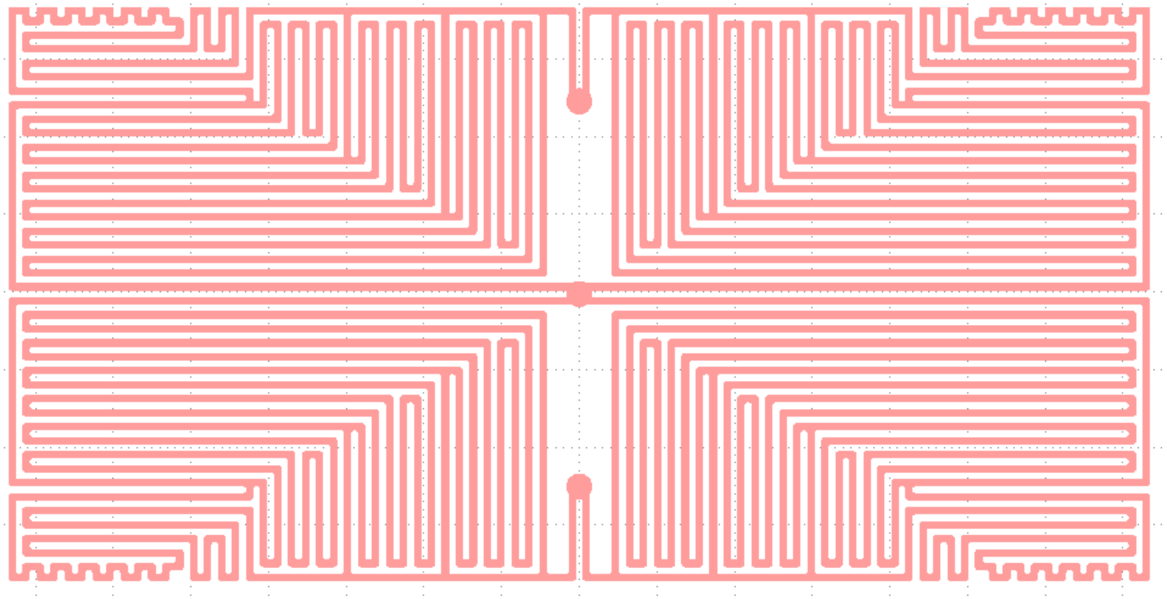
- PIC is interface to outer world and data acquisition system
- "3 layer" approach for maximum flexibility and modularity
  - "Power layer": raw supplies for HIC
  - "Service layer": offers connectivity periphery
  - "Brain layer": FPGA based preprocessor / data wrapper

MCC production



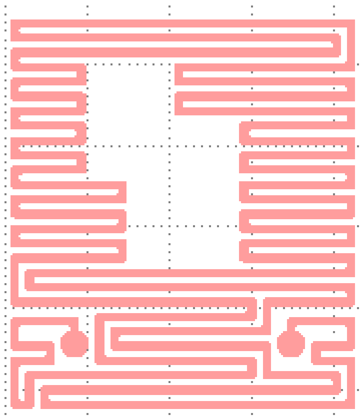
- Large area (~ 8 x 8 cm^2) structure as base for 4SBC AI
- Performance test
- Used to furnish first prototype systems
- 4 quadrants
- 2 inlets
- 1 central outlet

FSP MCC

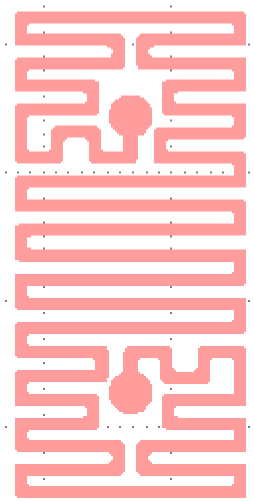


- Large area (~ 8 x 4 cm^2) structure as replacement for the FSP Heat spreader
- 4 quadrants
- 2 inlets
- 1 central outlet
- Interfaces FSP cooling block (redesign with slight changes required)
- Lower effective length
- Optional replacement for TEC
- Eases system design and assembly
- Lower cooling requirements
- Will not have AI

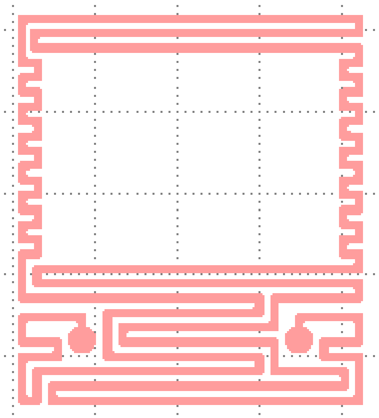
Prototype coolers



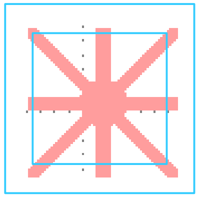
- XS MCC
- Test MCCs for DEPFET XS device sizes
- GREST hybrid etc.



- Terminal test structures
- Qualify gluing process for coolant terminals
- Check tightness, handling etc…



- MP MCC (Multipurpose)
- Test MCCs for undefined size
- Variable detector size
- Max. cutout 13 x 17 mm^2
- Tradeoff flexibility vs. thermal performance
- CCD etc..



- Lid test structures
- Test structure for process of opening the access point to the MCC channels
- Contour cut opens channels at the edges to visually inspect for particle contamination

AI production

Standard dummy Material

- 450 mm material thickness
- NO embedded MCC

SOI raw wafers:

- 150 mm cover layer
- 300 mm channel depth
- 150 mm bottom layer

AI dummies:

- Test of AI layout
- Simpler technology (1 Al, 1 x Cu)
- SMD components for one ASIC
- One ASICs
- Heater structure for power deposition
- Functional verification

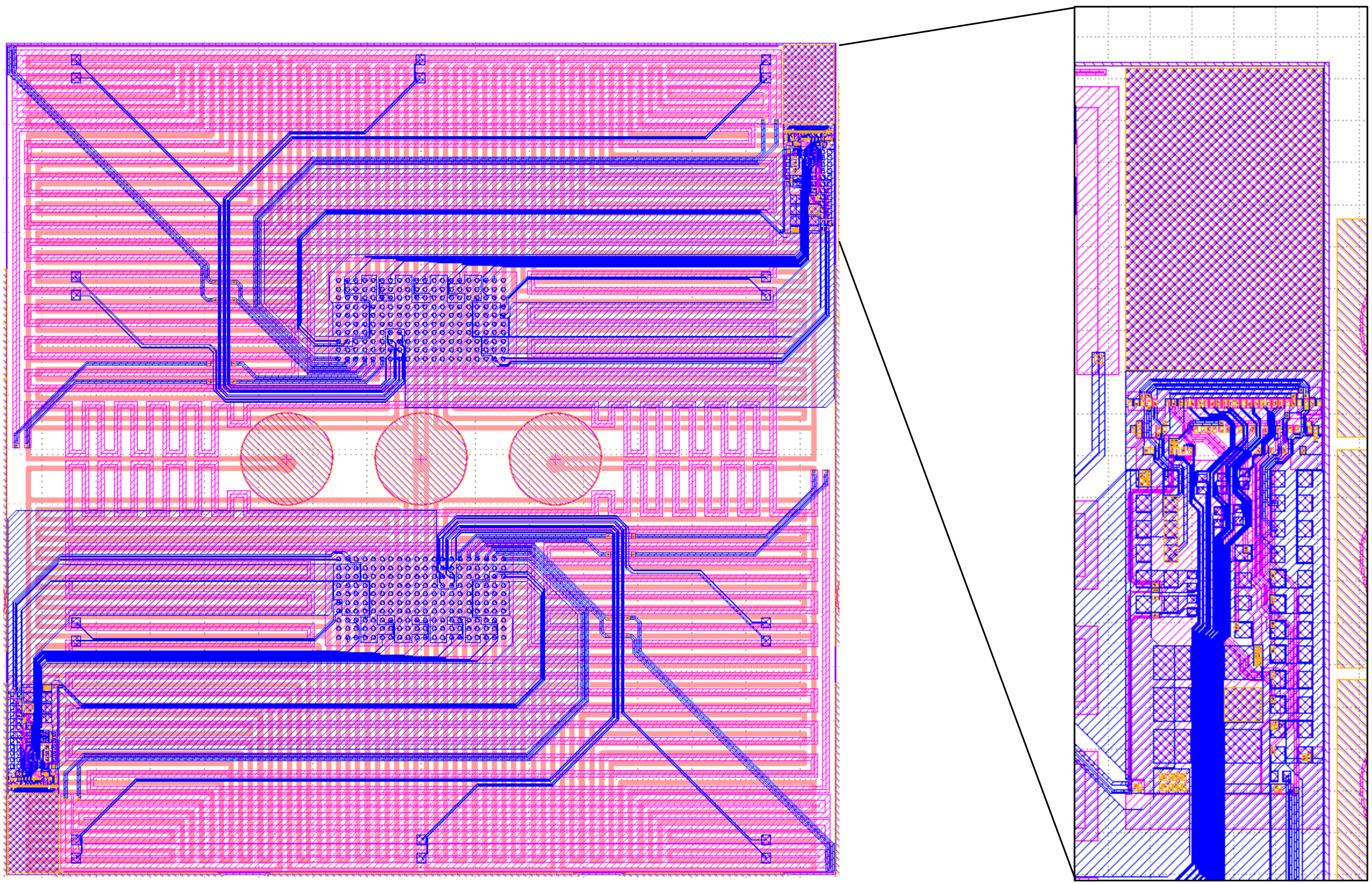
MCC heaters:

- Same layout / technology as AI dummies
- Test of MCC performance
- Test of pump equipment
- Parametrization
- Evaluation of displacement / distortion etc.
- Reliability test

AI V 1.0:

- All SMD components
- More advanced technology (2x Al, 1 x Cu)
- Fully populated with ICs
- For use with CCD

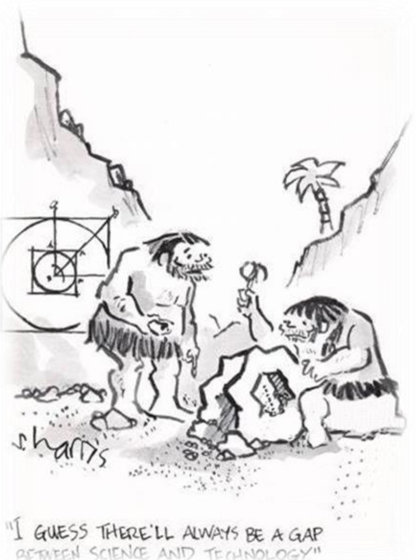
Al production

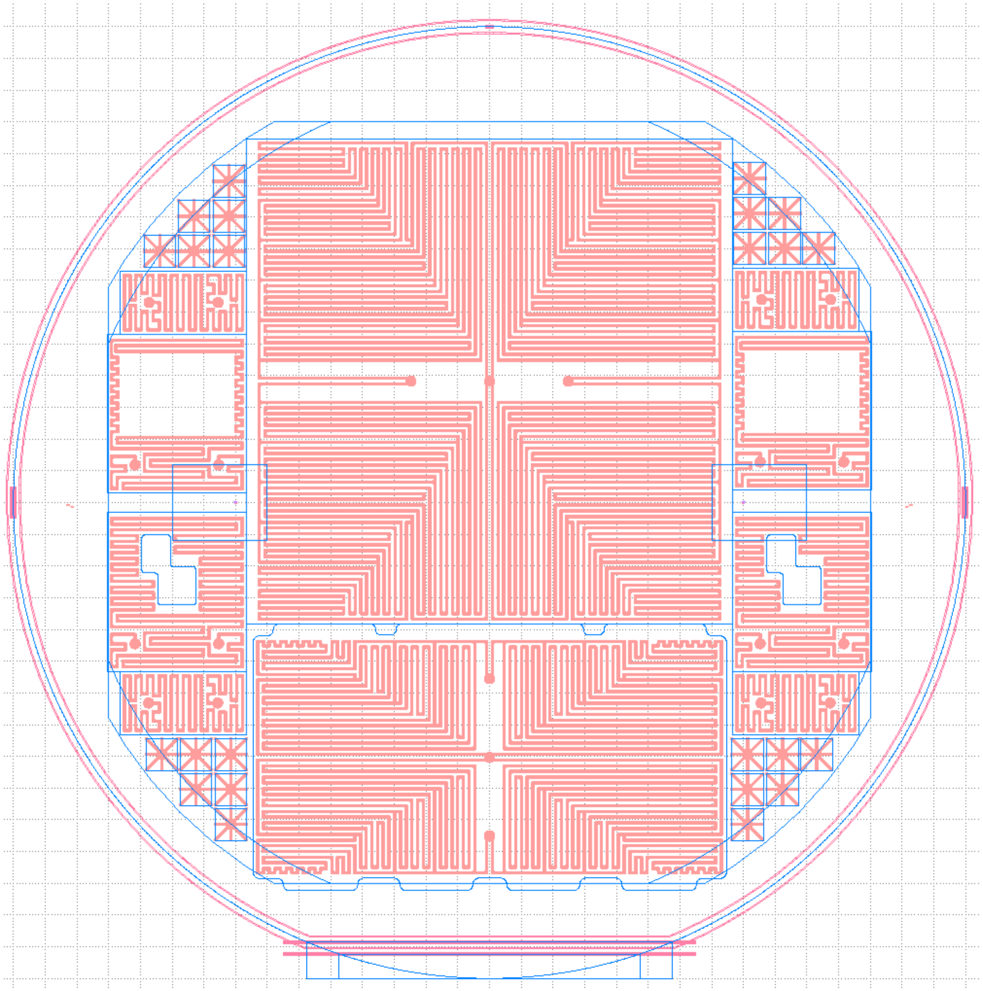


Status

AI development:

- MCC wafer layout submitted to ICEMOS
- **Scheduled delivery 10/18**
- **Postponed**
- **Date still open…**
- AI dummies in fabrication





4SBC PCU development

Pump/Chiller unit (PCU):

- Delivers required cooling power to detector at specified temperature
- Product of volumetric mass flow, density and heat capacitance
- Required pressure depends on MCC channel geometry and coolant viscosity
- **Parameters:**
    - Volumetric flow / Pressure
    - Temperature

$$\tau = \dot{v} \cdot \rho \cdot c_p$$
$$\Delta P = R_{fl} \cdot \eta \cdot \dot{v}$$

Detector

- Power dissipation
- Power distribution
- Operating temperature

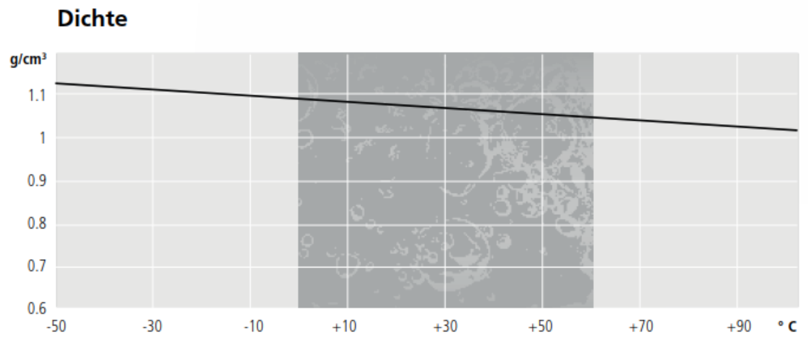
Coolant

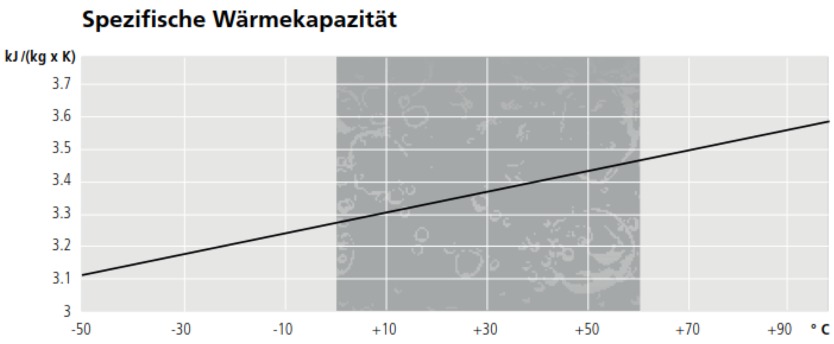
- Heat capacitance
- Density
- Viscosity
- Temperature dependence

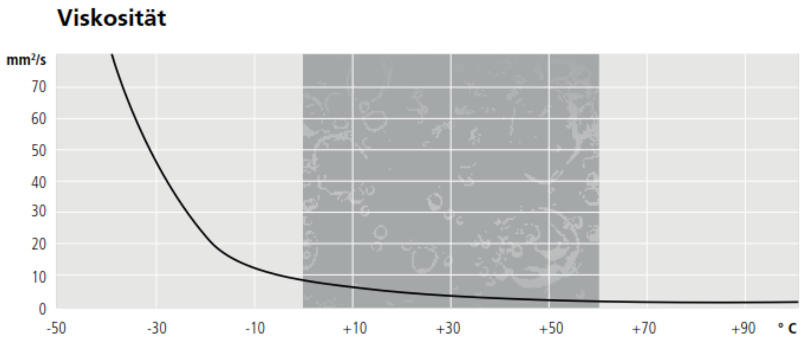
MCC

- Design
- Eff. channel length
- Channel geometry

The right coolant







- **Example:**
  - Data from Julabo
  - Thermal G (Water / Glycol mixture (50 : 50)

The right coolant

Class	Pro's	Con's	Comment
Silicone oil	Inert Low viscosity	Creeps "Sticky", contaminates Material limitations	Dissuasion due to contamination issues
Fluorocarbons	Inert High density	Low specific heat High vapour pressure Pollute	In-house experience
Hydrocarbons	Good specific heat	Low density High viscosity Flammable Material limitations	
Gylcol / water based	High specific heat High density	High viscosity Purity / composition monitoring	Excellent for high temperatures

- **Cooling requirements:**
  - Target temperature at MCC inlet ~ -40°C
  - Coolant temperature @ chiller -50 °C to - 60 °C to account for losses
  - Power dissipation per MCC ~ 6 W with low gradient

Overview

#	Fluid	Manufacturer	Material	T_{low}	Dyn. Viscosity (mPa s) @20°C	@-40°C	Specific heat J/ (g K) @20°C	@-40°C	Density [g/cm³] @ -40°C
1	**DW therm**	Huber	Triethoxysilan	-90°C	1.936	9.19	1.77	1.64	0.93
2	**SilOil M60**	Huber	Silicone oil	-60°C	4.62	23.5	1.61	1.53	0.98
3	**SilOil M80**	Huber	Silicone oil	-80°C	2.7	10.6	1.66	1.57	0.97
4	**SilOil M90**	Huber	Silicone oil	-90°C	1.74	5.64	1.76	1.65	0.96
5	**Kryo 95**	Lauda	Silicone oil	-95°C	1.38	5.52	1.75	1.65	0.96
6	**Kryo 70**	Lauda	Silicone oil	-70°C	4.6	21.3	1.52	1.45	0.97
7	**Kryo 60**	Lauda	Silicone oil	-60°C	2.99	12.5	1.66	1.57	0.96
8	**Kryo 65**	Lauda	Hydrocarbons	-65°C	1.30	8.9	2.1	1.8	0.8
9	**HT135**	Galden	Perfluoropolyether	-60°C	1.72	6.32	0.96	n/a	1.72
10	**HT170**	Galden	Perfluoropolyether	-50°C	6.04	39.1	0.96	n/a	1.77
11	**HT110**	Galden	Perfluoropolyether	-70°C	1.32	6.76	0.96	n/a	1.71
12	**HT80**	Galden	Perfluoropolyether	-80°C	0.96	3.58	0.96	n/a	1.69
13	**HT70**	Galden	Perfluoropolyether	-90°C	0.84	3.19	0.96	n/a	1.68
14	**HT55**	Galden	Perfluoropolyether	-100°C	0.74	2.45	0.96	n/a	1.65
15	**Thermal HY**	Julabo	Silicone oil	-80°C	< 3.6	13.4	1.5	1.45	0.96
16	**Thermal H5**	Julabo	Silicone oil	-50°C	5.21	22.5	1.5	1.42	0.97
17	**Thermal HL60**	Julabo	Silicone oil	-60°C	5.21	24.5	1.48	1.41	0.98
18	**Thermal HL80**	Julabo	Silicone oil	-85°C	2.86	11.5	1.7	1.55	0.96
19	**Paratherm CR**	Paratherm	Hydrocarbons	-88 °C	1	2	1.84	1.68	0.89
20	**Paratherm LR**	Paratherm	Hydrocarbons	-60 °C	3	16	1.93	1.76	0.81
21	**Duratherm XLT-120**	Duratherm	Hydrocarbons (?)	-85°C	0.96	4.46	2.05	1.89	0.83
22	**Dynalene MV**	Dynalene	Hydrocarbons	-100°C	1.07	2.63	1.80	1.59	0.892
23	**PSF-1.5cSt**	Clearco	Silicone oil	-80°C	1.27	5.46	1.7	n/a	0.851
24	**PSF-5cSt**	Clearco	Silicone oil	-70°C	4.57	37	1.63	n/a	0.918
25	**PSF-10cSt**	Clearco	Silicone oil	-60°C	9.35	71	1.51	n/a	0.935
26	**Dowtherm J**	Dow	Hydrocarbons	-80°C	1.39	2.88	1.75	1.66	0.91
27	**Syltherm XLT**	Dow	Silicone oil	-100°C	1.4	> 3.1	< 1.83	< 1.69	0.9
28	**Syltherm HF**	Dow	Silicone oil	-73°C	1.7	12	1.71	1.48	0.92
29	**Dowtherm 4000**	Dow	Glycol-based	-50°C	4.5	44	3.21	3.05	1.11
30	**Dowtherm SR-1**	Dow	Glycol-based	-50°C	4.5	44	3.29	3.09	1.1
31	**HFE-7100**	3M	Hydrocarbons	~ -80°C	3	16.3	1.17	1.05	1.63

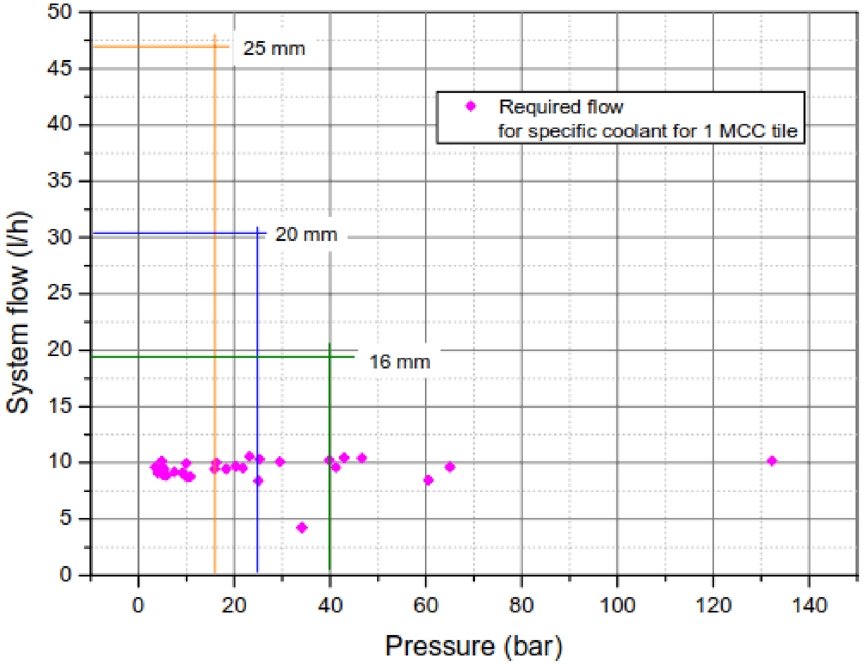
Examples for all classes

Available on the market in suitable quantities

Probably there are more…

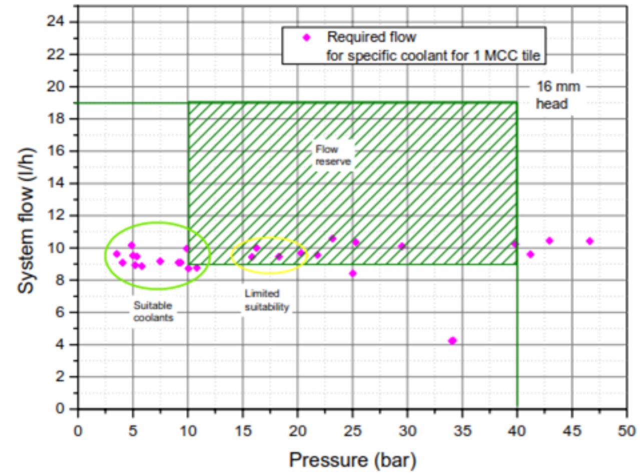
Chosen coolant has big impact on required pump / chiller system!

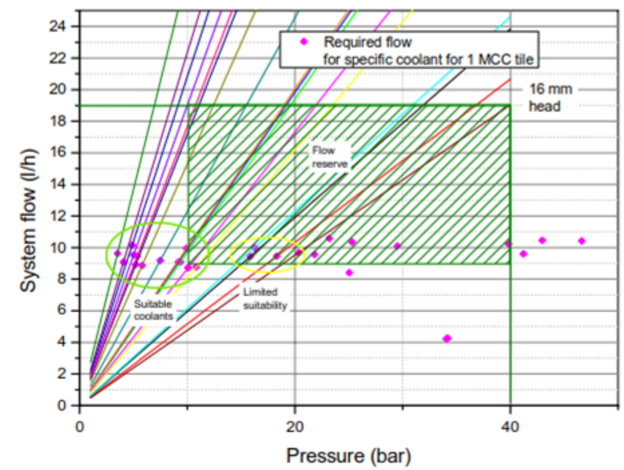
Pump vs. coolant



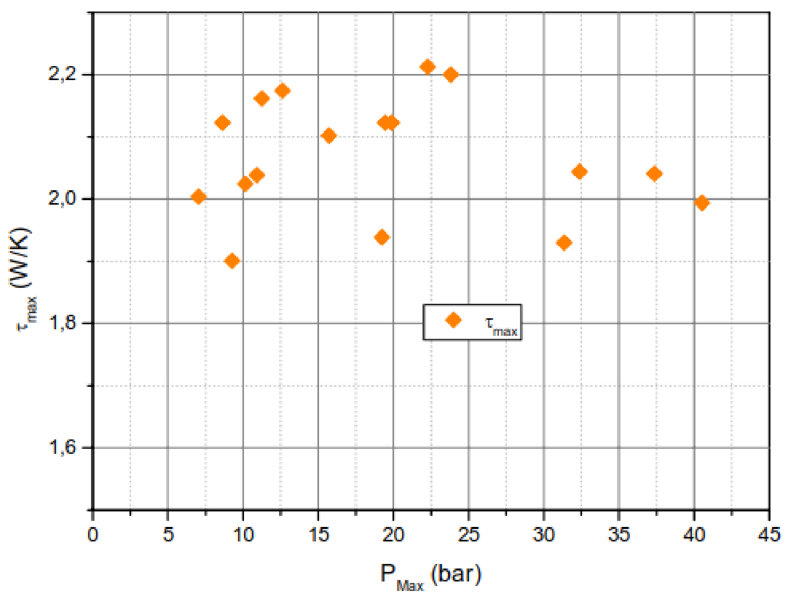
Example:

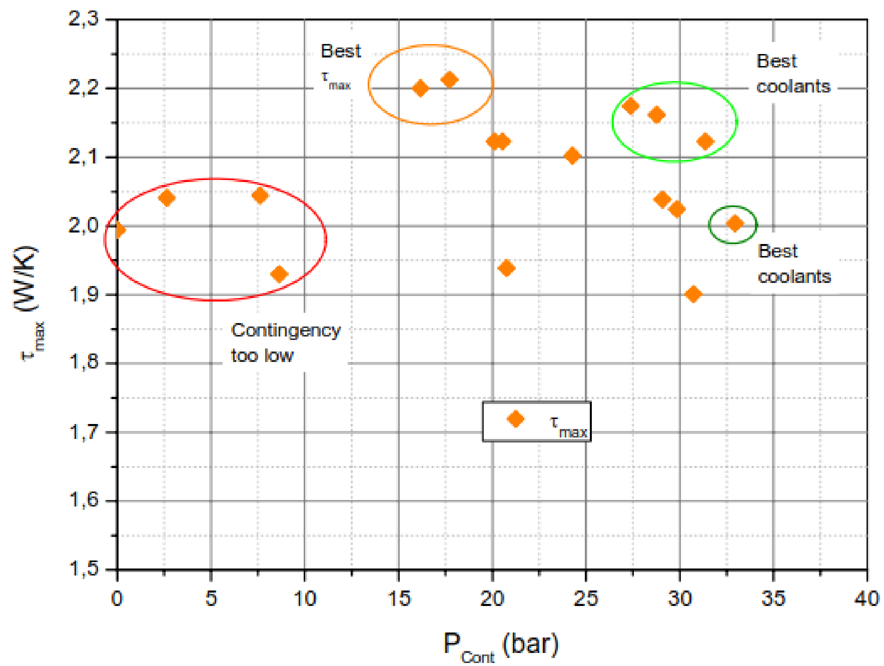
Lewa FC metering pump line





Pump vs. coolant II





Contingency:

- High pressure contingency required
- Compensate flow-dependent pressure drop on pipework
- Best medium is high achievable τ_{max} for max. contingency
- Pump-dependent

Pump vs. coolant III

#	Fluid	Manufacturer	Material	Ref. flux [l/h]	Ref. pressure [bar]	P_{Max} [bar]	τ_{max} [W/K]	P_{Cont} [bar]	Evaluation
1	**DW therm**	Huber	Triethoxysilan	2,4	16	32	2,0	8	Contingency too low
3	**SilOil M80**	Huber	Silicone oil	2,4	18	37	2,0	3	Contingency too low
4	**SilOil M90**	Huber	Silicone oil	2,3	10	20	2,1	20	
5	**Kryo 95**	Lauda	Silicone oil	2,3	9	20	2,1	20	
8	**Kryo 65**	Lauda	Hydrocarbons	2,5	16	31	1,9	9	Contingency too low
9	**HT135**	Galden	Perfluoropolyether	2,2	10	22	2,2	18	Best tau_{max}
11	**HT110**	Galden	Perfluoropolyether	2,2	11	24	2,2	16	Best tau_{max}
12	**HT80**	Galden	Perfluoropolyether	2,2	6	13	2,2	27	Best
13	**HT70**	Galden	Perfluoropolyether	2,2	5	11	2,2	29	Best but high vapour pressure
14	**HT55**	Galden	Perfluoropolyether	2,3	4	9	2,2	31	Best but high vapour pressure
18	**Thermal HL80**	Julabo	Silicone oil	2,4	20	40	2,0	0	No contingency
19	**Paratherm CR**	Paratherm	Hydrocarbons	2,4	4	7	2,0	33	Best contingency
21	**Duratherm XLT-120**	Duratherm	Hydrocarbons (?)	2,3	8	16	2,1	26	
22	**Dynalene MV**	Dynalene	Hydrocarbons	2,5	5	9	1,9	31	
23	**PSF-1.5cSt**	Clearco	Silicone oil	2,5	10	19	1,9	21	
26	**Dowtherm J**	Dow	Hydrocarbons	2,4	5	10	2,0	30	
27	**Syltherm XLT**	Dow	Silicone oil	2,4	5	11	2,0	29	

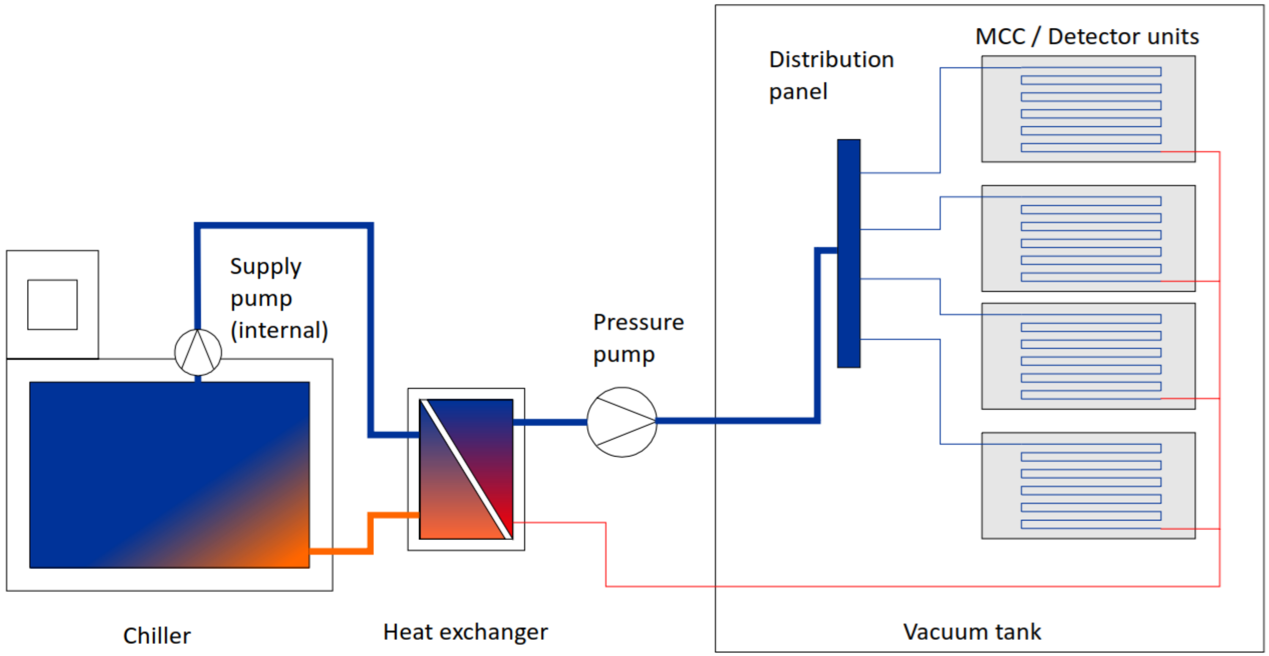
Result:

- Fluorocarbons win (for this pump…)
- Low viscosity, low operating temperature

4SBC Pathfinder: Pump system

Chiller unit:

- System adequate for 4 4SBC modules
- Temperature at inlet of MCC -40°C
- Min. Chiller temperature ~ -60 °C
- Cooling power ~ 25 - 30 W per module (including contingency)
- Total cooling power ~ 120 W (plus some overhead for losses)
- Target flow **in MCC** min / max~ 10 - 40 l / h (2.8 – 11.1 ml/s) including contingency
- Target pressure range 25 – 30 bar including contingency
- Short distance to pressure distribution panel (< 10 cm), bridged with 1 mm inner Ø pipes
- Compact, as small form factor as possible
- Flow measurement possible
- Low pulsation (snubber?)



4SBC Pathfinder: Pump system

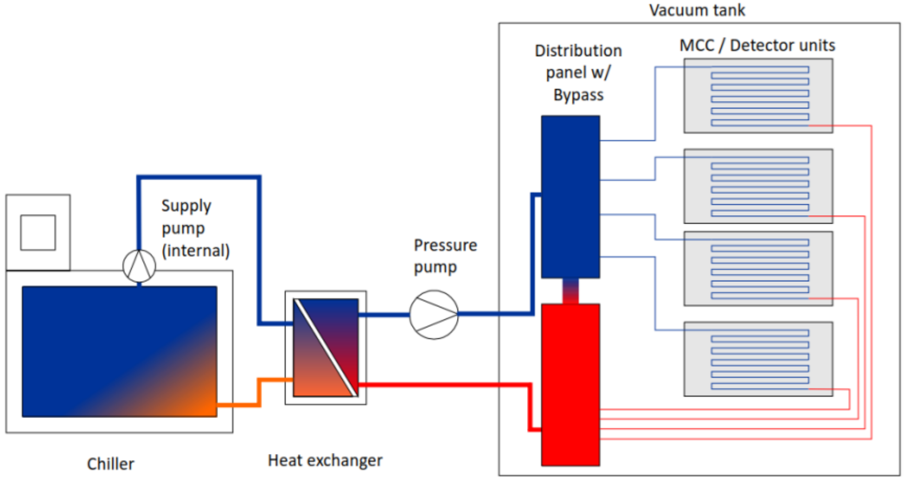
Problem: Long pipes!

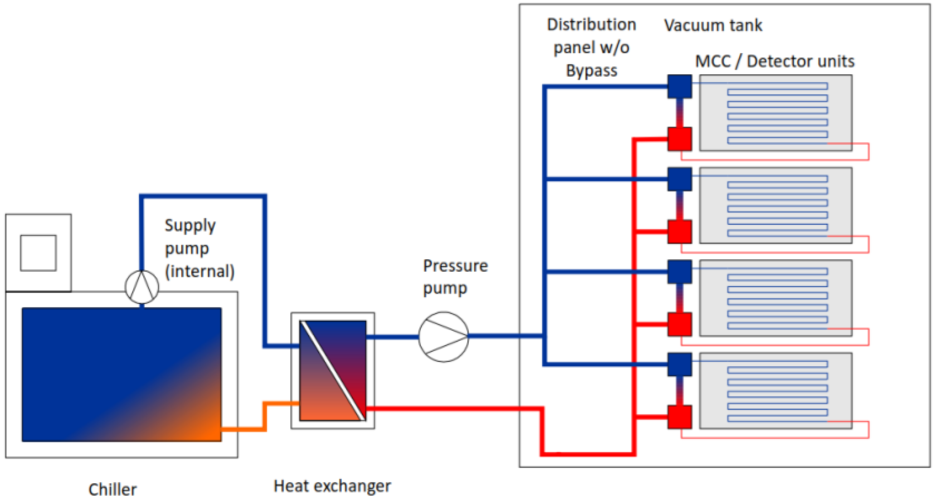
- Thermal losses in pipe system

- **Large pipe diameters:**
    - Low pressure overhead
    - Small exchange rate
    - Big impact on system losses

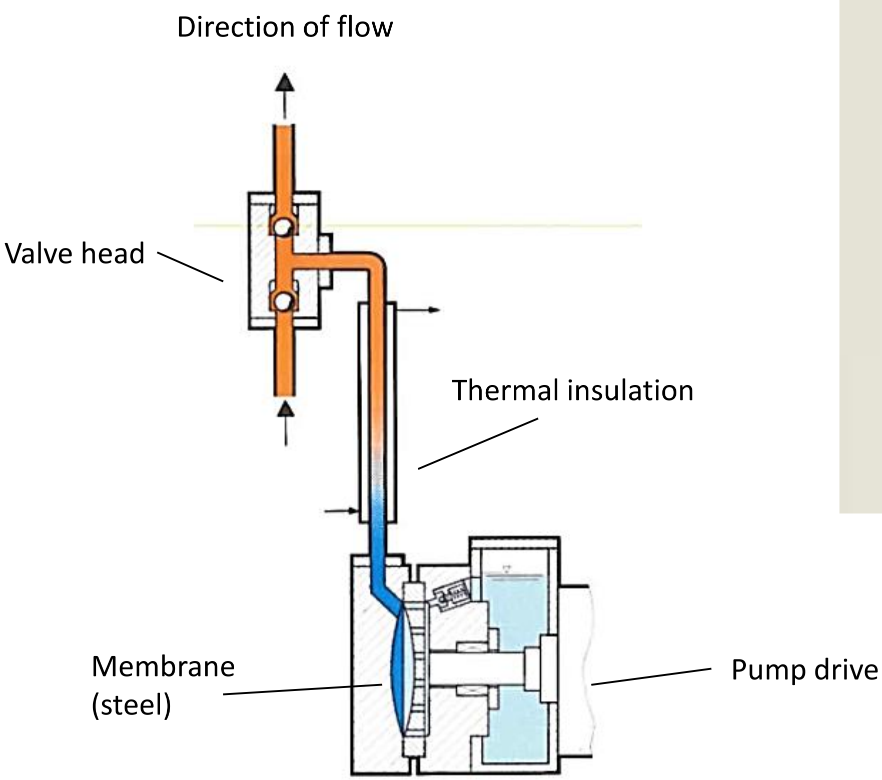
- **Small pipe diameters**
    - High pressure overhead
    - Large exchange rate
    - Big impact on system safety

- **Suggestion:**
    - Implement bypass
    - Large pipe diameters
    - Large exchange rate
    - low pressure overhead
    - overall flow around 10 x MCC flow
    - Reevaluation of pump concept required





4SBC Pathfinder: Pump concept

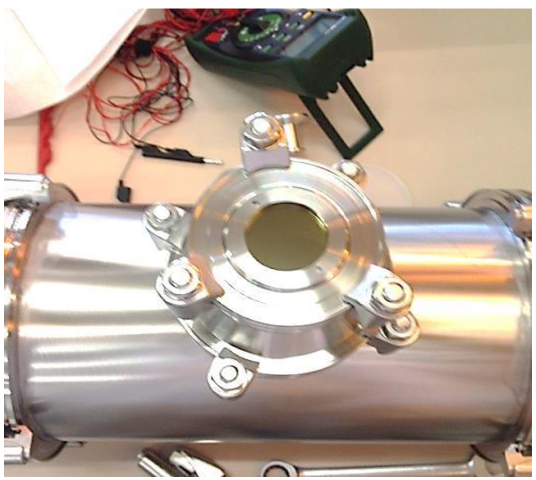


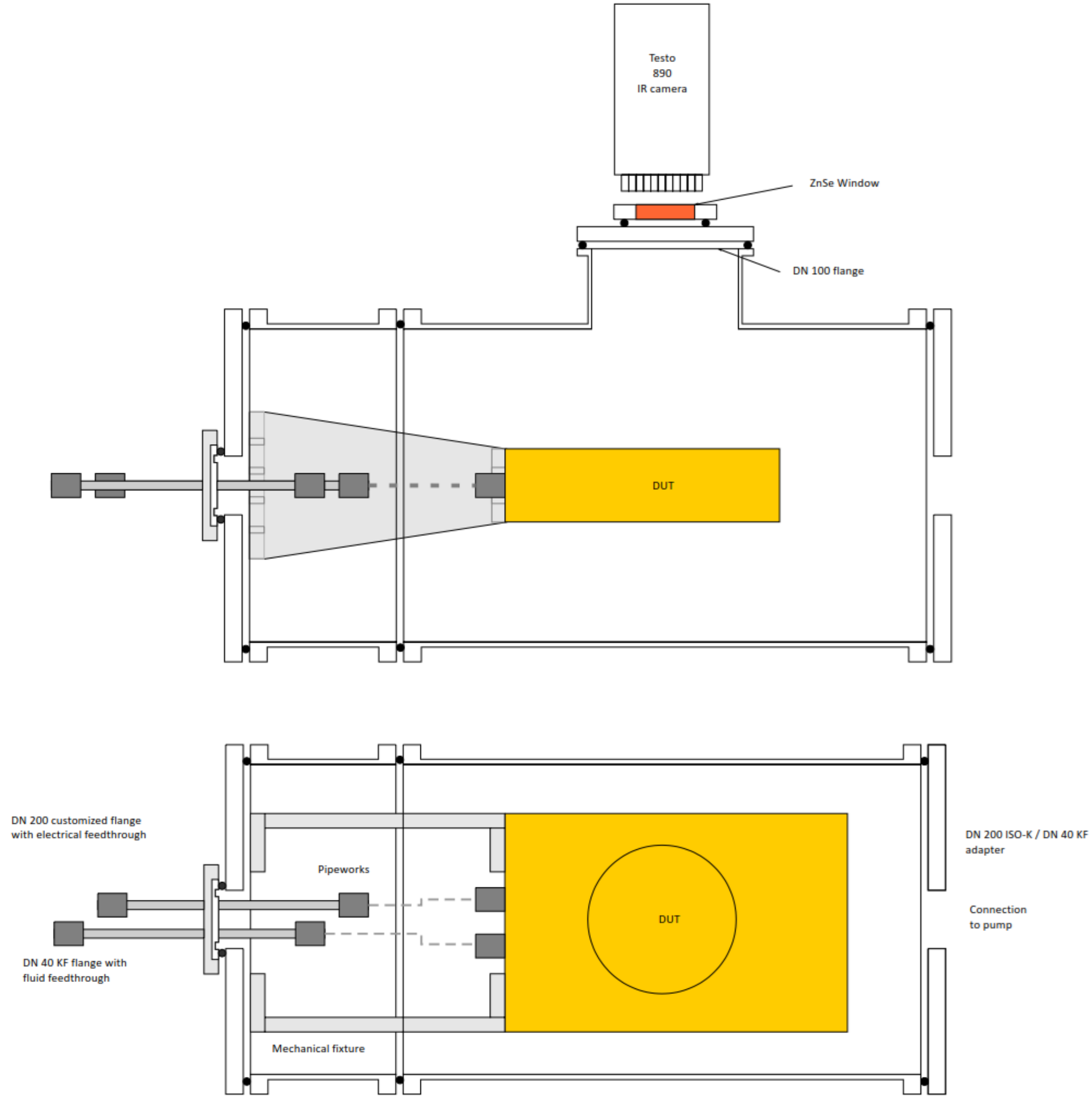
"Hot media" case

Pump:

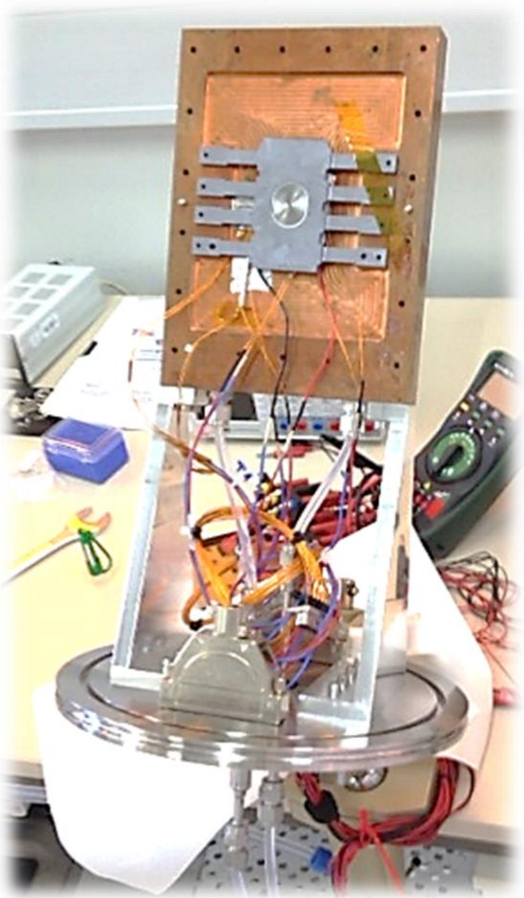
- LEWA Eco line series
- Provide sufficient flow for bypass
- Hydraulic coupling
    - limits heat intake
    - prevents cooldown of pump drive below operating temperature range
    - Possible "active cooling" of link

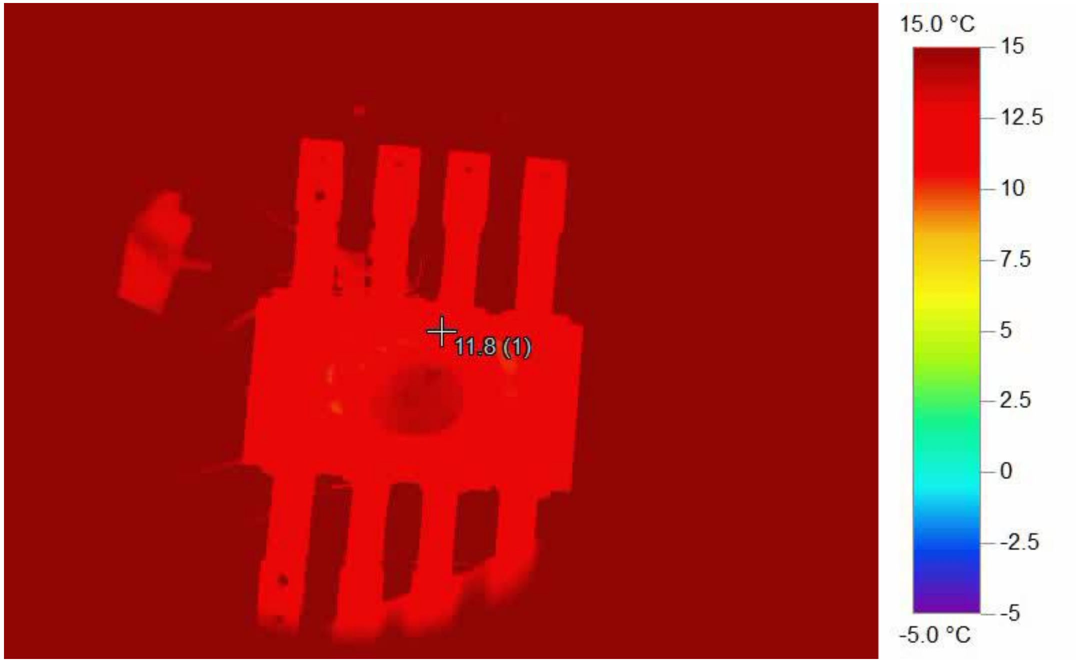
Thermal test setup





Thermal test setup





Outlook

CCD production

- In progress
- Ready mid '19

MCC development

- In progress
- **Waiting for SOI delivery**
- Evaluation of prototype required

AI development

- In progress
- **Waiting for AI dummies**
- **Waiting for SOI delivery**

PCU development

- Back to square one
- Bypass required
- Implement simple solution for prototype evaluation

Additional activities:

- Adaption of electronics
- Through-Silicon Vias
- Tooling / Test facilities
- Glueing / mounting processes

Biggest issue:

Availability of SOI

base material!

Status

-------- Weitergeleitete Nachricht --------
Betreff: RE: Request for 2019
Datum: Tue, 19 Feb 2019 15:06:07 -0000
Von: Hugh Griffin <hughgriffin@icemostech.com>
An: lca@hll.mpg.de

Hello Laci,

Unfortunately i do not have positive news to share with you.
The operations team are working through a large backlog of orders from 2018 as well as planning what is already a full order book for 2019.
The IceMOS factory is at full capacity.

The team are working to re-plan the production and shipping schedule and we will be issuing revised order confirmation/delivery dates to customers as soon as possible.
I do apologise that I cannot offer better news at this time.

Sincerely,
Hugh

Thanks for your attention

Questions?