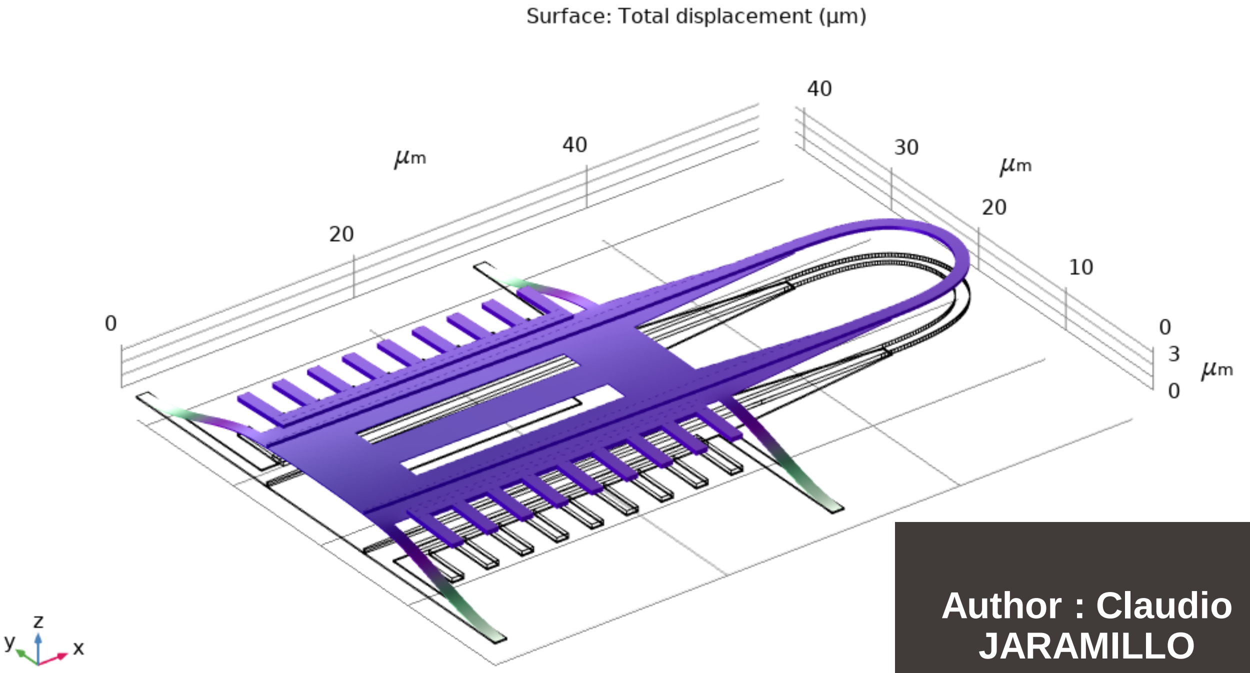

Optimization of Bistable Silicon Photonic MEMS Switch Architectures

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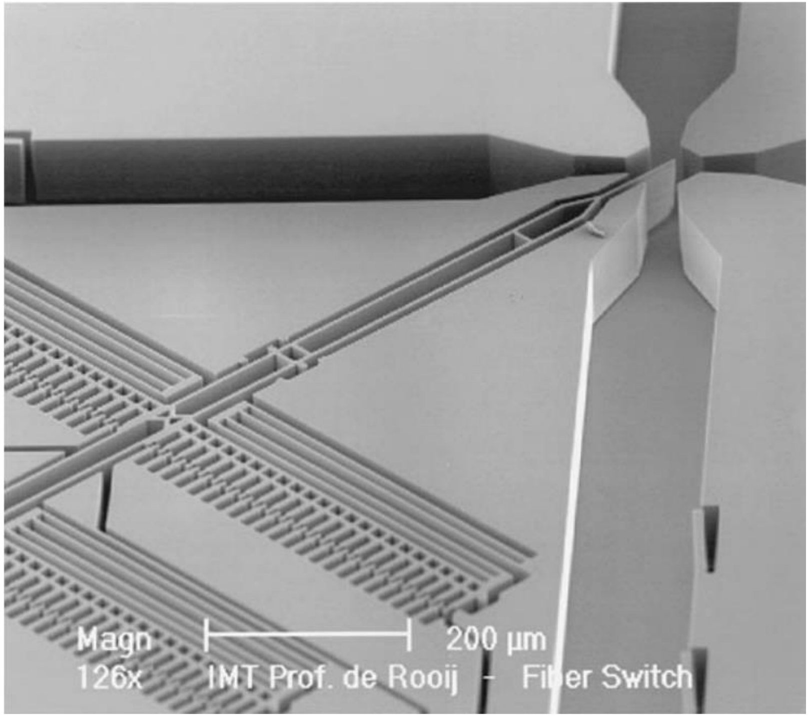
1. Introduction

1. Introduction – Optical Switches

- Optical switch : device that switches optical signals between channels.
- Historically using **mirrors**.
- MEMS are advantageous for their **integration** capabilities, **reliability**, and **low power consumption**.
- Silicon photonic MEMS allows us to use well **understood fabrication procedures.**
- Exploiting mechanical properties of MEMS, instability under buckling creates 2 stable states : **we have created a latching switch**.



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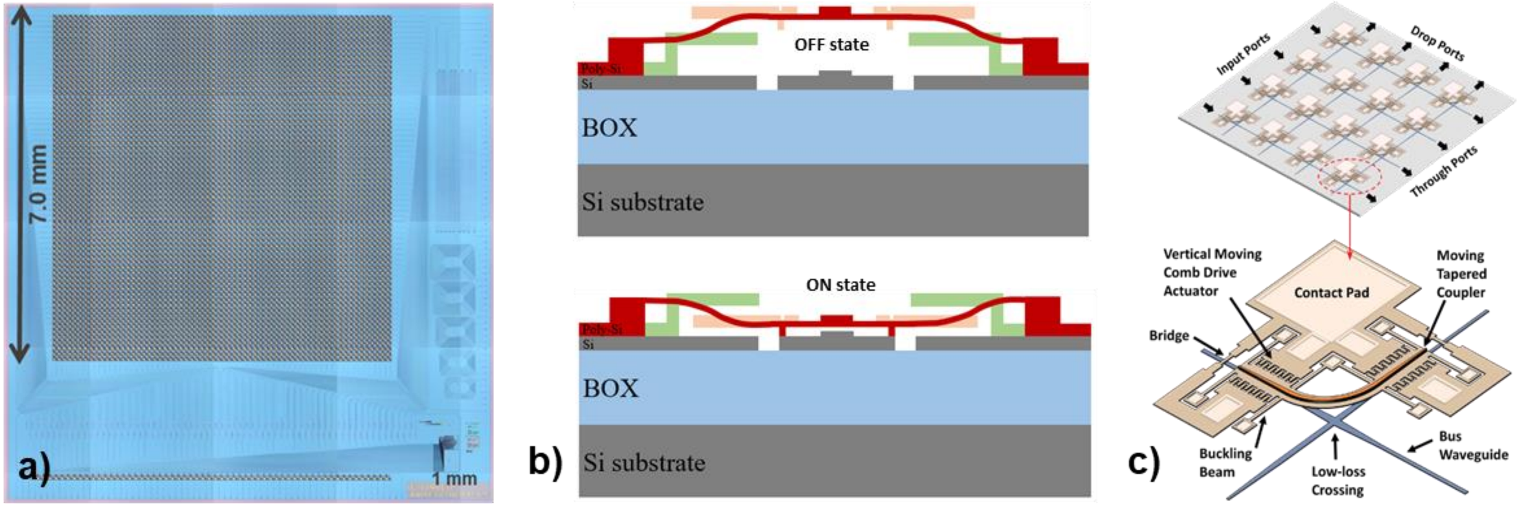
1.2 Introduction – Scope of the project

- "Silicon Photonic MEMS Switches have recently been shown to be an excellent contender for large-scale photonic integrated circuit **switch matrices**."
- We want to design and simulate **optimized** silicon MEMS switch architectures.

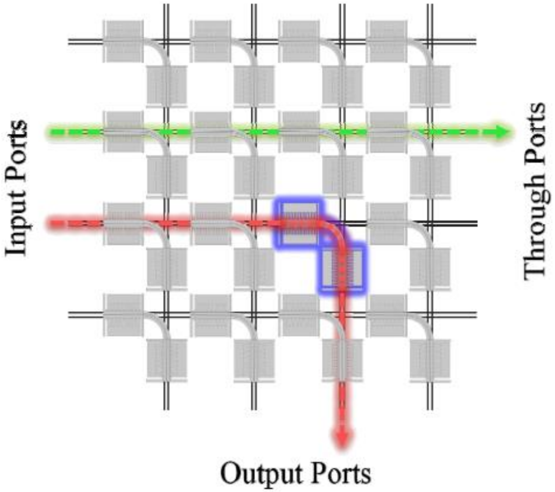


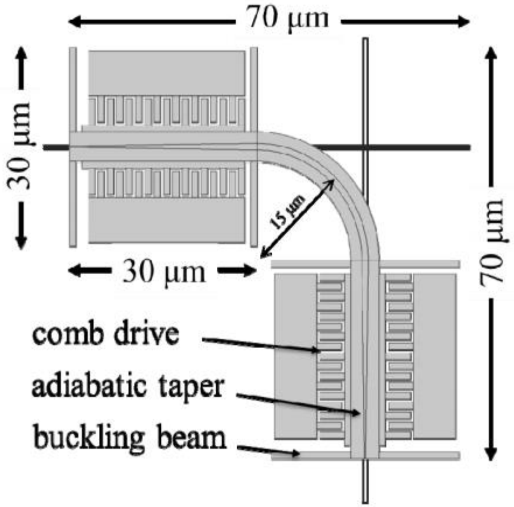
2. Current implementation

2.1 Current implementation – Original design

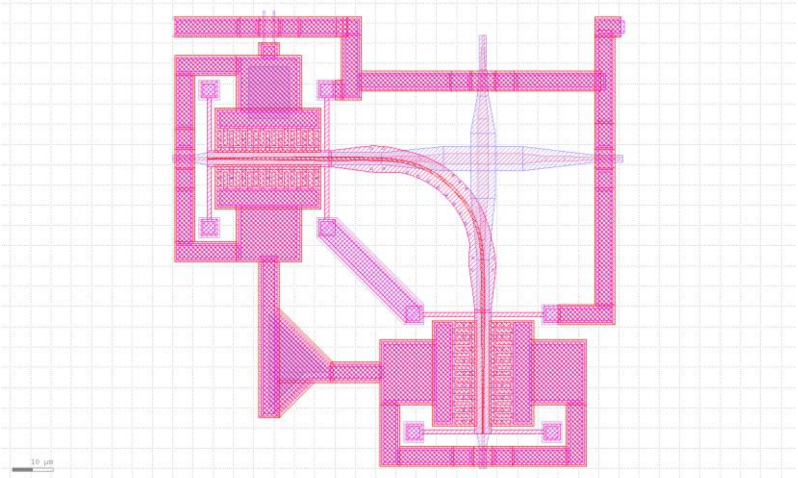
- The original design exhibits **bi-axial stress**. Leads to instabilities, and torsion.
- **Footprint** could be reduced.
- Any design must maintain the same **optical losses**.
- Low-loss crossing is **untouched**.

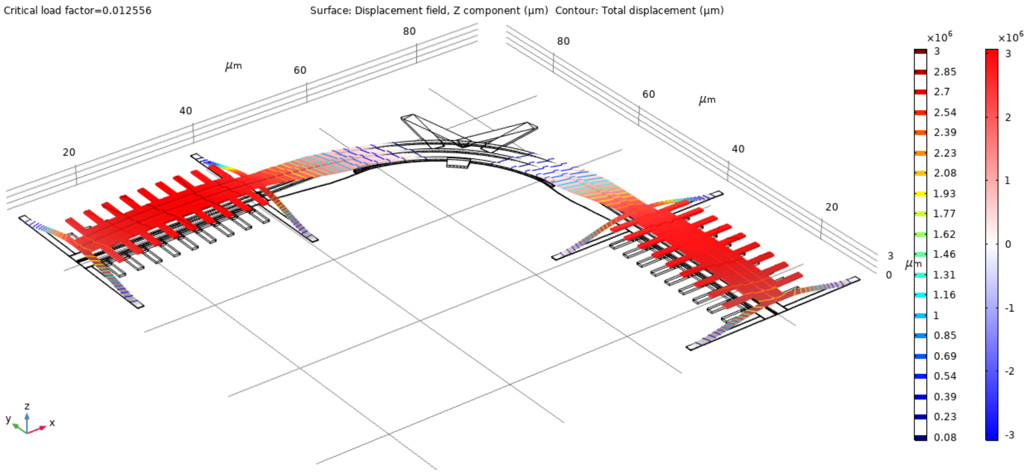
The matrix exists on 2 levels (top & bottom)





2.2 Current design – Optimization criteria





- Uniaxial stress only.
- Smaller footprint.
- Increase switching speed.
- Low losses.
- (optional) all inputs (resp. outputs) on the same side.

3. Design and development

3.1 Design and development - Methodology

1. Geometry design on paper.
2. Implementation of specific elements using **MATLAB**.
3. Verification using **KLayout** & **L-Edit**.
4. Assembly on **L-Edit**.
5. Simulation on **COMSOL**.

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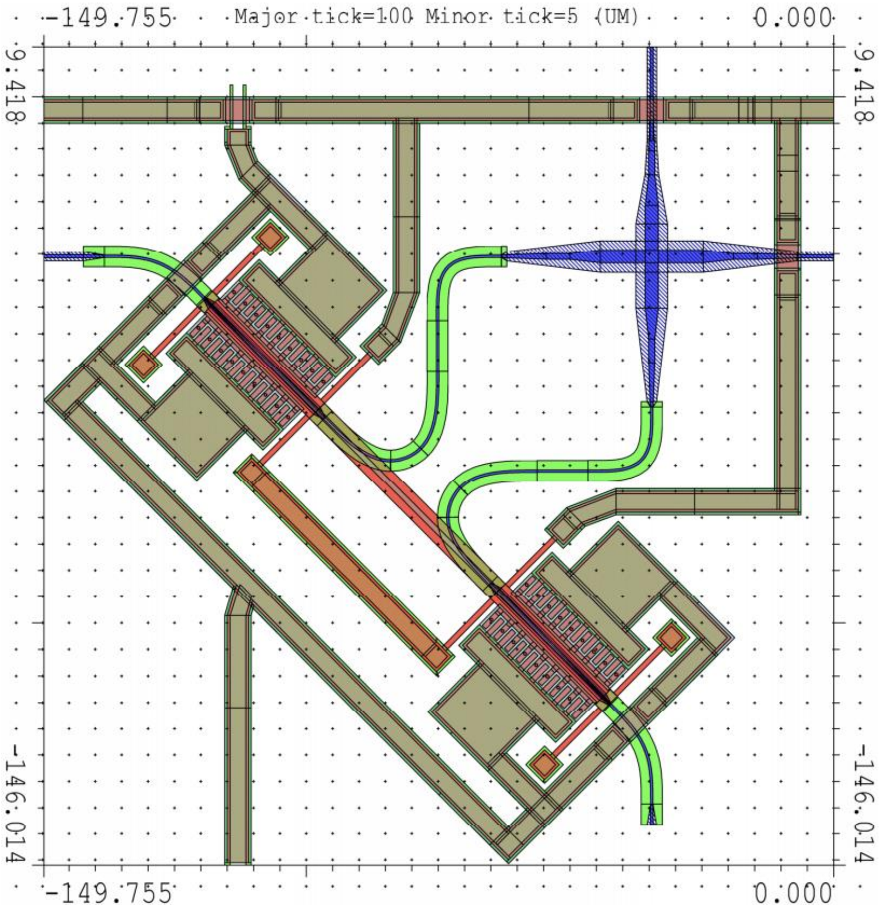
Design 1 : Linear Coupler

EPFL

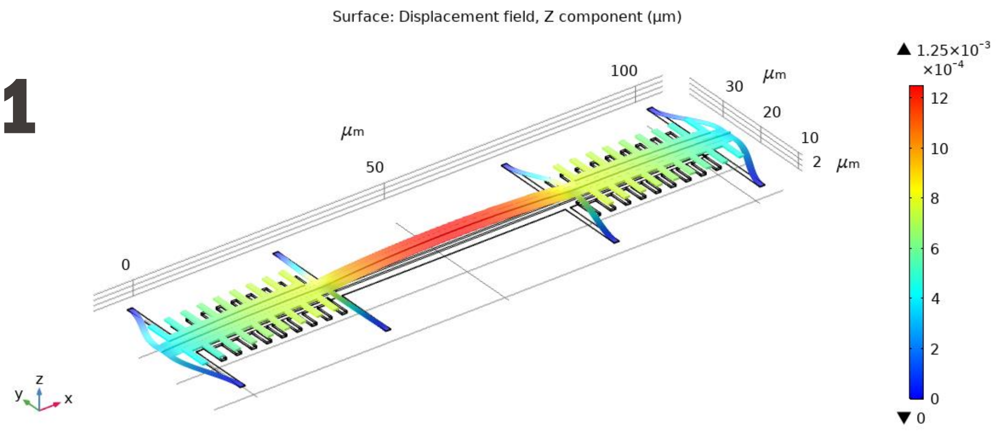
3.2 Design and development – Design 1

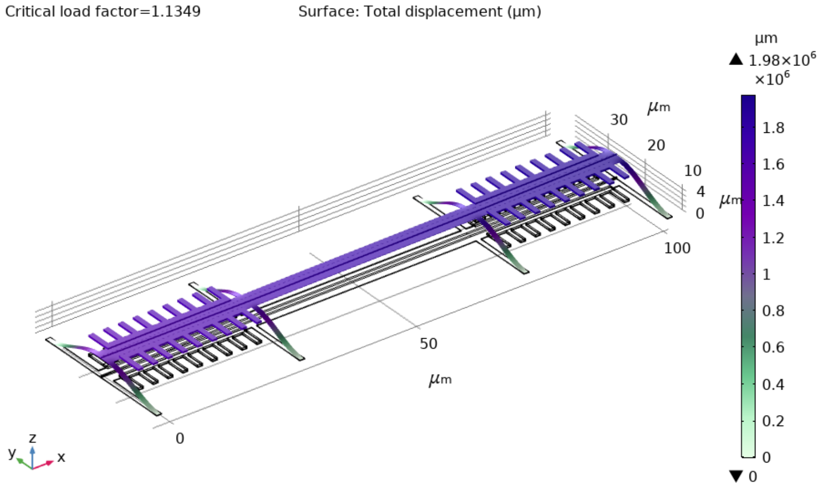
- Coupler principle : linear **clamped-clamped** beam.
- **Bottom waveguide** is deformed to comply with the geometry.
- We use a **Sine-Circle-Sine** curve matching strategy.
- Minimum radius of curvature is **5 um (strip)**. Curvature is continuous.
- Estimated loss :
  - 0.06 dB/cell (BWG)
  - 0.48 dB/coupler



3.2 Design and development – Design 1 (cont'd)

- Compressive stress of **7.78 MPa** is applied. Load of **0.27 nN** applied.
- Upwards buckling at critical load factor of **λ=1.13**.
- Stationary deflection is **too small**, because the load is small (less than 1 nm).





First buckling mode, critical load factor = 1.13

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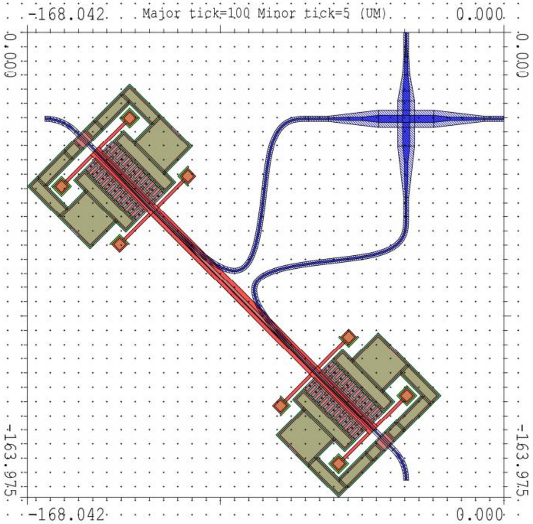
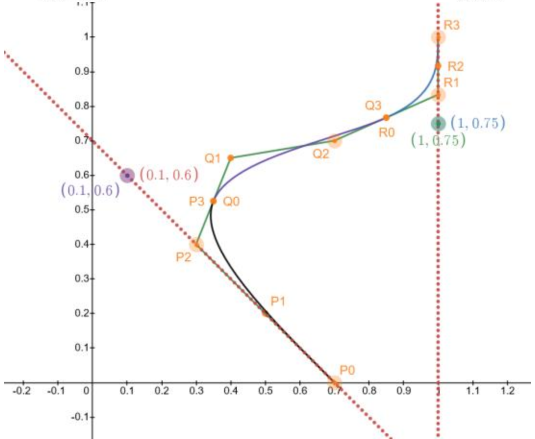
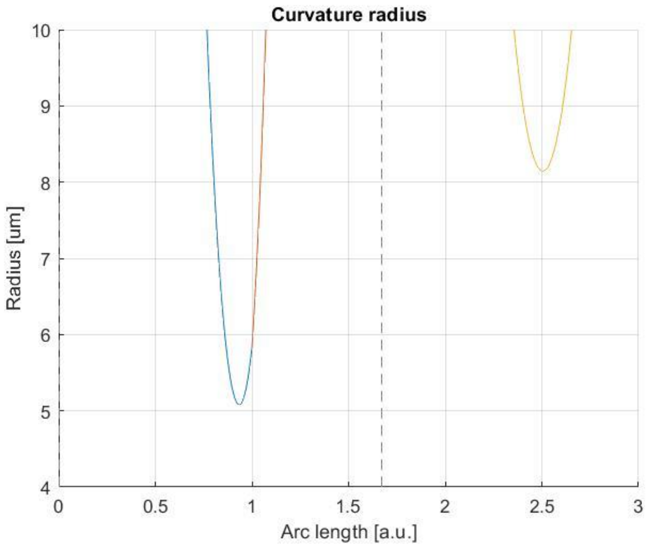
3.2 Design and development – Design 1 alternative

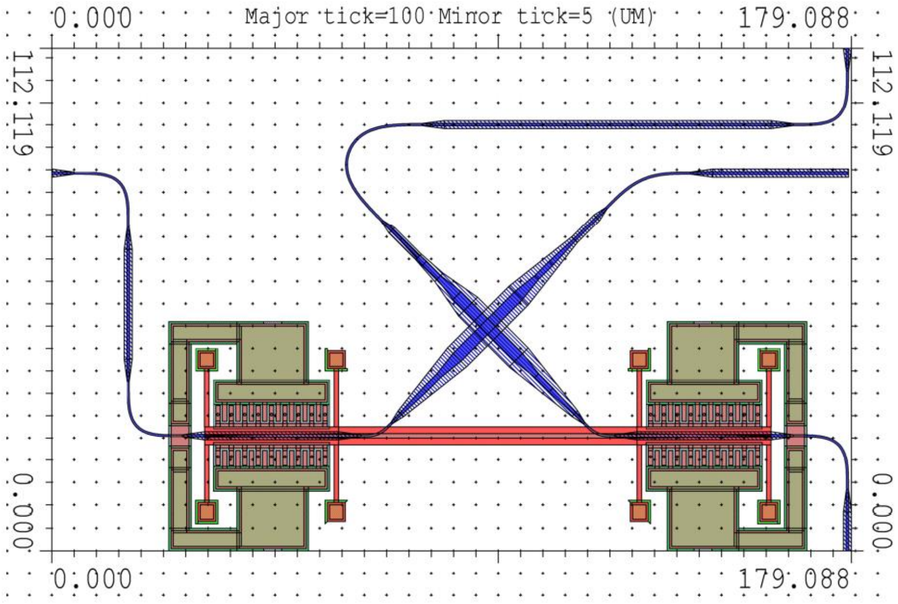




- Using 3rd order Bézier curves
  - The design **respects all constraints**.
  - However the entire path should be **rib waveguides**.
  - Coupler length is **higher**.
  - Estimated loss : 0.05 dB/cell (BWG).



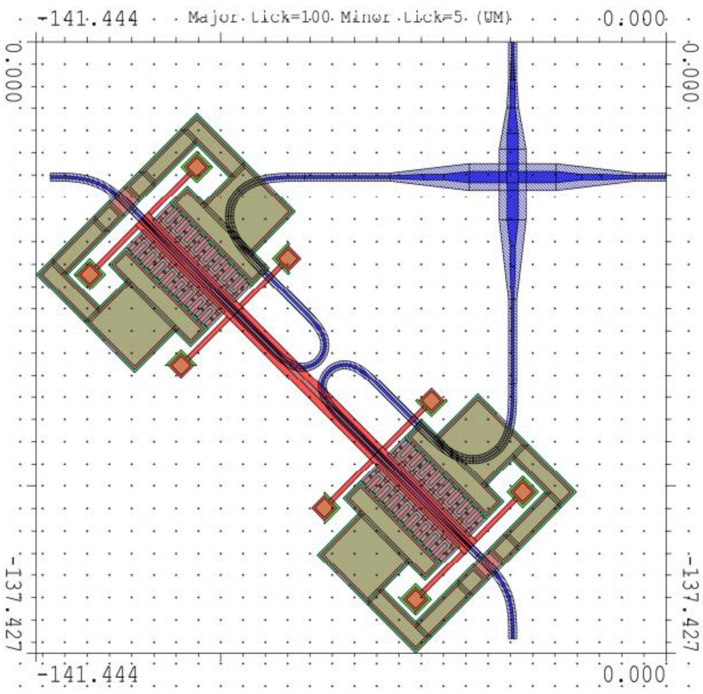
3.2 Design and development – Design 1 alternative (cont'd)



- We attempt to reduce the overall footprint by changing the **orientation of the low-loss crossing**.
- The coupler is pushed **as close as possible** to the crossing.
- Main problem : **high optical losses**.
- If we try to reduce the bends, we increase the footprint, and stagger the cells : **bad design** !

3.2 Design and development – Design 1 conclusions

- Main limiting parameter is the **crossing of both ‘’lobes’’** on the bottom waveguide. Pushing the drive closer to the low-loss crossing creates an **overlap in the lobes**.
- A more compact design also **interferes** with the **suspension** and the **row/column** addressing.
- 3rd order Bézier curves provide an **elegant solution** to the problem.
- Main problems : **footprint of low loss crossing, optical losses.**

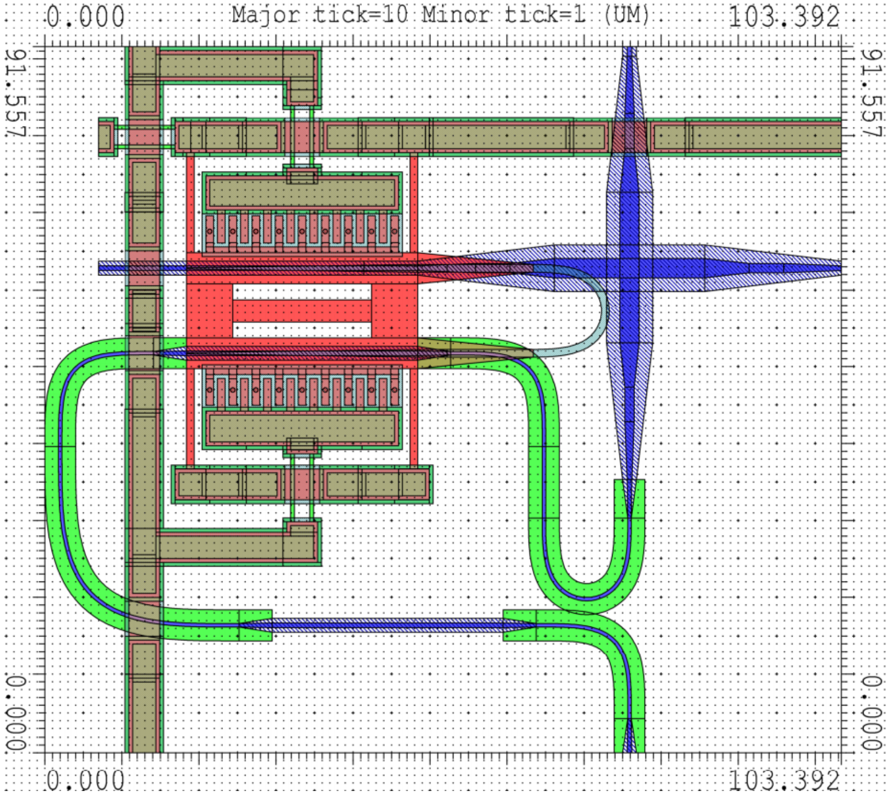


Linear design with lobes pushed close together

Design 2 : U-Turn coupler

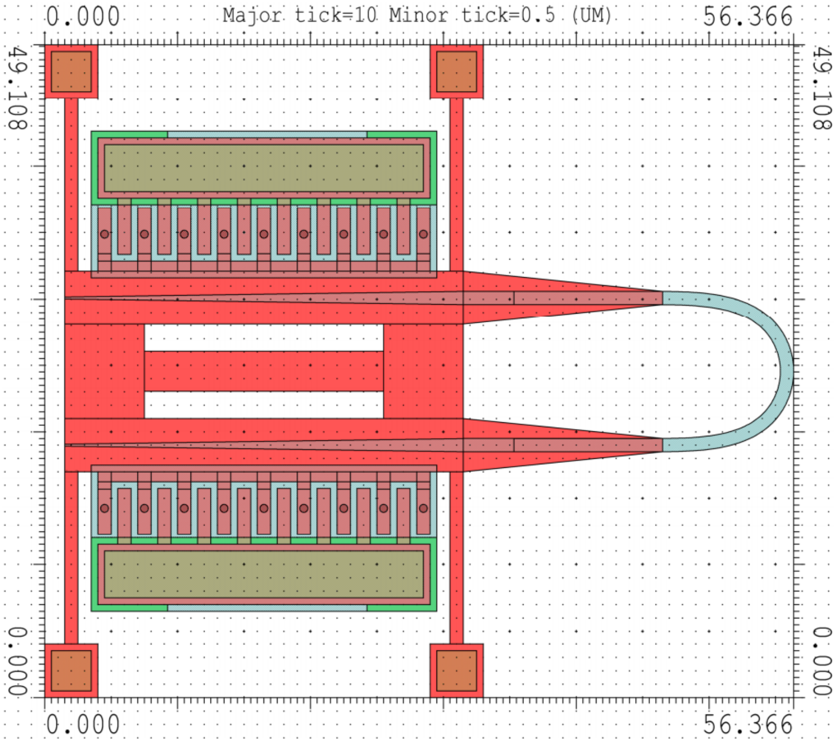
3.3 Design and development – Design 2

- Coupler principle : suspended U-Turn.
- **Bottom waveguide** is deformed using **sine-circle sine** methods.
- **MEMS redesigned.**
- Minimum radius of curvature is **5 um (strip)**.
- Estimated loss :
  - 0.13 dB/cell (BWG)
  - 0.52 dB/coupler



3.3 Design and development – Design 2 MEMS redesign

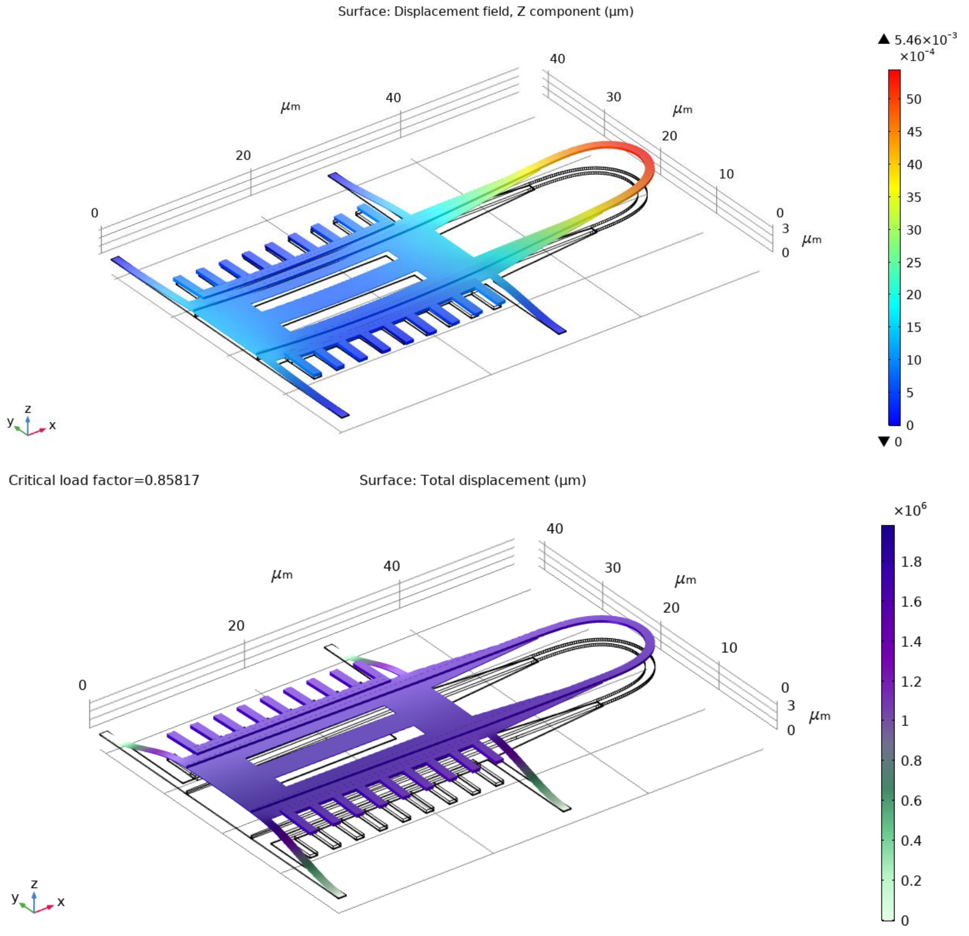
- We remove 2 comb drive actuators and join both inlet-outlet together.
- Beam in the middle acts as anti-roll bar.
- The MEMS is already **smaller** than the crossing.
- Further mechanical simulations could reduce the MEMS mass.



U-Turn coupler with smallest possible radius.

3.2 Design and development – Design (cont'd)

- Compressive stress of **7.78 MPa** is applied. Load of **0.27 nN** applied.
- Upwards buckling at critical load factor of ***λ*=0.86**.
- Stationary deflection is **too small**.
- Deflection of **150 nm** achieved for approx. 100 times the initial load.



First buckling mode, critical load factor = 0.86

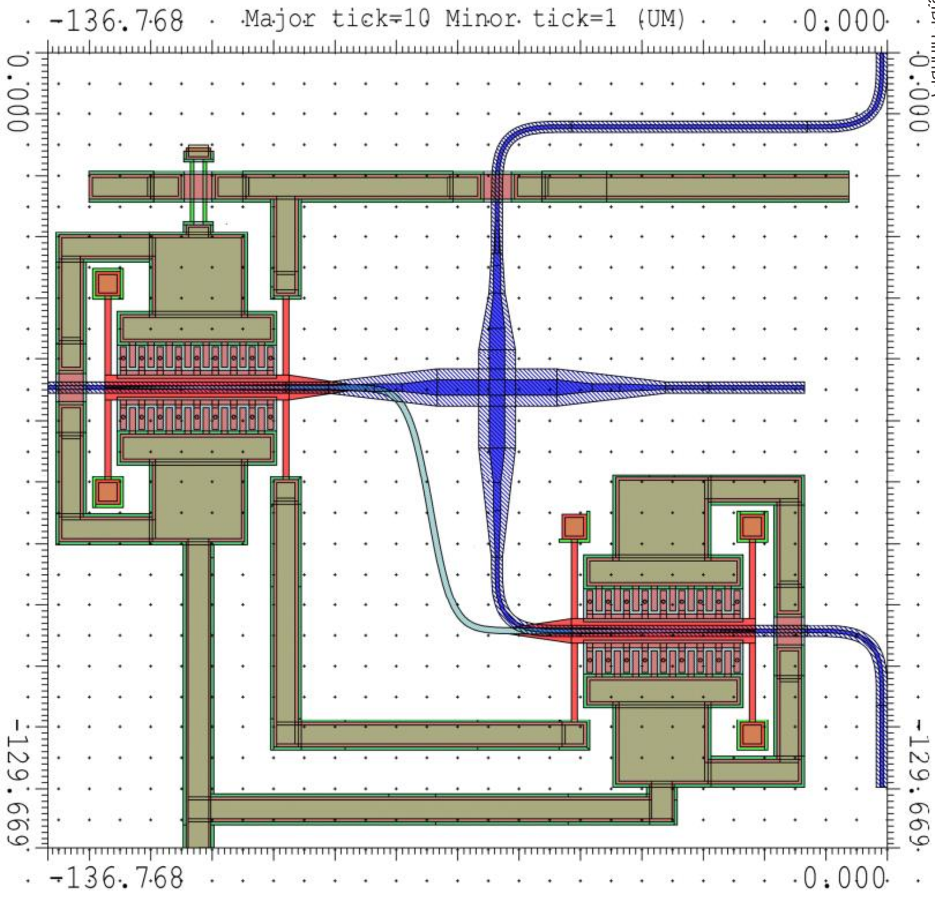
3.2 Design and development – Design 2 conclusions

- The geometry is limited by the **low-loss crossing.**
- We **redesigned** the comb drives.
- Applied load is **not sufficient** to obtain the required deflection.
- Buckling mode behaviour **as expected**.
- Highly **compact**.
- Main problem : **high optical losses**.

Design 3 : Sigmoid Coupler

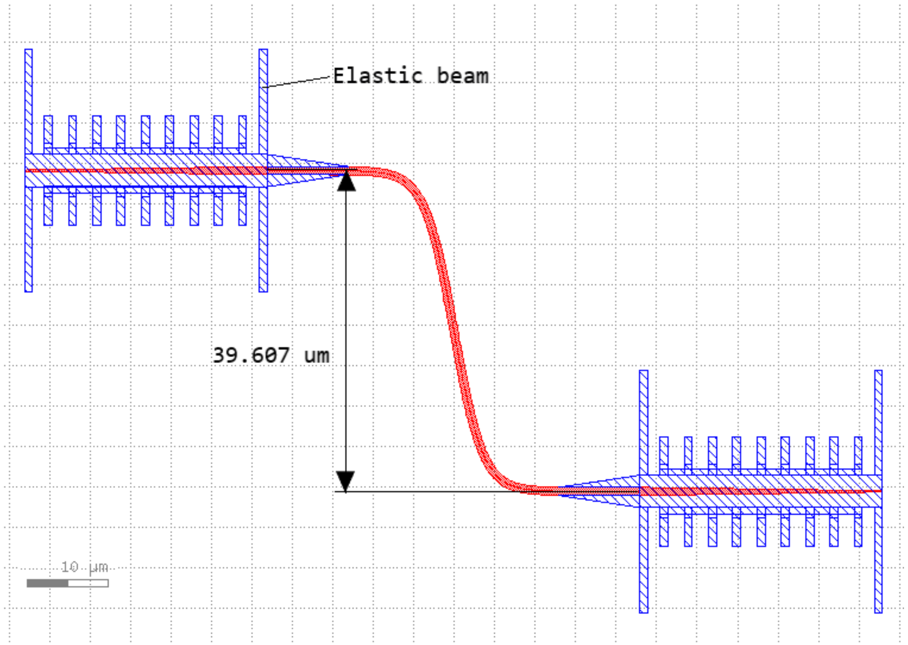
3.4 Design and development – Design 3

- Coupler principle : suspended logistic sigmoid function.
- **Both waveguides** are deformed using **sine-circle sine** methods.
- Minimum radius of curvature is **5 um (strip),** obtained via parametrization.
- Estimated loss :
  - 0.08 dB/cell (BWG)
  - 0.54 dB/coupler



3.4 Design and development – Design 3 Coupler

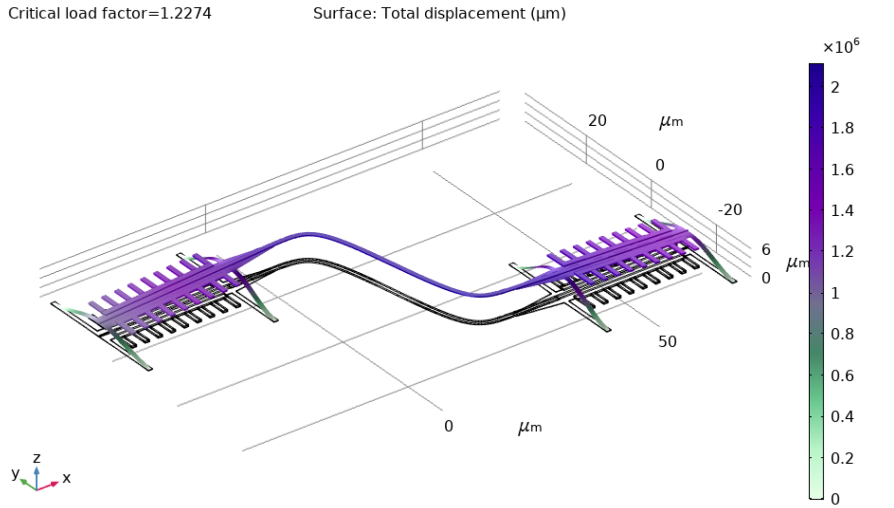
- The sigmoid height is **limited by the low-loss crossing** (again !).
- A smaller coupler would require a **redesign of the BWG** : tight turns, high losses.
- Mechanically **compromised**.



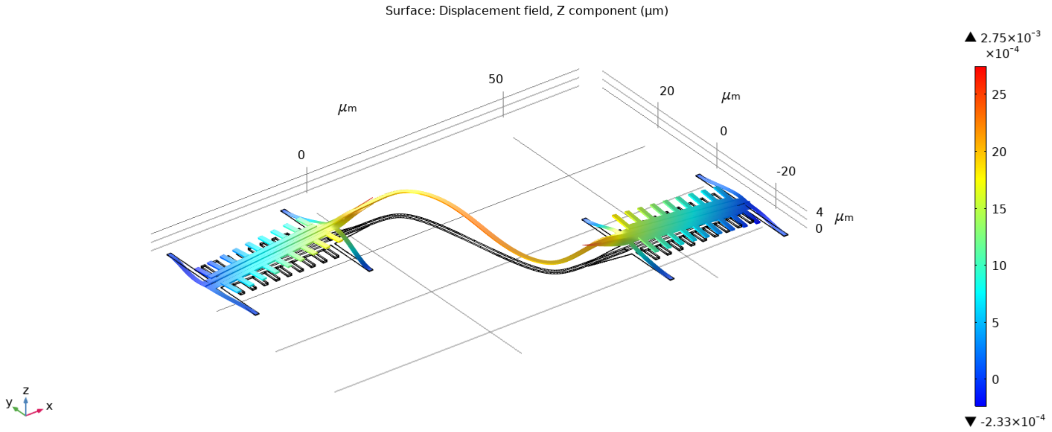
Sigmoid coupler with a height limited by the low-loss crossing.

3.2 Design and development – Design 3 simulations

- Compressive stress of **7.78 MPa** is applied. Load of **0.27 nN** applied.
- Upwards buckling at critical load factor of **λ=1.23**.
- Stationary deflection shows that the **design is mechanically unstable**.



First buckling mode, critical load factor = 1.23



3.2 Design and development – Design 2 conclusions

- Elegant solution because of the parametrization capabilities.
- The geometry is limited by the **low-loss crossing.**
- MEMS is thin and long, therefore mechanically unstable, as expected and demonstrated by the FEM simulation.
- Design could be useful for a lower height (approx. 15 um).
- Main problems : **high footprint, mechanically unstable MEMS.**

4. Performance characteristics & Limitations

4.1 Performance characteristics – Summary

	Linear Design	U-Turn Design	Sigmoid Design
Estimated losses for the BWG [dB]	0.0595	0.1344	0.0845
Estimated losses for the coupler [dB]	0.0167	0.0496	0.0698

Table 1: Estimated optical losses for the 3 designs.

	Linear Coupler	U-Turn Coupler	Sigmoid Coupler
λ : 1st mode	1.135	0.858	1.227
λ : 2nd mode	1.152	1.016	1.281
λ : 3rd mode	1.954	1.118	1.653

Table 2: Summary of the critical load factors λ for each coupler, for the first 3 buckling mode shapes.

4.2 Limitations - Summary

Design size limitations

- Main limitation in the design is **the low-loss crossing**.
- For all 3 designs it is the limiting factor.
- But**,** the low-loss crossing **cannot be miniaturized** : current dimensions minimize cross-talk.

Performance limitations

- Main limitation in performance is the **optical loss**.
- If BWG's optical losses are in the range of the crossing, **then the design is too lossy.**
- All designs show high losses because the BWG needs to accommodate **small MEMS**, and a **big LLC**.

5. Conclusions

5. Conclusions

- The linear design as the lowest losses, and the simplest MEMS.
- The U-Turn design has the smallest MEMS, the smallest footprint, but the **highest** losses.
- It is important to keep in mind that the low-loss crossing is the limiting factor for all future work.
- These designs could be used for other projects.

	Pros	Cons
Linear design	• Simple MEMS. • Lowest optical losses.	• Larger footprint.
U-Turn design	• Most compact design. • Smallest MEMS.	• High optical losses.
Sigmoid design	• Low optical loss. • Design could be used for other projects.	• Mechanically unstable. • Large footprint.

Thank you for your attention !

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