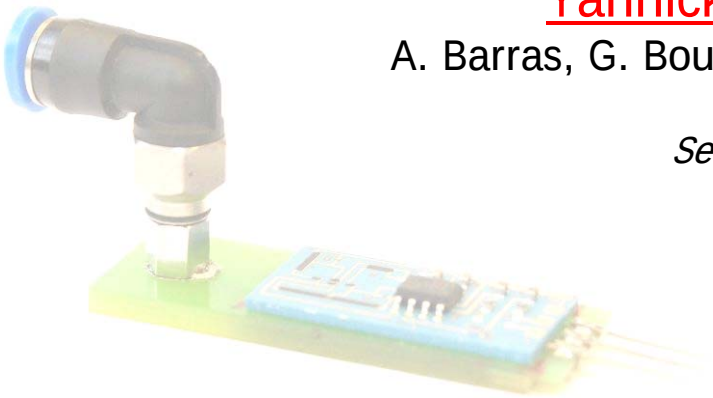
SMD Pressure and Flow Sensors for Industrial Compressed Air in LTCC Technology

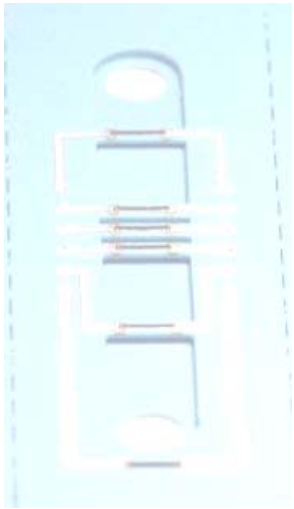


Yannick.Fournier@a3.epfl.ch

A. Barras, G. Boutinard Rouelle, T. Maeder, P. Ryser

Sensor Packaging session

June 17th, 15:15



Laboratoire de Production Microtechnique

http://lpm.epfl.ch/tf

Ecole Polytechnique Fédérale de Lausanne (EPFL)

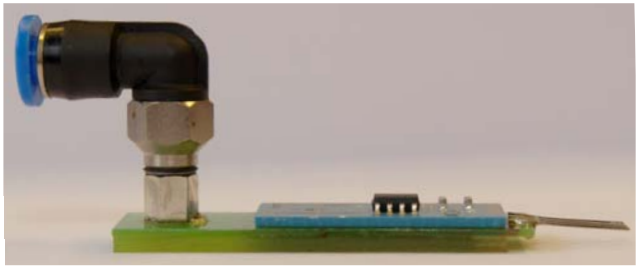
STI-LPM, Station 17, 1015 Lausanne, Switzerland

What is it all about?

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

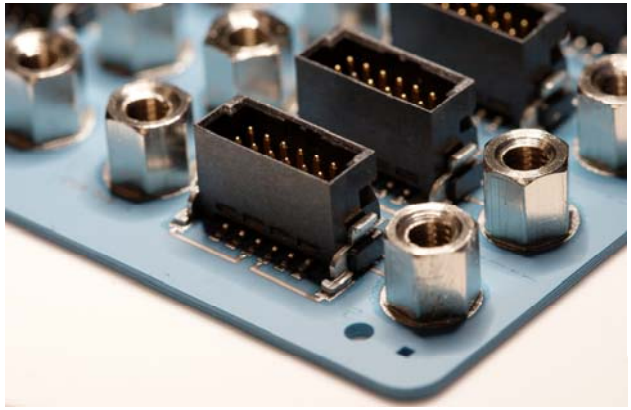
Two sensors:

- ...in **LTCC** for the pneumatic industry
- ...**SMD** mountable by soldering
- ...with **integrated electronics**



For measuring:

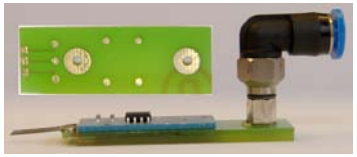
- **air pressure** 0...6 bar
- **air flow** 0...100 NL/min



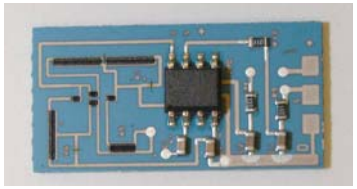
Presentation outline

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

1. Introduction – the needs of the industry

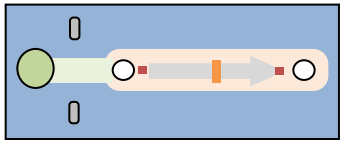


2. Pressure sensor – piezoresistive



3. Flow sensor – anemometer

4. Merging – integrated sensor



5. Conclusions

?

1. Motivations

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Precise fluid measurement (p, T, flow): **OK**

- numerous methods already exist
- usually with specific CMOS chips

Still an issue:

- circuit diagnostics
- coarse measurements

⇒ **Industrial devices need to be safe & reliable!**

1. Motivations, cont'd

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Focussing on custom pneumatic circuits:

- actuator feedback: *has the piston moved?*
- direct monitoring: *what's the valve output pressure?*
- circuit diagnostics: *is the channel clogged?*

⇒ **A solution: integrated sensors**

- simple
- cheap
- easily mountable (SMD)
- integrated electronics (no need for signal processing)

⇒ **Measurement of pressure and flow**

Presentation outline

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

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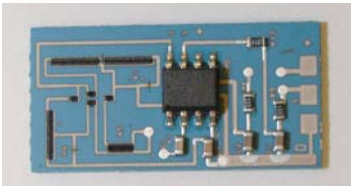

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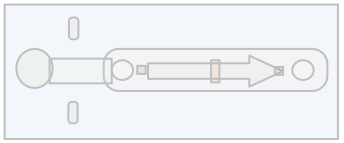


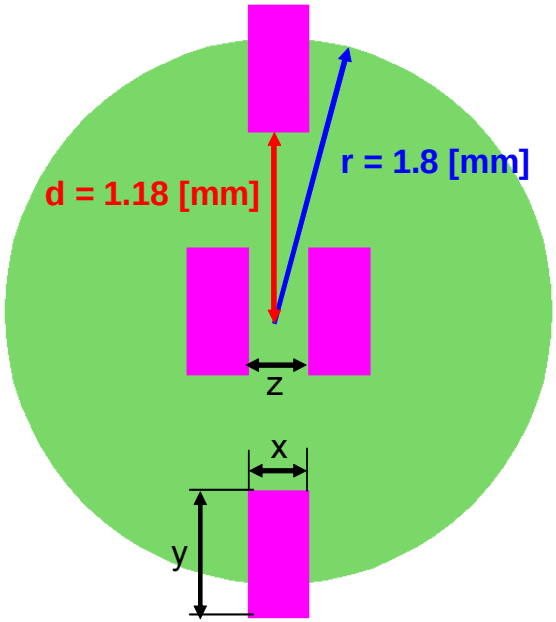
5. Conclusions

?

2. Requirements

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- LTCC technology
- Nominal pressure: **6 bar** (min 10 bar peak)
- **Piezoresistors** on circular membrane
- Assembly and connections by flip-chip
  ⇒ no external tubing and wires
  ⇒ tight proof
  ⇒ use of different solder pastes

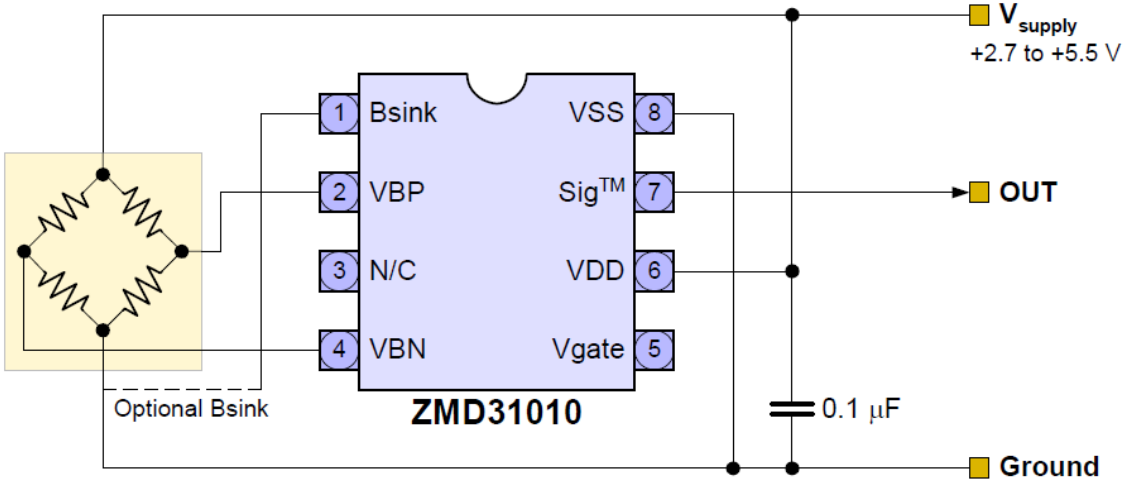


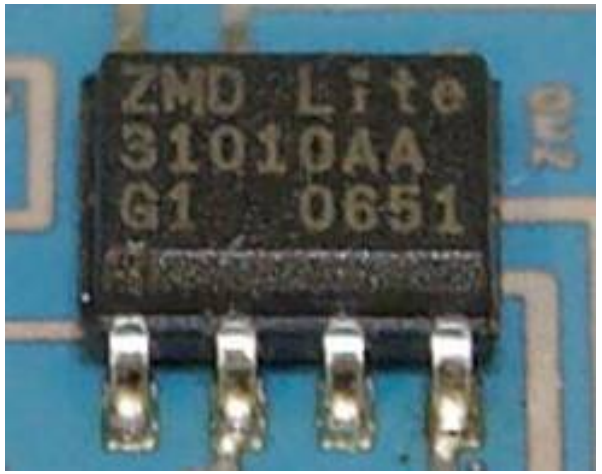
2. Requirements, cont'd

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- Robust and reliable:
  ⇒ must be insensitive to mounting stresses

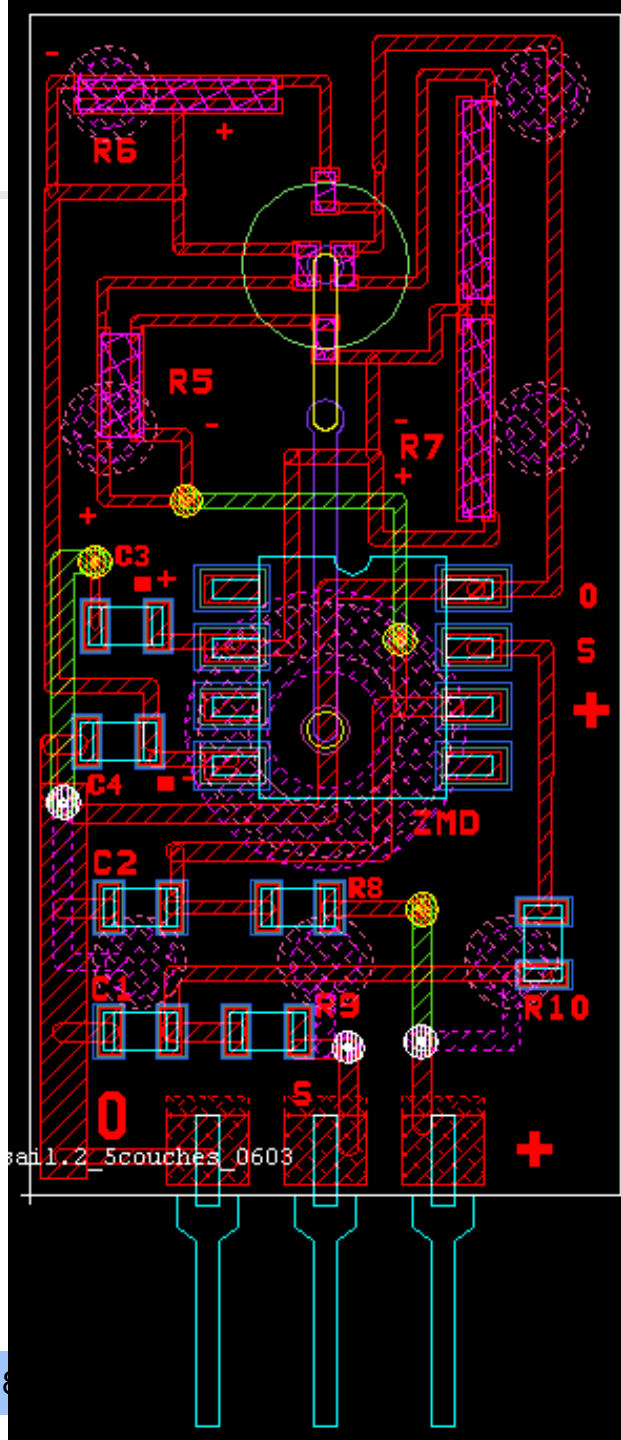
- Easy adjustment of gain/offset
  ⇒ Wheatstone bridge
  ⇒ **programmable integrated amplifier** (*ZMD 31010*)





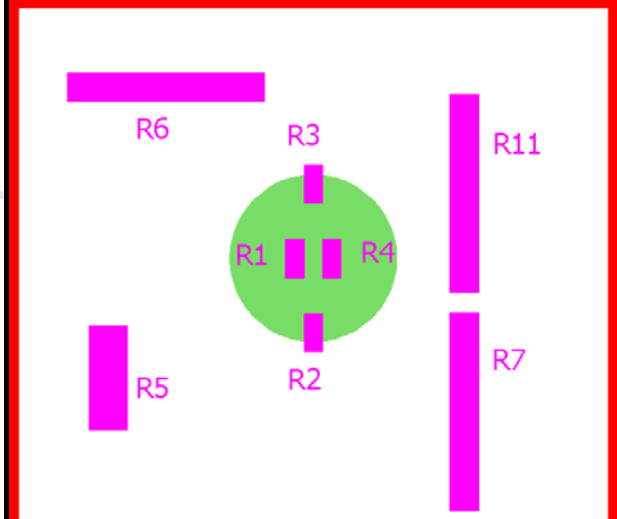
2. Electrical circuit

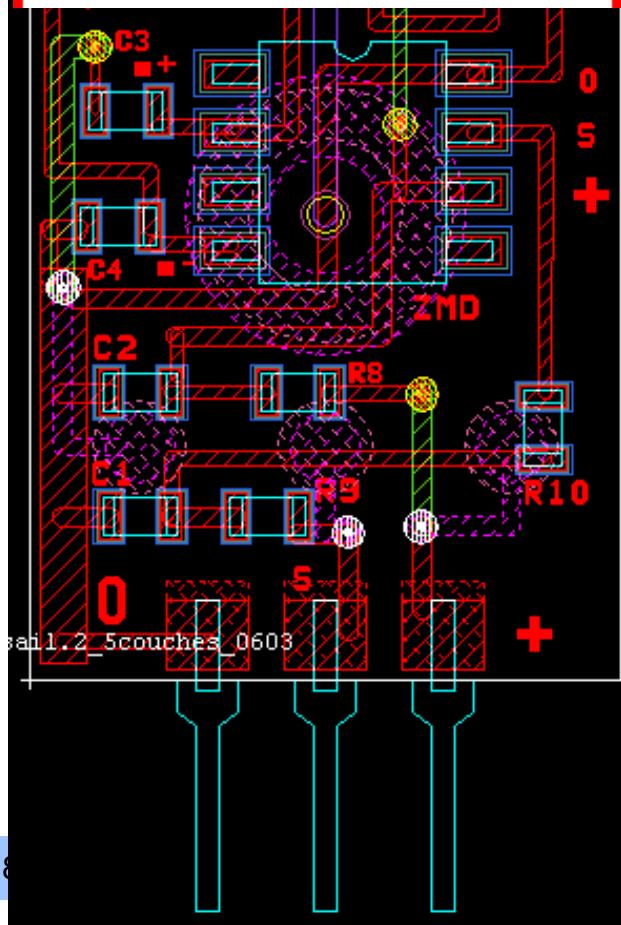
- 3 pins: ground, signal, power
- Hybrid design: thick-film + SMD devices



2. Electrical circuit

- 3 pins: ground, signal, power
- Hybrid design: thick-film + SMD devices
- First coarse offset adjustment:
  - by “digital” laser trimming
    (R_5...R_7 shunted, factor of 3^3=27)





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- Hybrid design: thick-film + SMD devices
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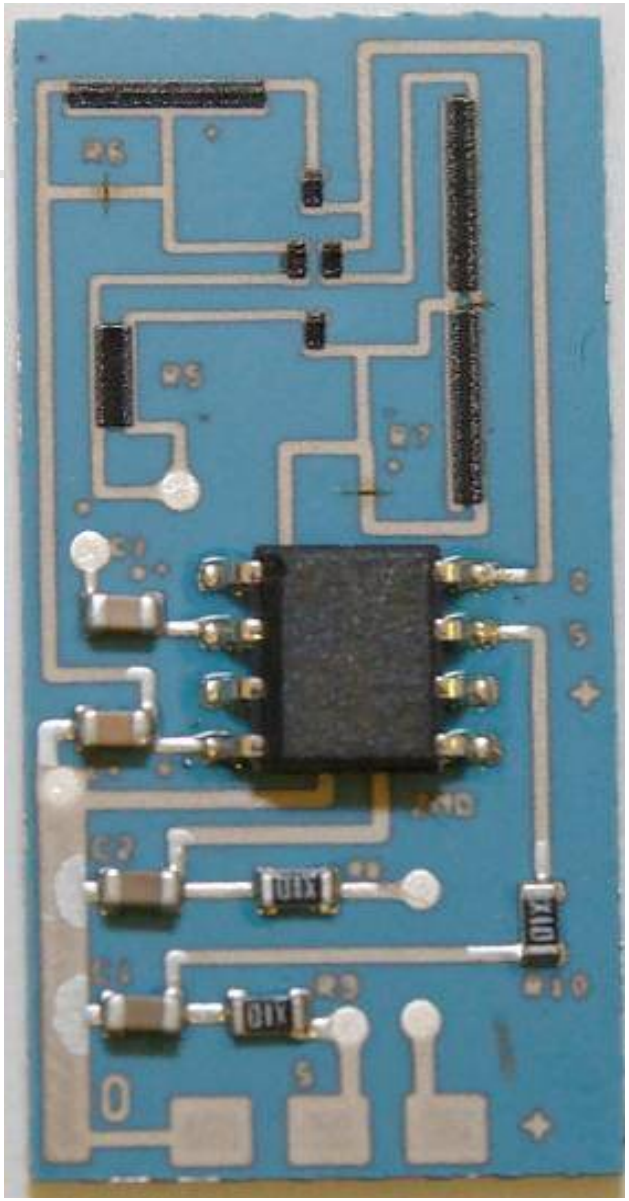
- Final offset & gain with *ZMD* chip



2. Fluidics

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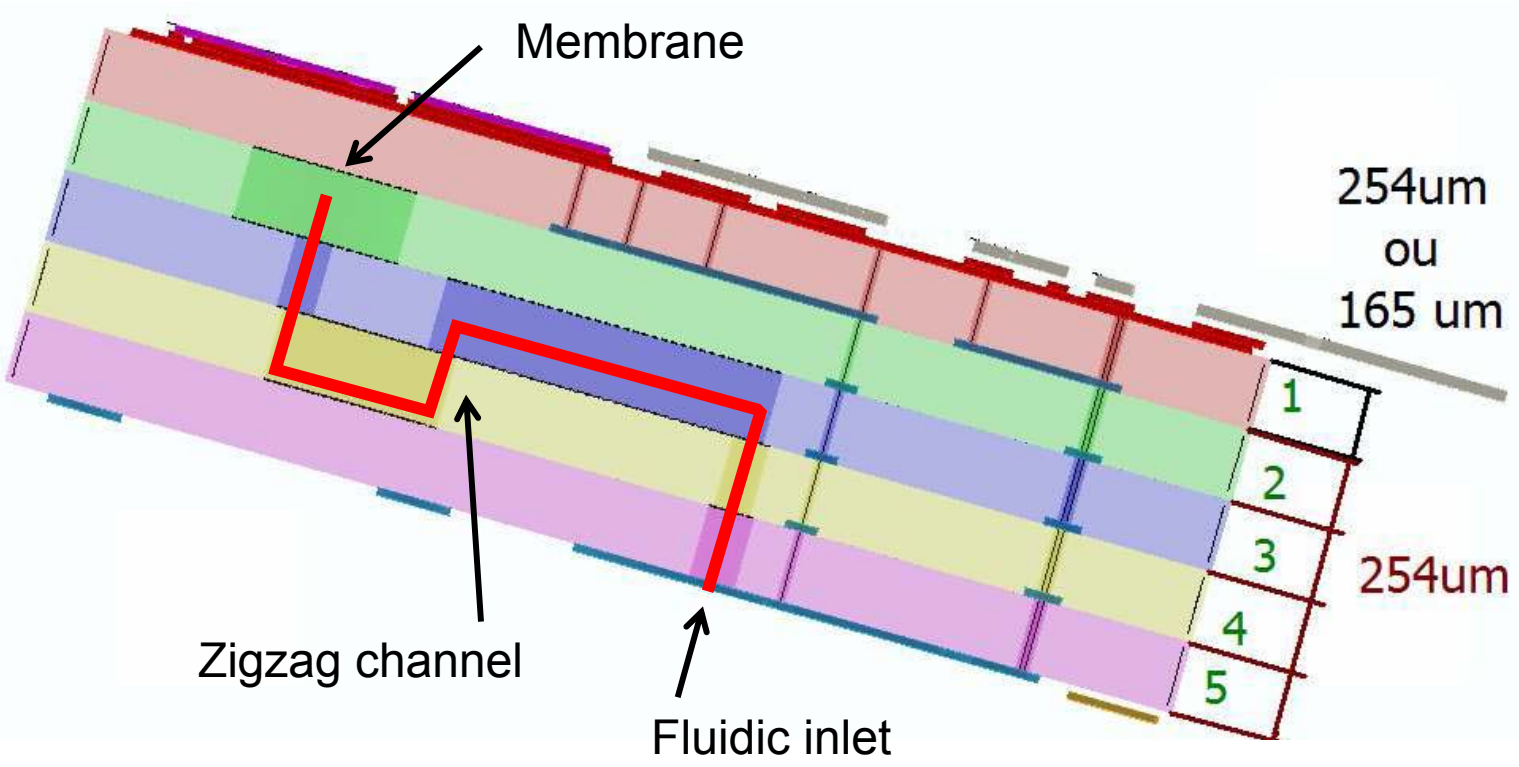
- 200-µm membrane decoupled from fluidic inlet (reduction of assembly stress influence)
- Channel in zigzag

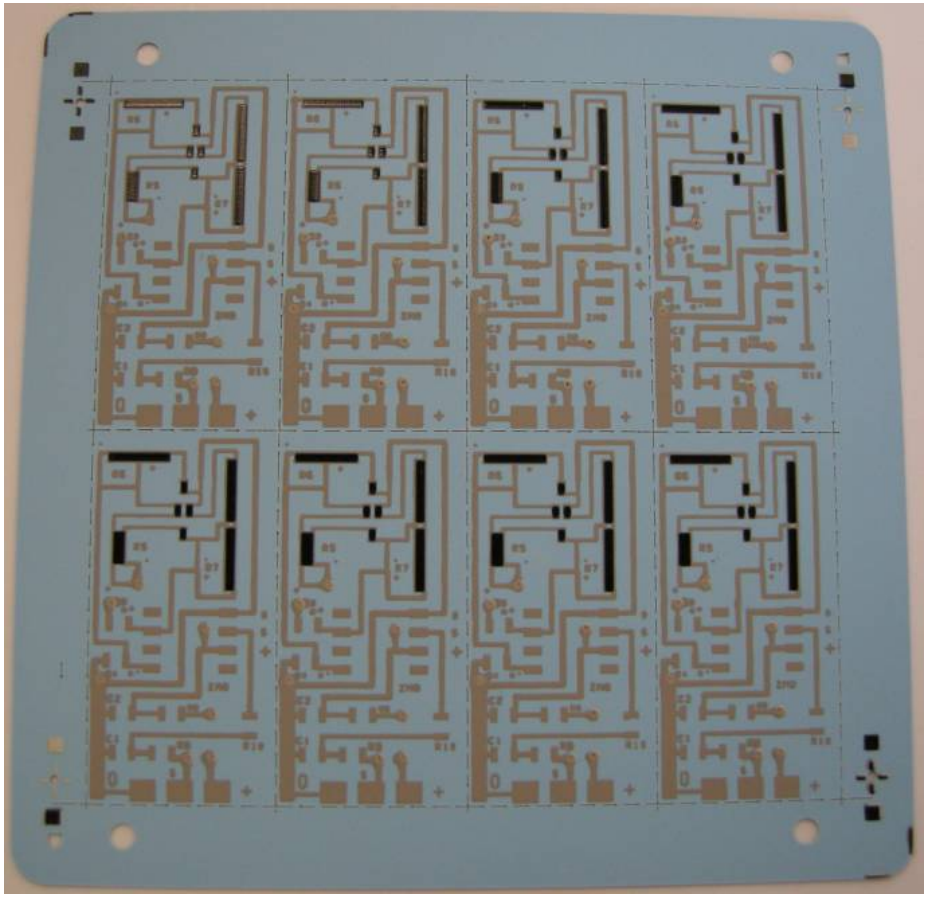


2. Screen-printing, stacking

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Visible on the right:

- **Vias**
  Ag, *DuPont 6141*
- **Conductor tracks**
  Ag:Pd, *DuPont 6146*
- **Resistors**
  DuPont 2041, 10 kΩ/□



Tape 1
Tape 2
Tape 3
Tape 4
Tape 5
Tape 5 (B)

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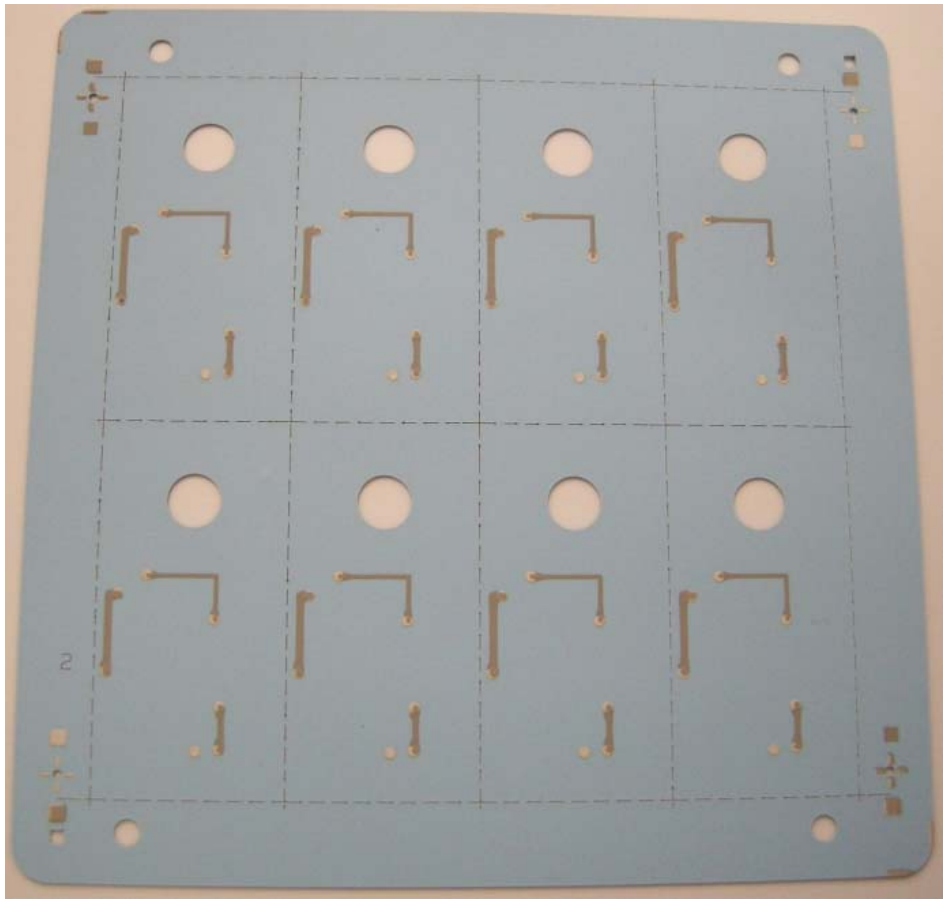

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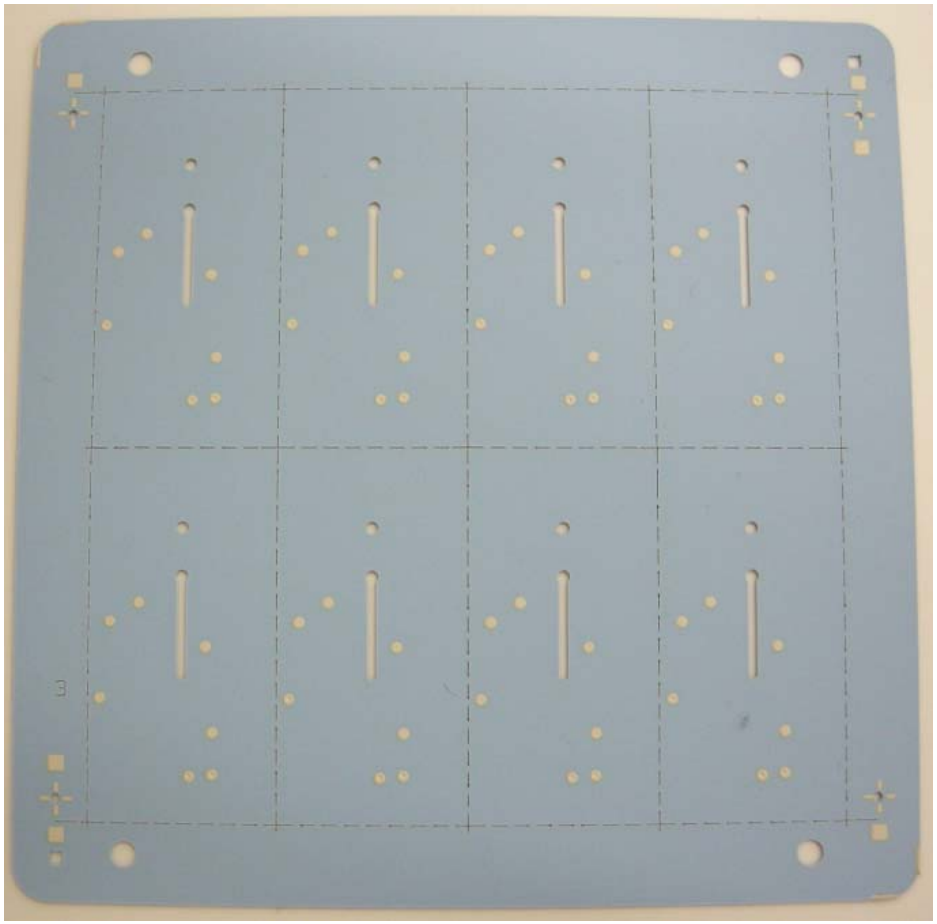

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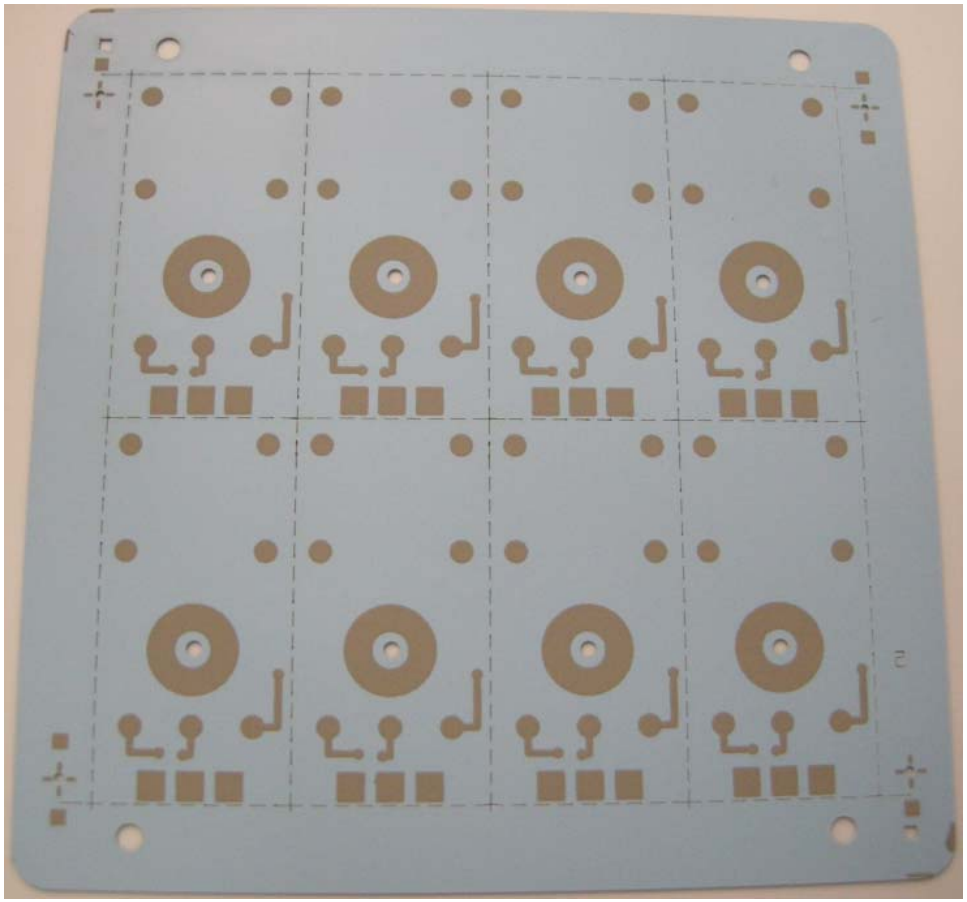
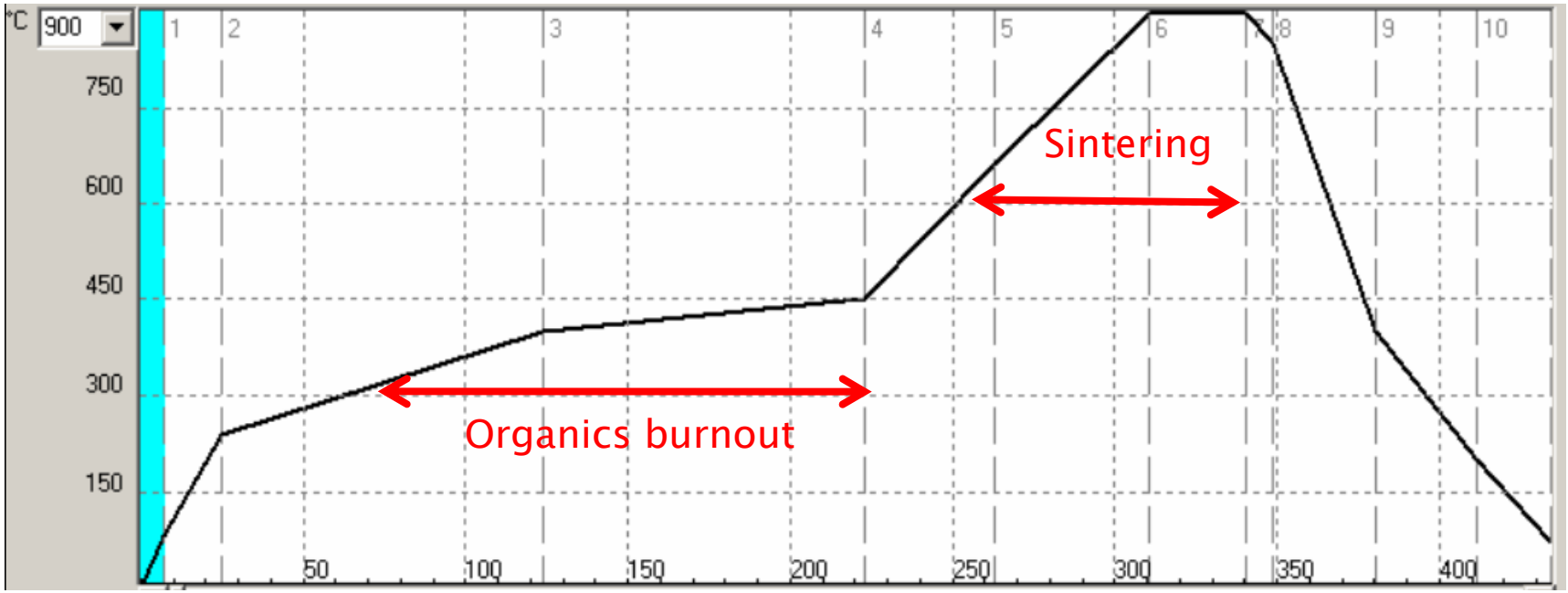


Tape 1
Tape 2
Tape 3
Tape 4
Tape 5
Tape 5 (B)

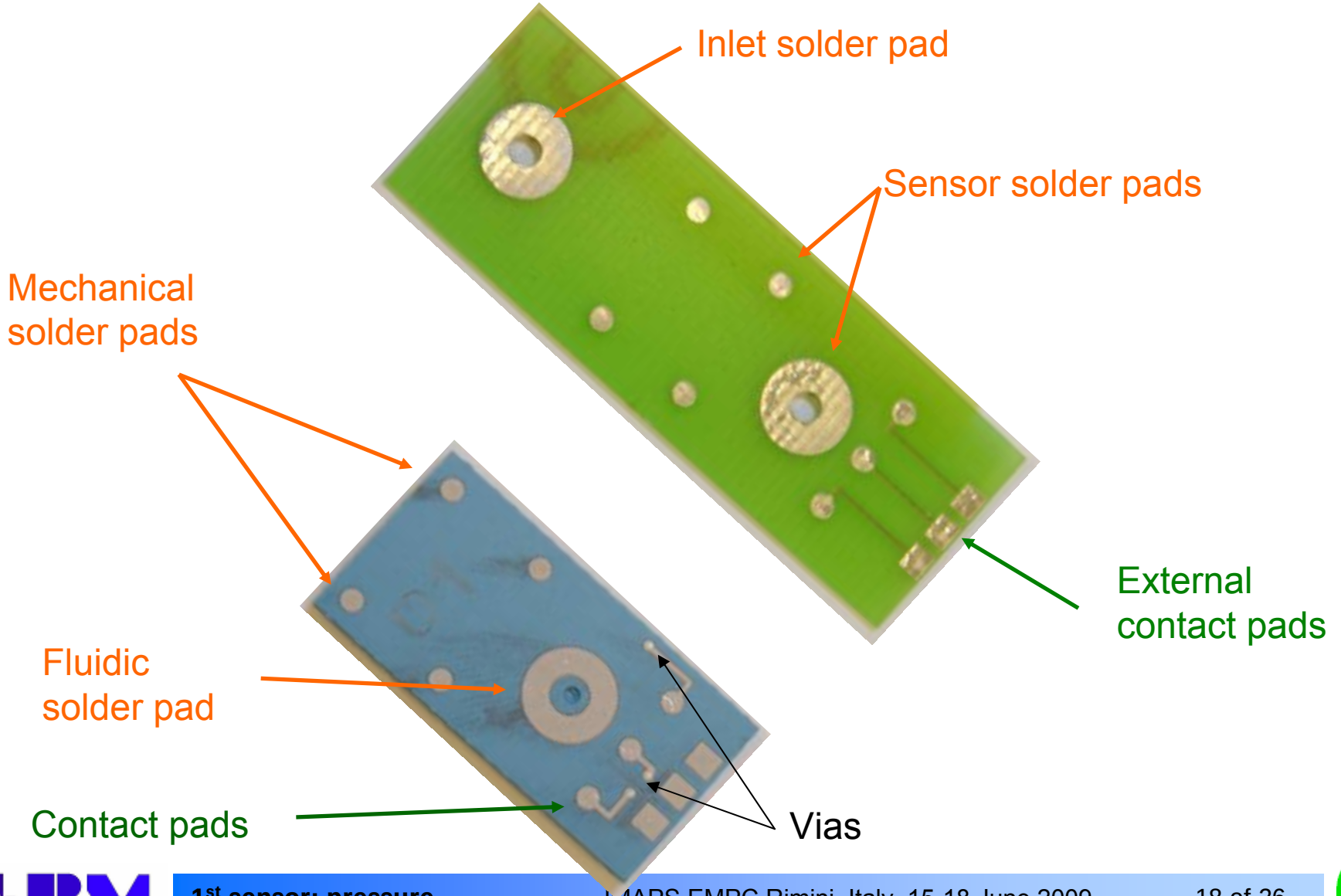
2. Lamination and firing

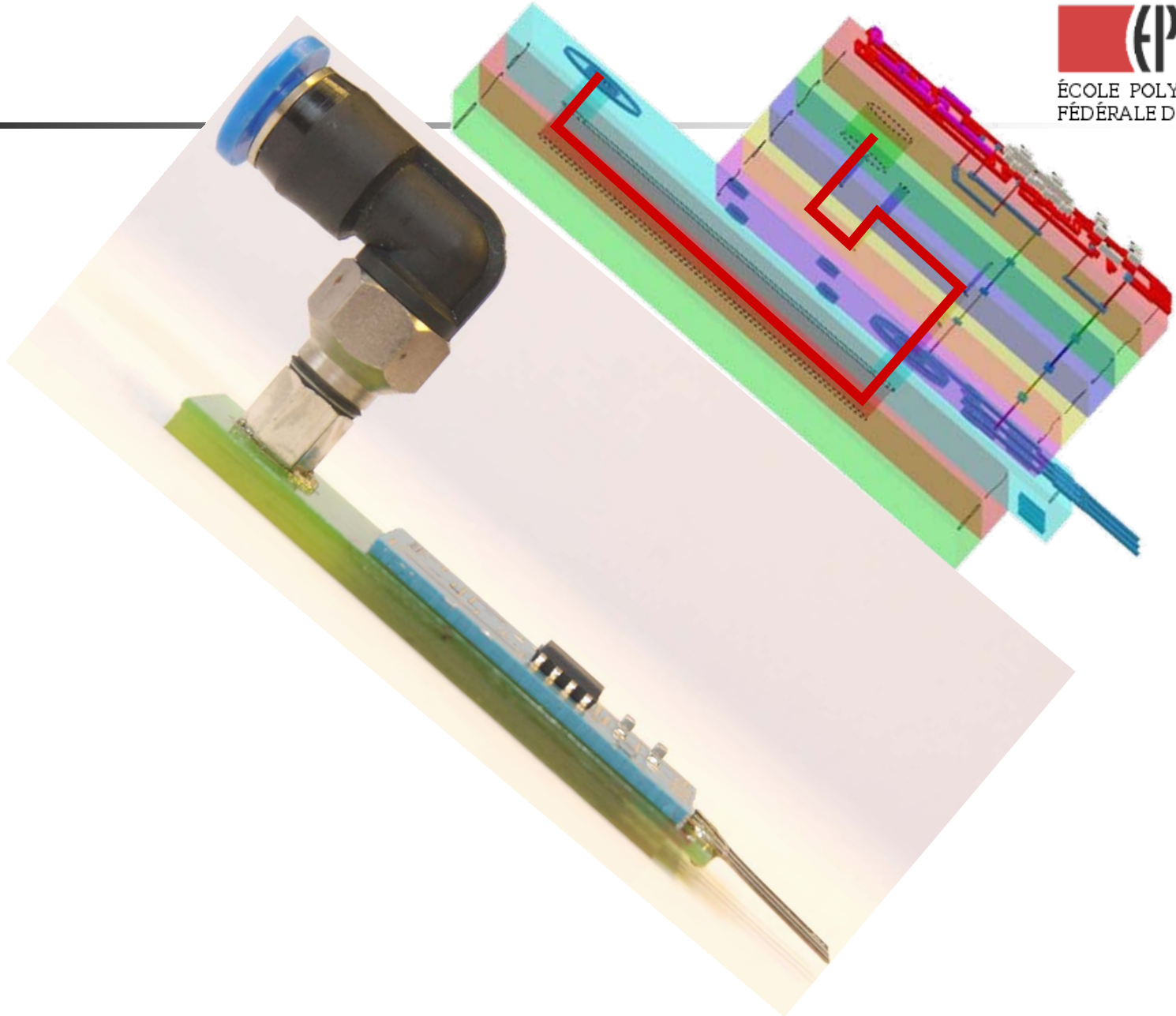
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- Lamination @ **80 bar, 25°C**, 10 min
- Firing in air, 875°C, heating ramp 5 K/min



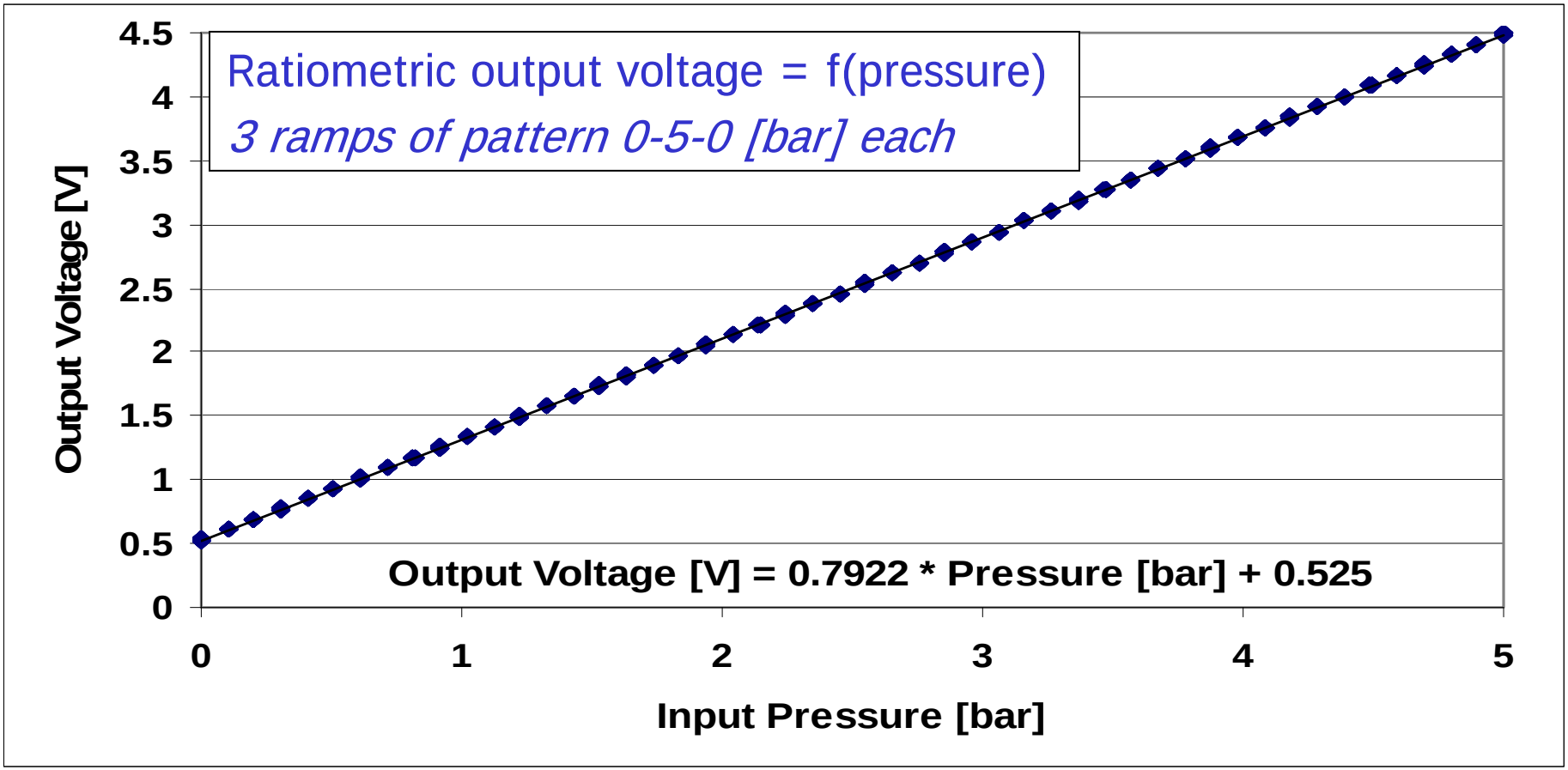
2. Assembly on test PCB





2. Performance

- Very good repeatability: <0.1%
- Influence of strain at solder joints: max ±0.3%



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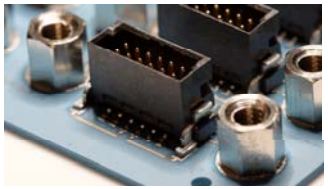
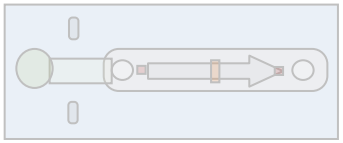


4. Merging – integrated sensor

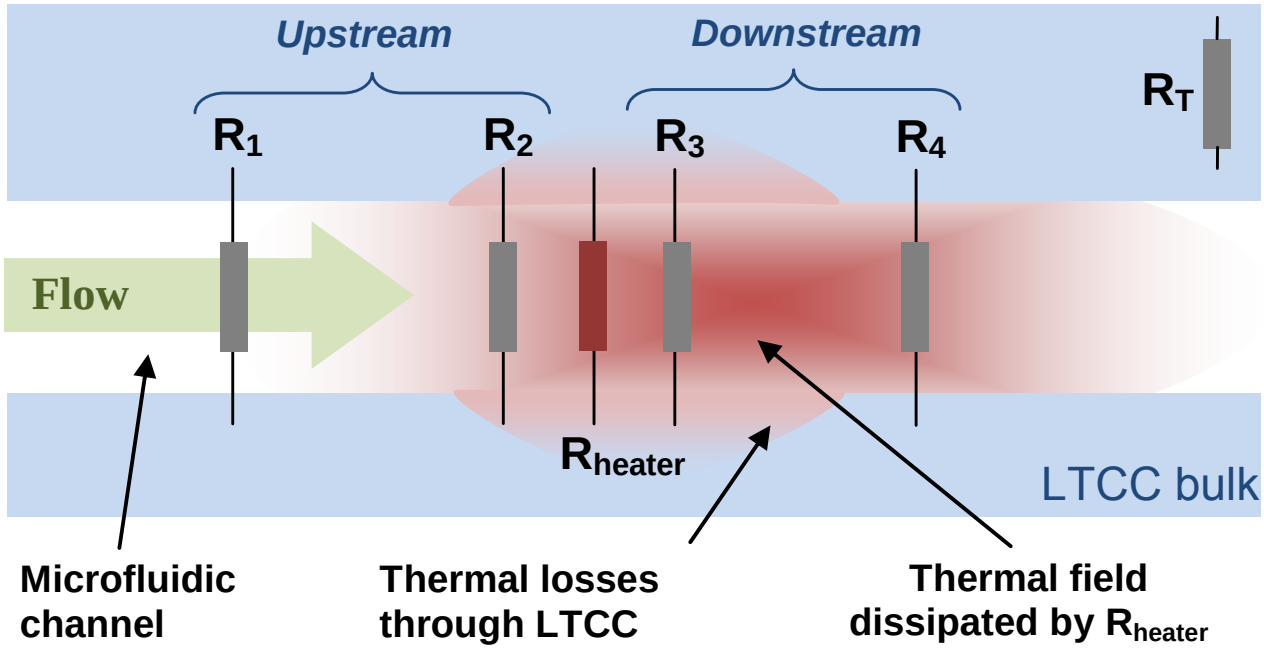


5. Conclusions

?

3. Requirements

- Fluids: compressed air, non agressive
- Flow range: 0...100 NL/min (with bypass)
- Working pressure: 6 bar
- Reaction time: <3 s
- Measuring principle: calorimetric + **anemometric**

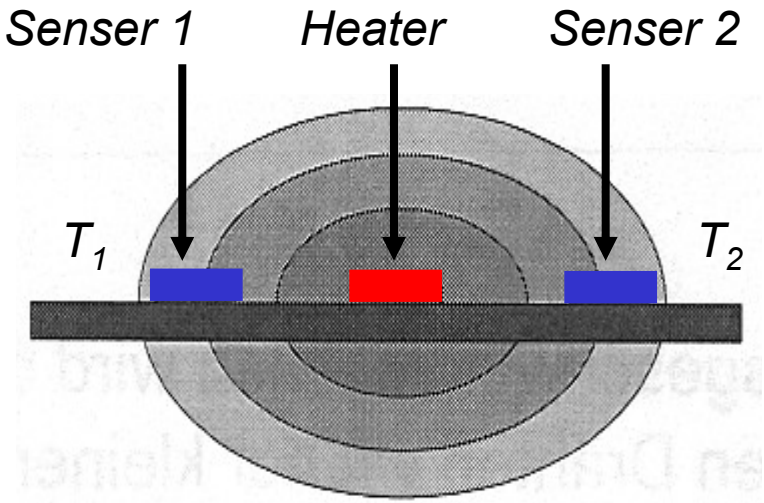


3. Calorimetric or anemometric?

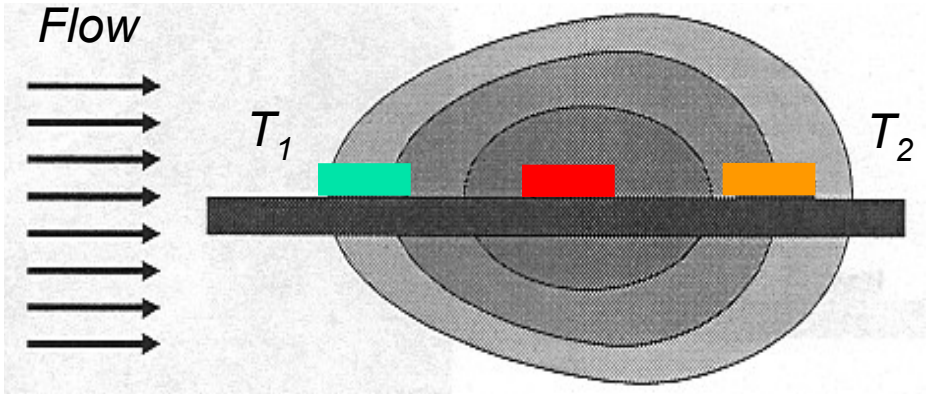
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Thermal mass flowmeter principles:

- Calorimetric: heat diffuses faster than air flow (small flows)
- **Anemometric**: flow goes faster than heat diffuses (high flows)
- Regulation: **constant heater temperature**



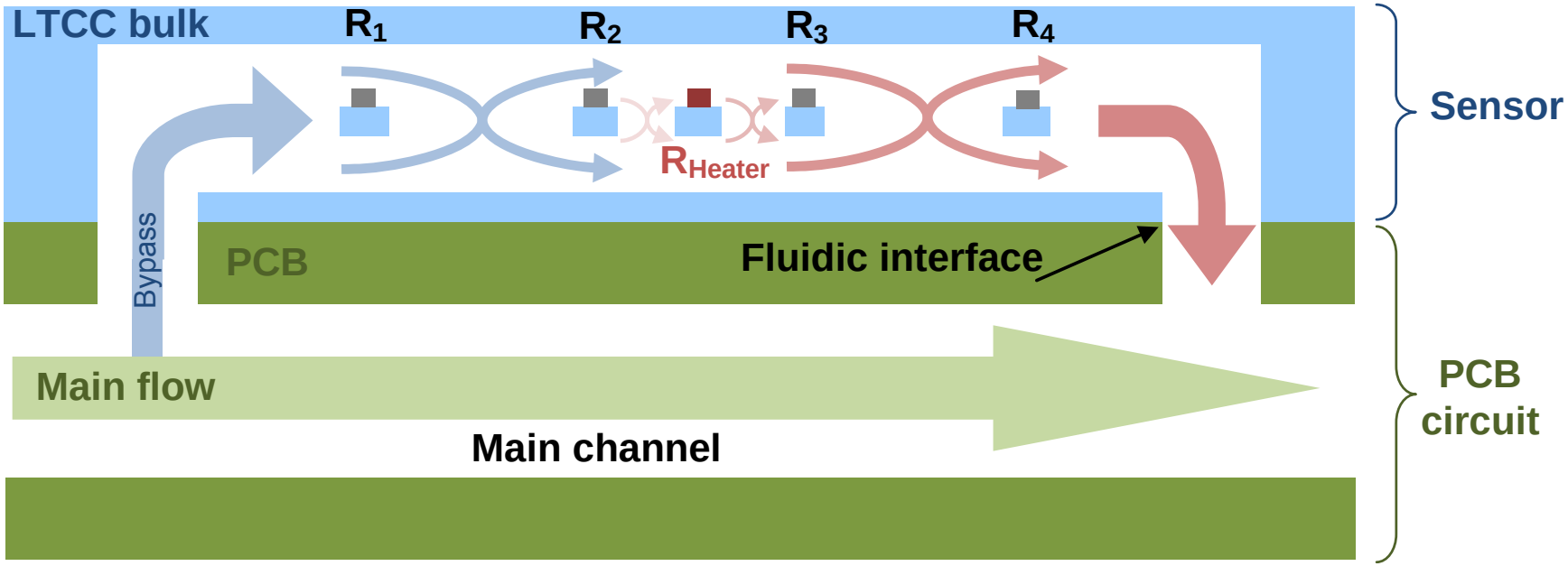
Flow = 0
Symmetric heat repartition
$T_1 = T_2$



Flow ≠ 0
Asymmetric heat repartition
$T_1 \searrow < T_2 \nearrow$

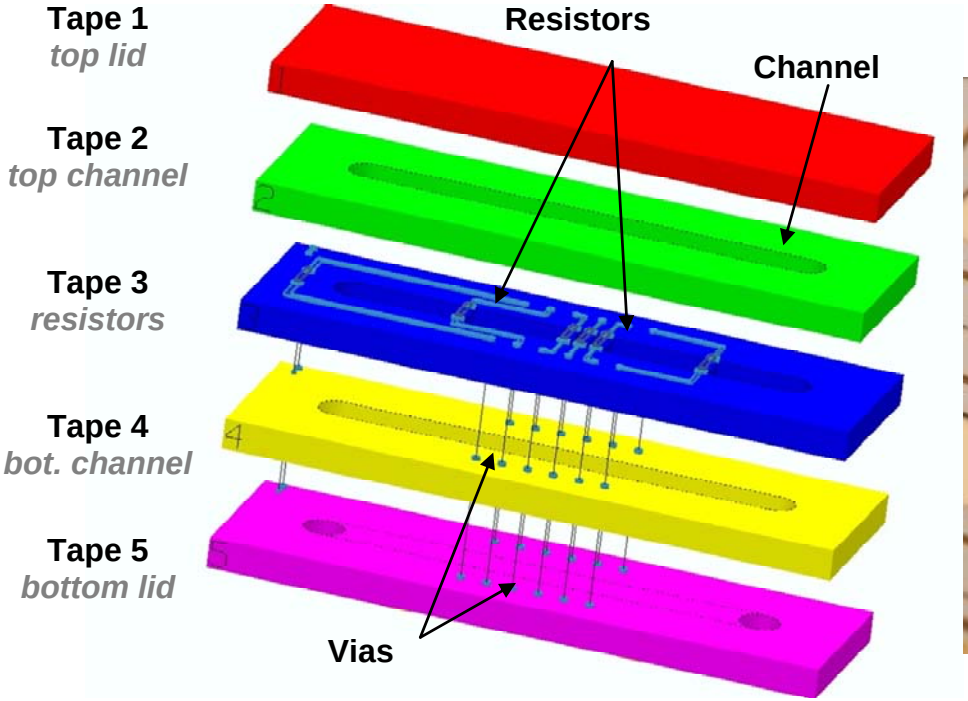
3. Design

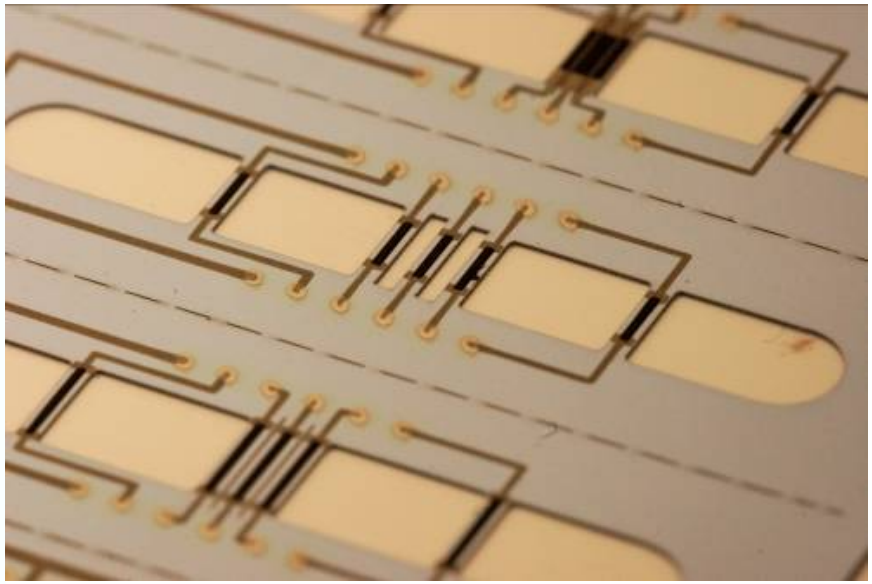
- 1 central heater, 4 sensing elements, 1 temperature probe
- Mounted onto PCB by soldering



3. Sensor layout + variants

- 5-layer structure
- Materials: DuPont 951; Heraeus HL2000, HL800
- Layout variants: channel width + height; bridge geometry





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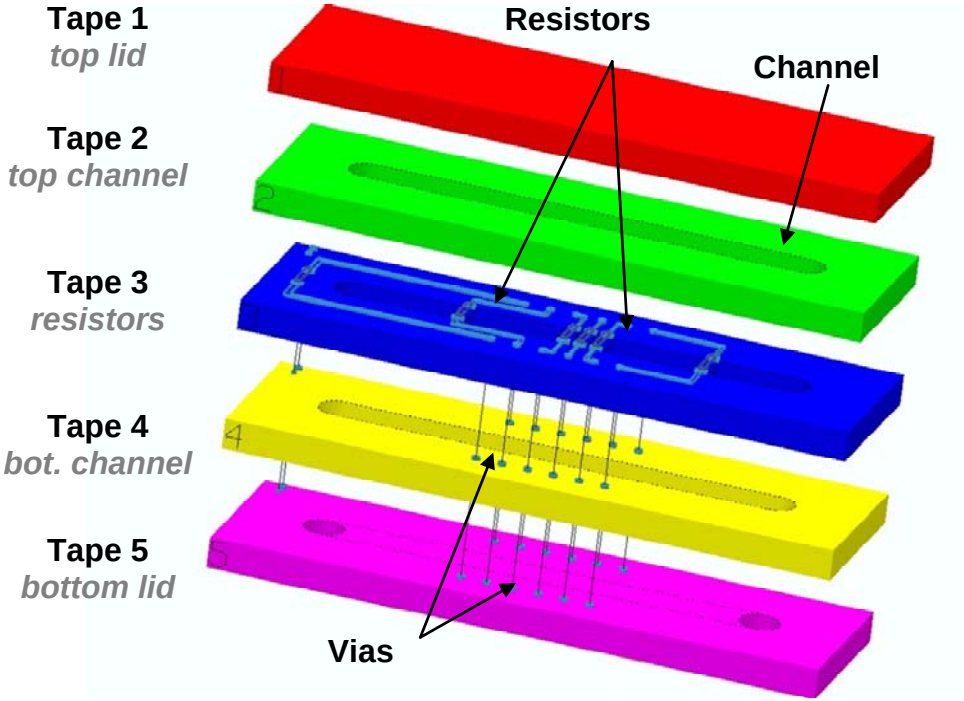
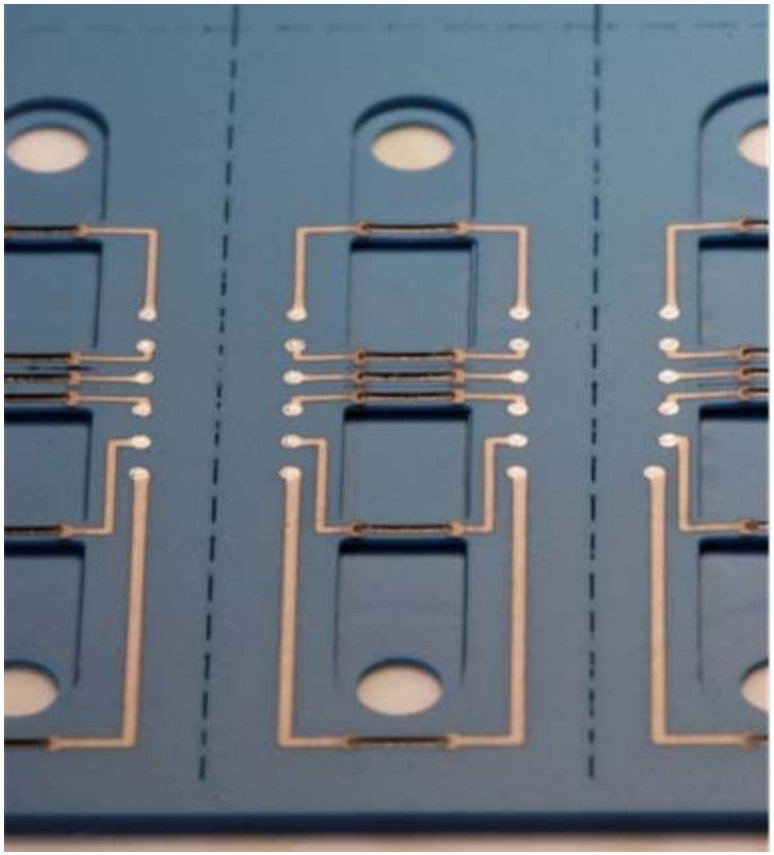
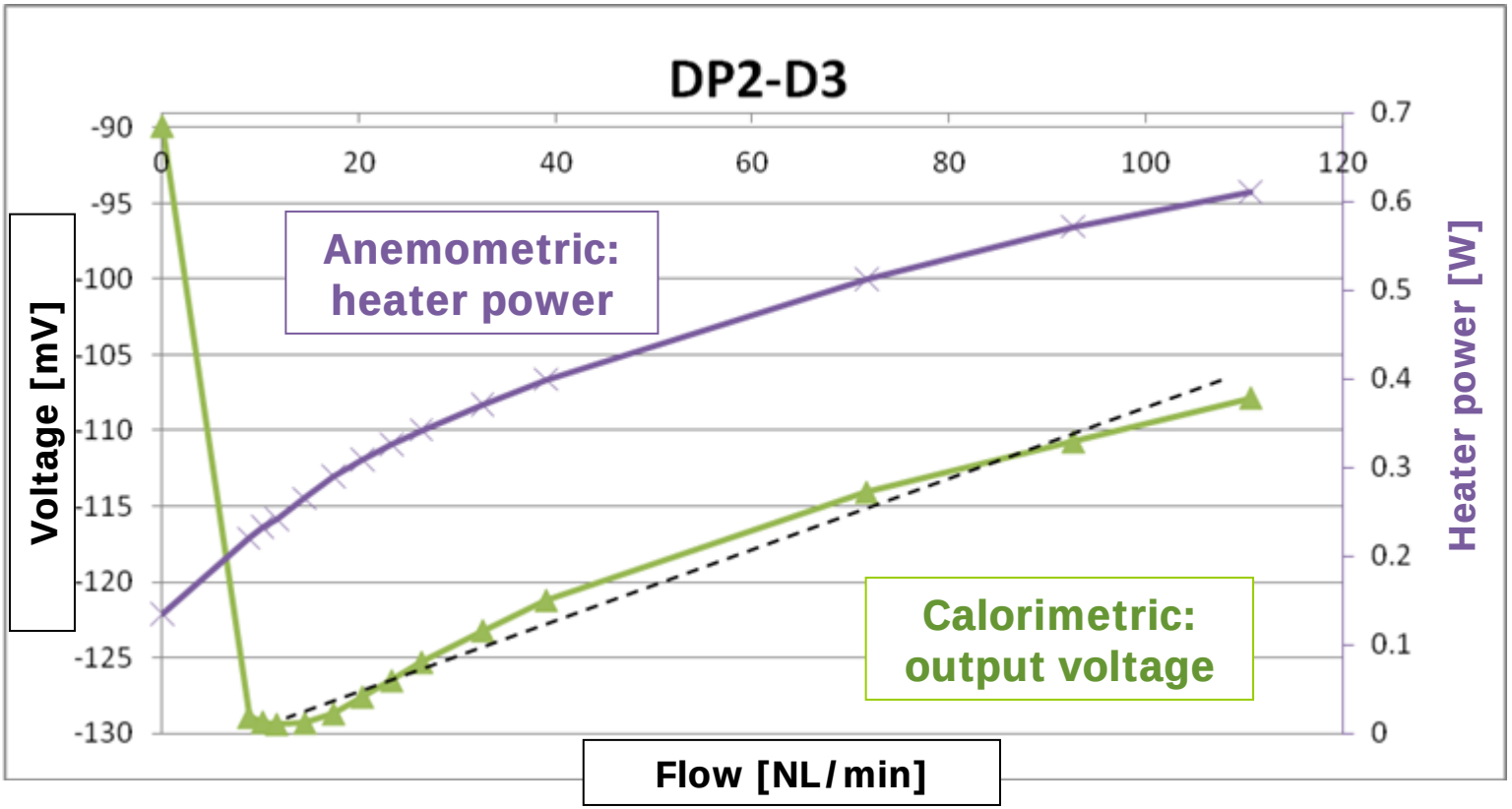




3. Results

- **Anemometric** output suitable for our flow range
- Calorimetric for precision measurement of very small flows

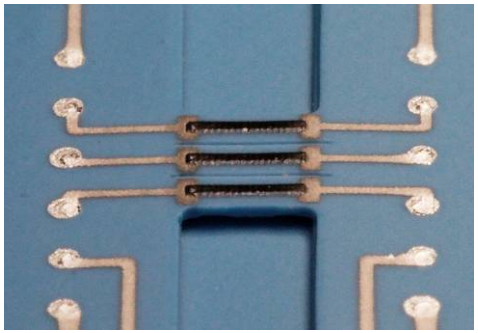


3. Tape issues

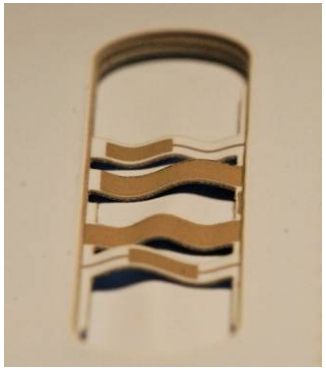
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

LTCC tapes:

- *DuPont 951* takes advantage of drum skin effect
- *Heraeus HL2000* promising results, **no drum skin effect**
- *Heraeus HL800* higher tendency to warp; OK for thicker structures

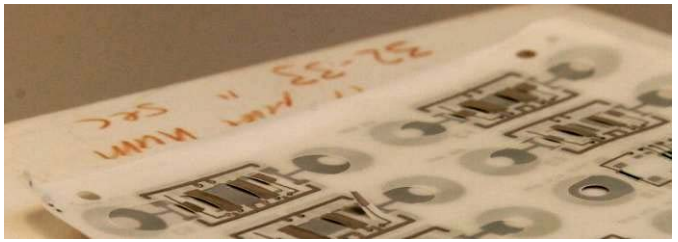


DP951



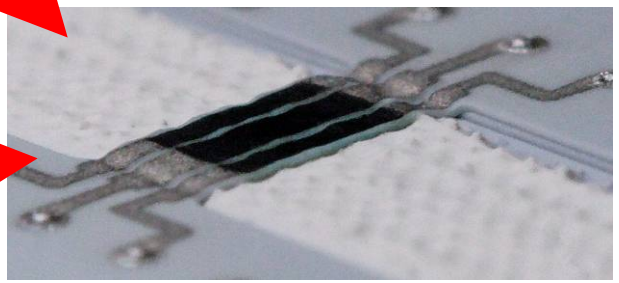
HL2000

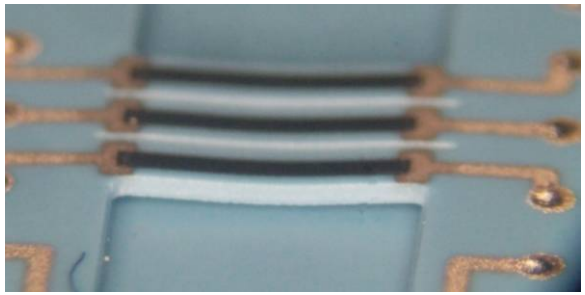
Differential sintering issues



HL800

Use sacrificial layers





Sagging of slender structures

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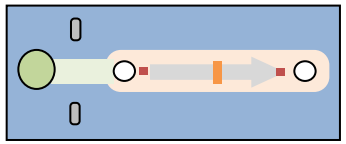


5. Conclusions

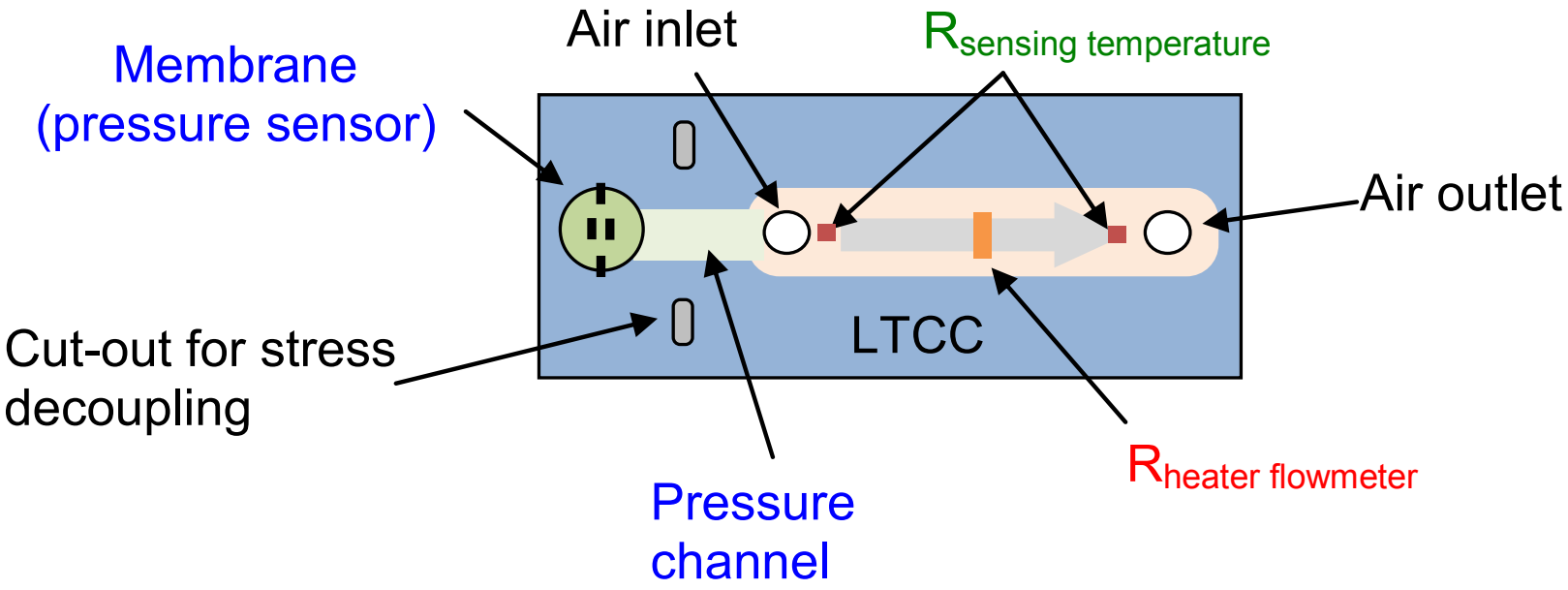
?

4. Merging sensors

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

On-going development: integrated sensor and electronics

- pressure
- flow
- temperature



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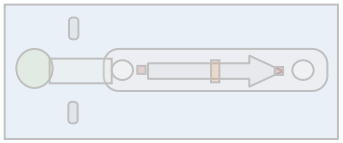

5. Conclusions

?

5. Conclusions

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- **Simple & cheap LTCC air pressure + flow sensors**

- **Pressure**
  - 0…6 bar
  - Piezoresistive measurement
  - Programmable integrated *ZMD* bridge signal conditioner

- **Flow**
  - Anemometric (heating power) sufficient for industrial diagnostics
  - Calorimetric (diff. voltage) optional for precise measurements

The end – questions?

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Thank you for your attention…
…and enjoy Rimini!