Optimization of Bistable Silicon Photonic MEMS Switch Architectures

Midterm presentation

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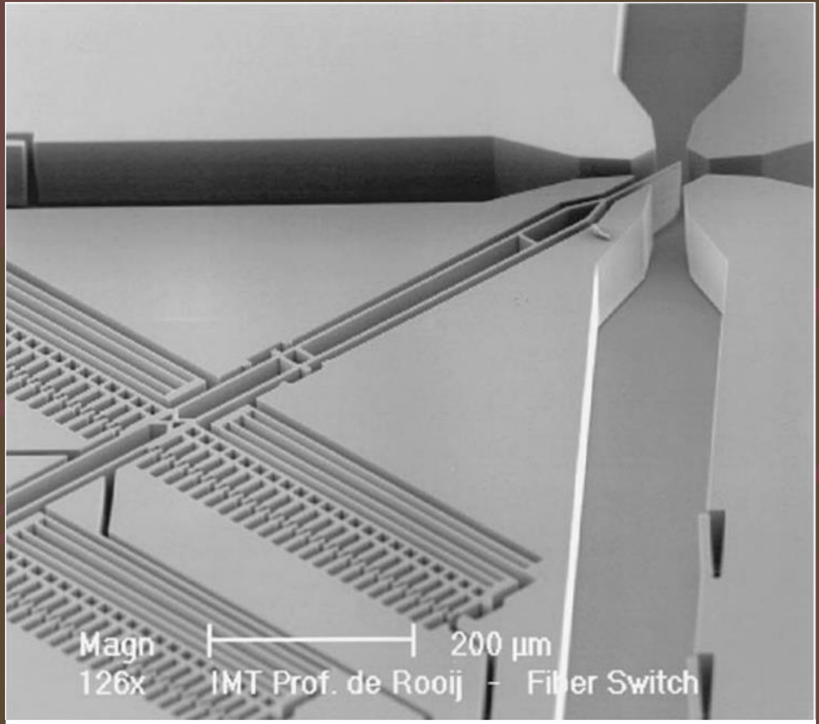
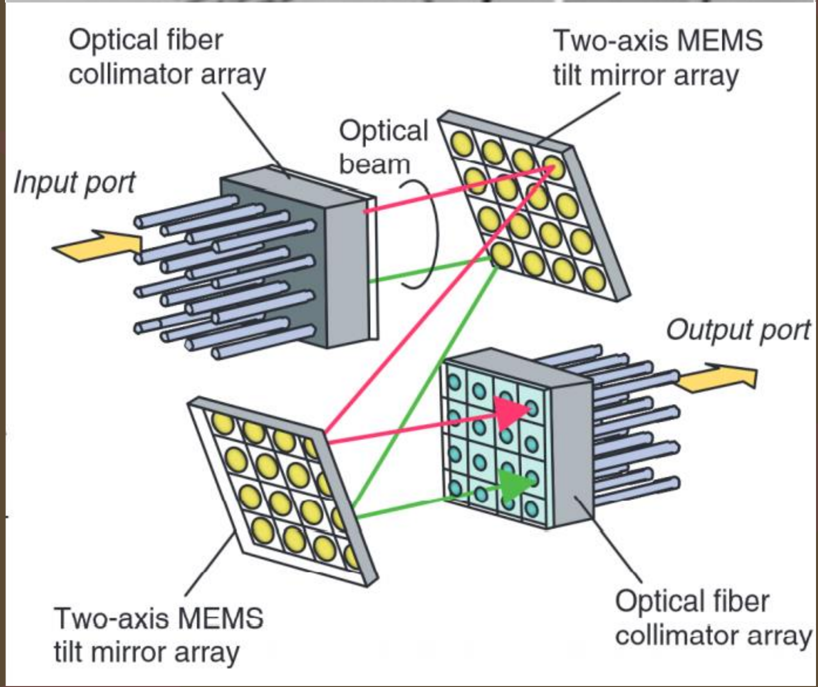
1.1 Introduction – Optical switches

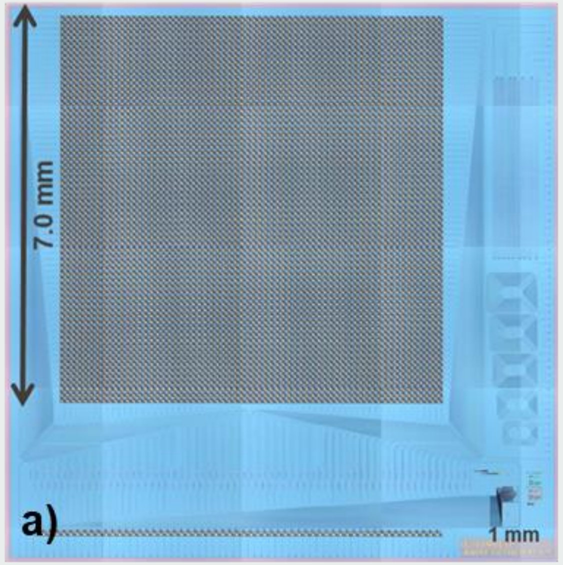
- Optical switch : device that switches optical signals between channels.
- Historically using **mirrors**.
- MEMS are advantageous for their **integration** capabilities, **reliability**, and **low power consumption**.
- Silicon photonic MEMS allows us to use well **understood fabrication procedures**.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





1.2 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.



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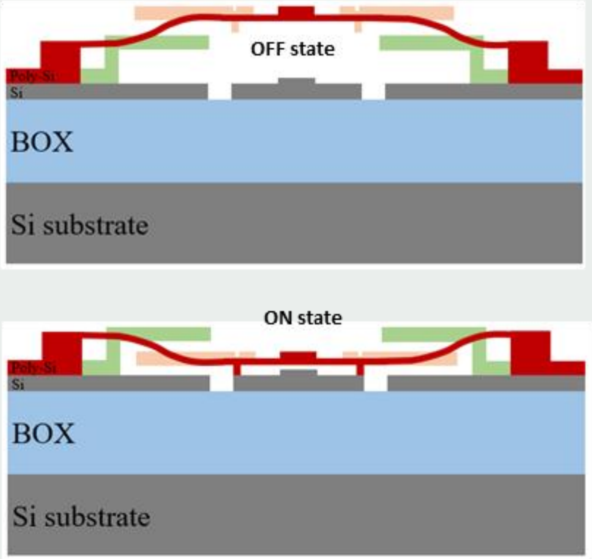

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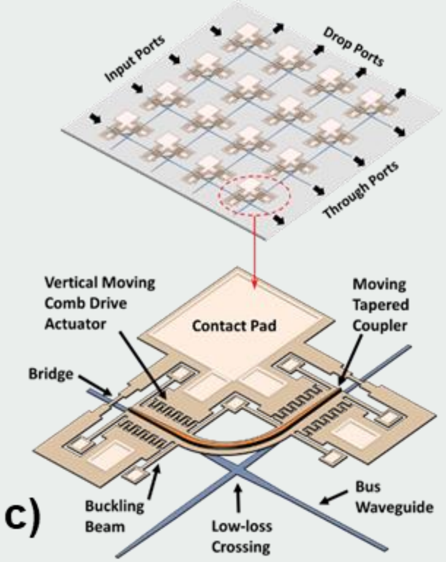


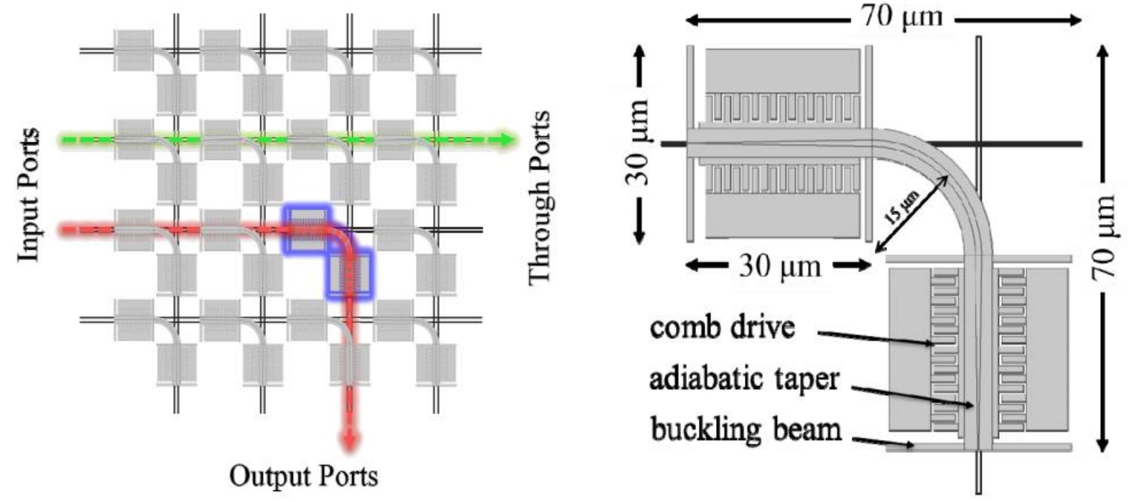
c)

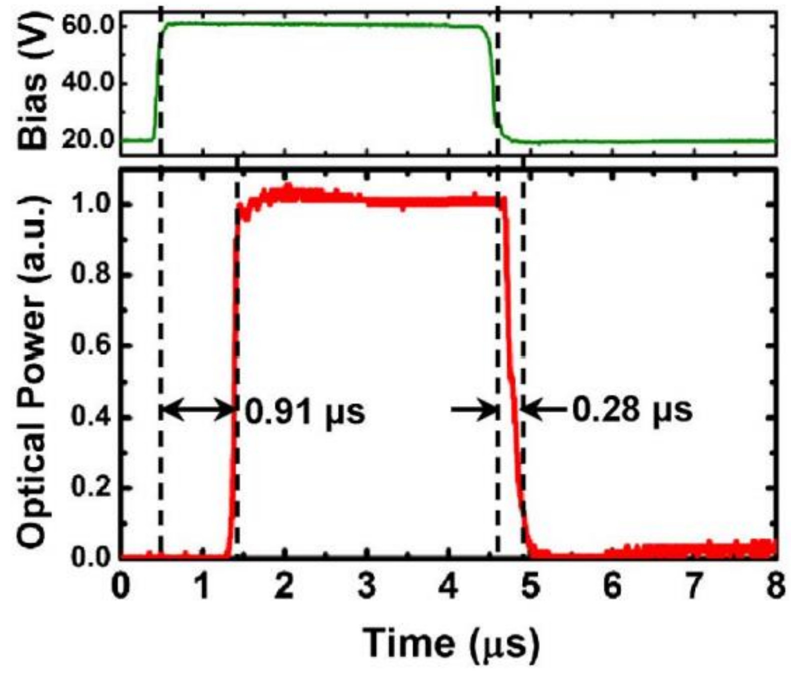
- OFF state : light stays in the **bottom level**
- ON state : light is coupled from the **bottom level to the top level** in the coupler, and then **bottom again.**

2.1 Original design & optimization

- The original design exhibits **bi-axial stress**. Leads to instabilities, and torsion.
- **Footprint** could be reduced and **switching speed** could be improved (currently : 1 us).
- Any design must maintain the same **optical losses**.
- Low-loss crossing is **untouched**.

The matrix exists on 2 levels (top & bottom)

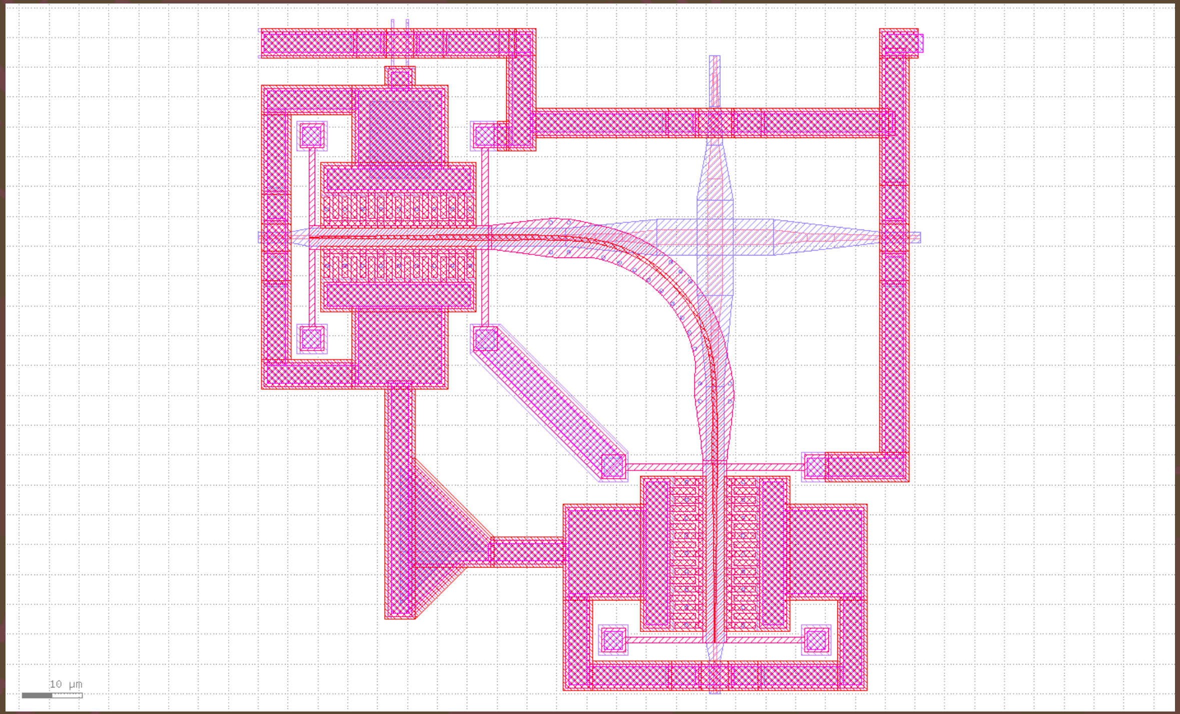


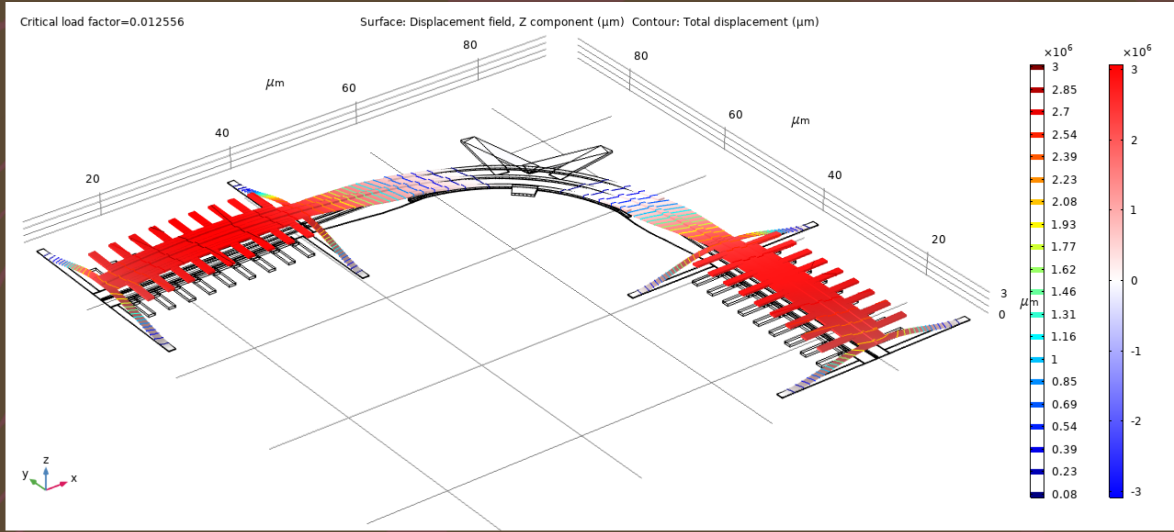


Temporal response of unit cell

2.1 Original design & optimization (cont'd)

- Optimization criteria :
  1. Uniaxial stress only
  2. Smaller footprint
  3. Increase switching speed
  4. Low losses
  5. (optional) all inputs (resp. outputs) on the same side





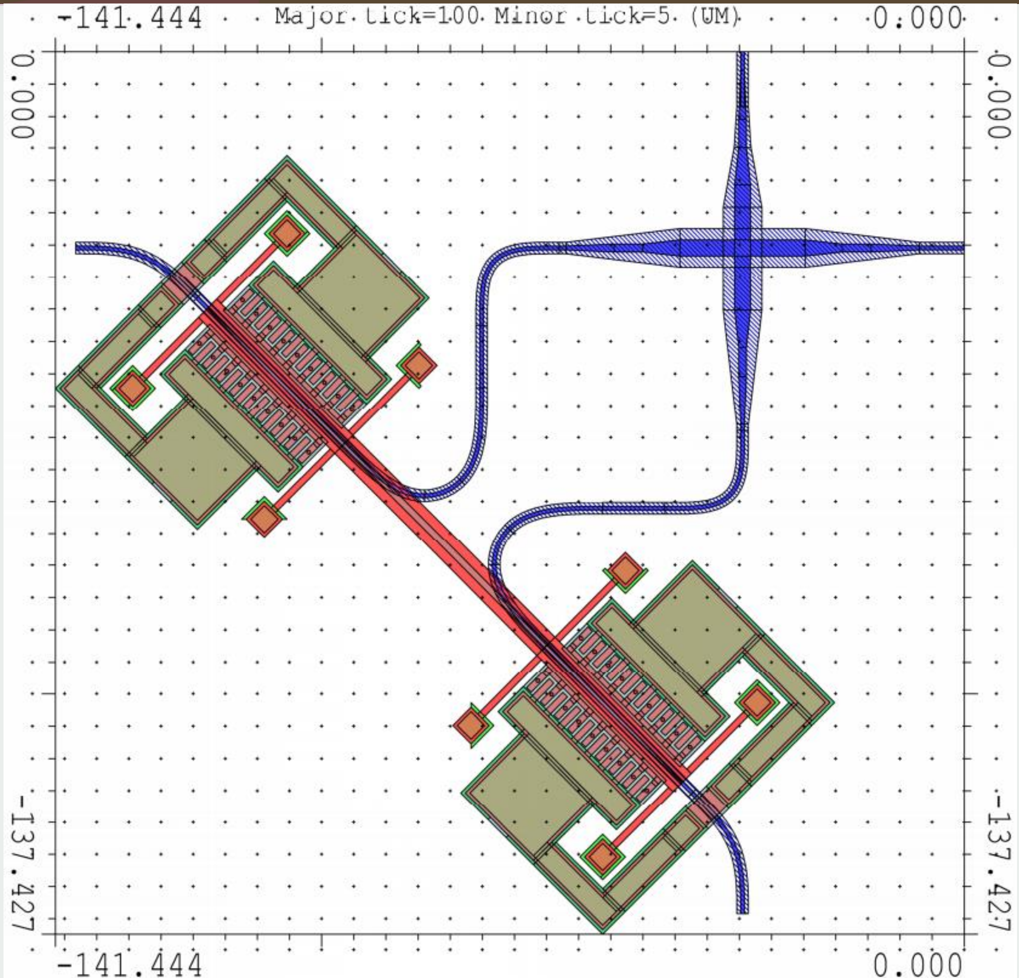
EPFL

2.2 Methods and tools

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**.

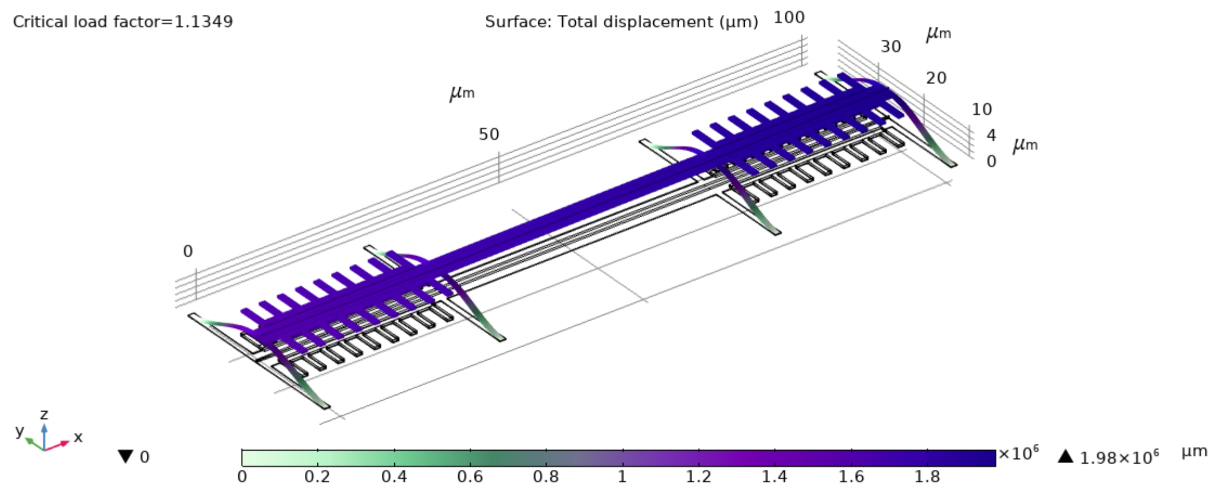
3.1 Design 1 : Linear Coupler

- 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 must be continuous.
- Estimated loss : 0.036 dB

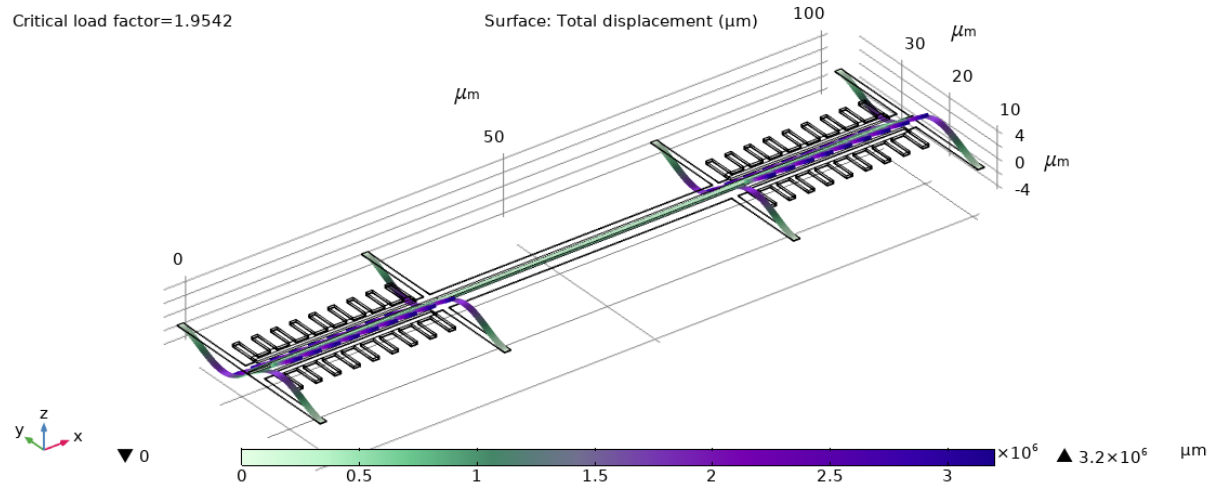


3.2 COMSOL simulations

- Compressive stress of 7.75 MPa is applied.
- Upwards buckling is seen for a critical load of $\lambda = 1.13$.
- Torsion appears in the third mode, for $\lambda = 1.95$.



First mode, critical load factor = 1.13

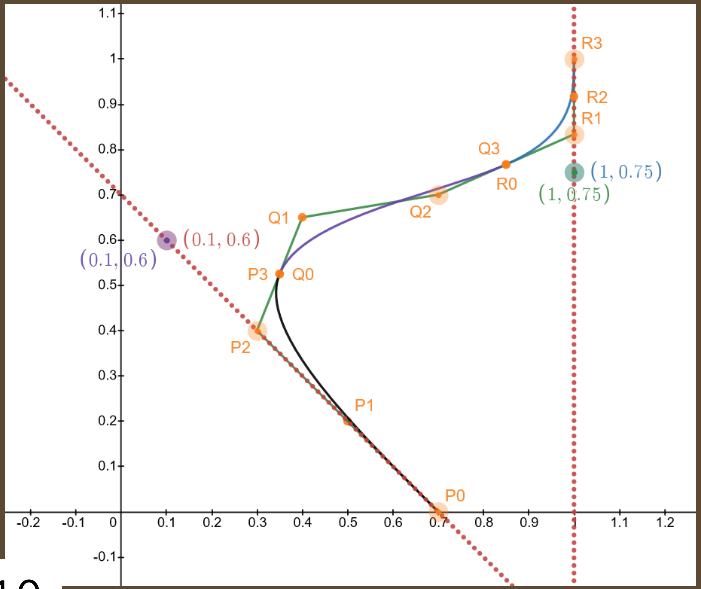


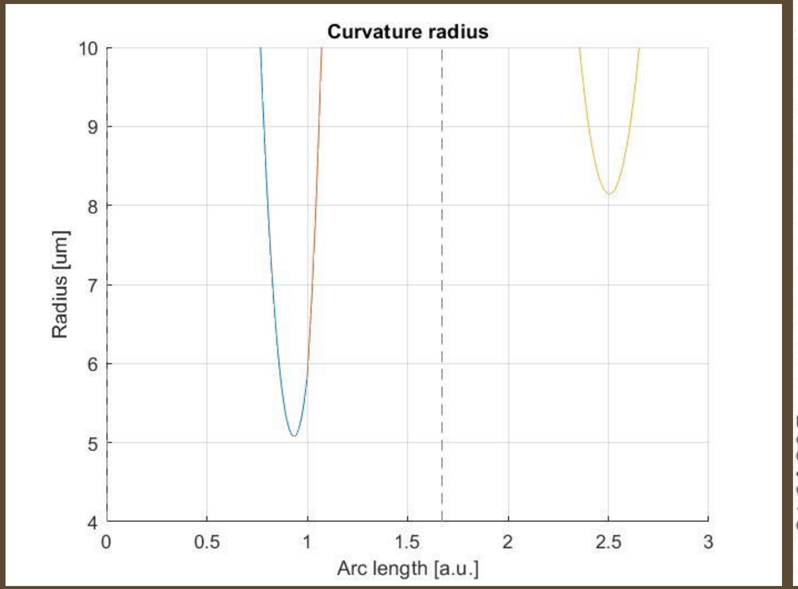
Third mode, critical load factor = 1.95

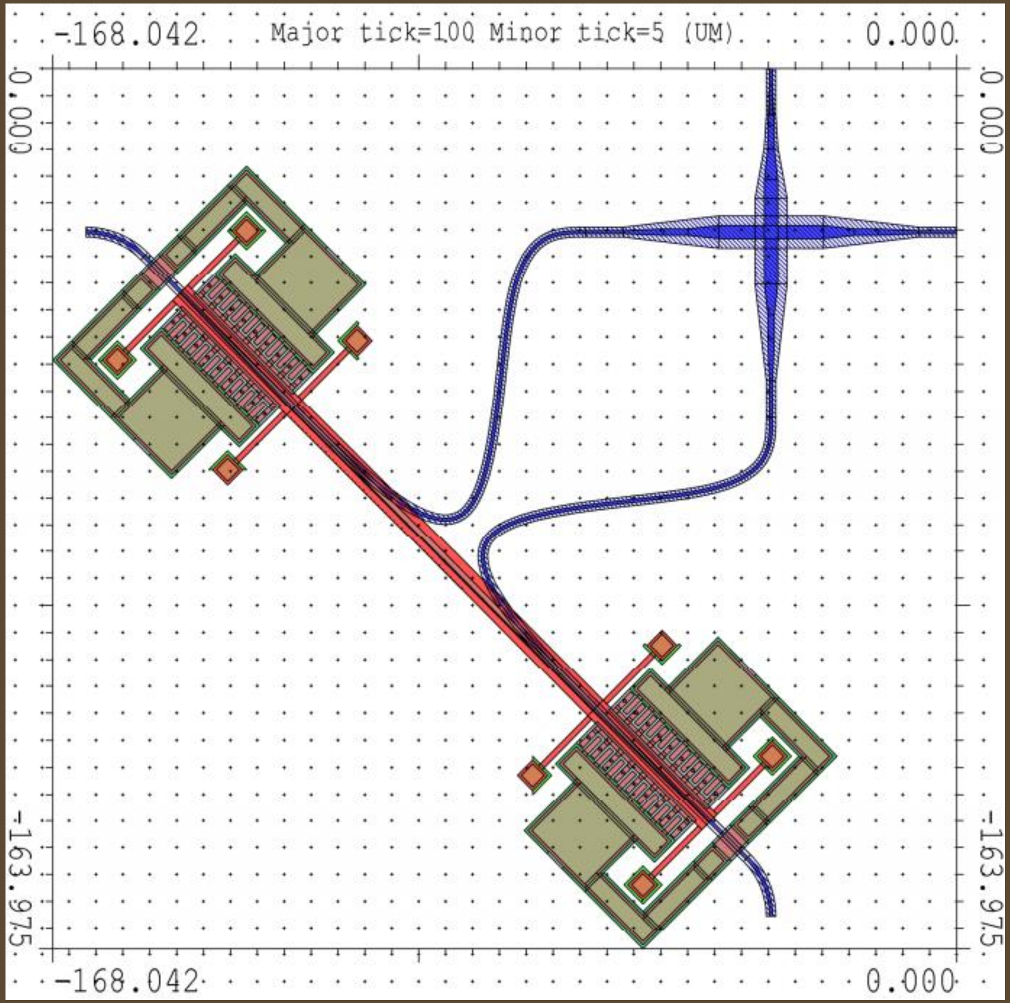
3.3 Other waveguide designs

Using 3rd order Bézier curve segments

- The design **respects all constraints**.
- However the entire path should be **rib waveguides**.
- Coupler length is **higher**.
- Estimated loss : 0.033 dB

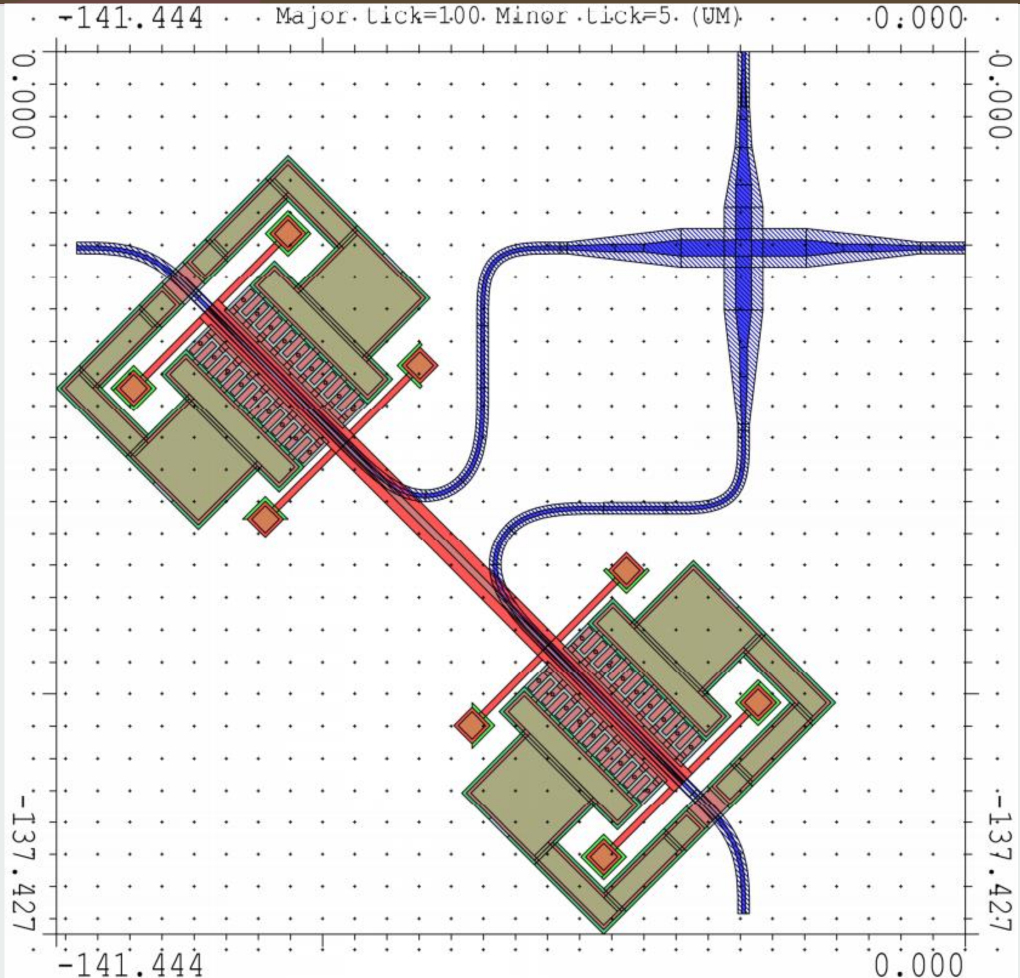




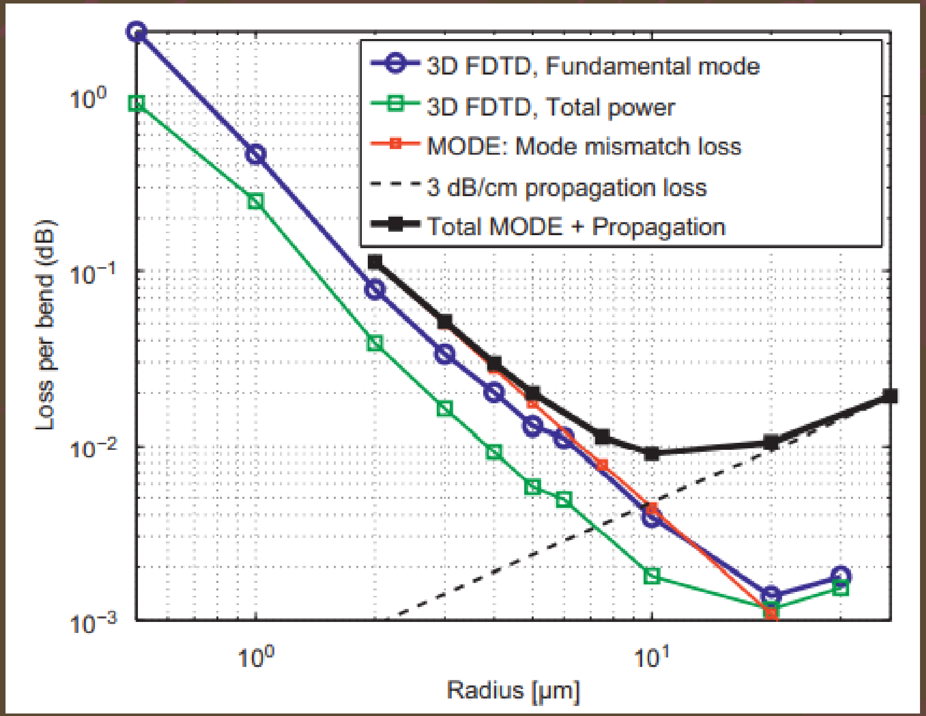


3.4 Design 1 : Limitations

- 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.



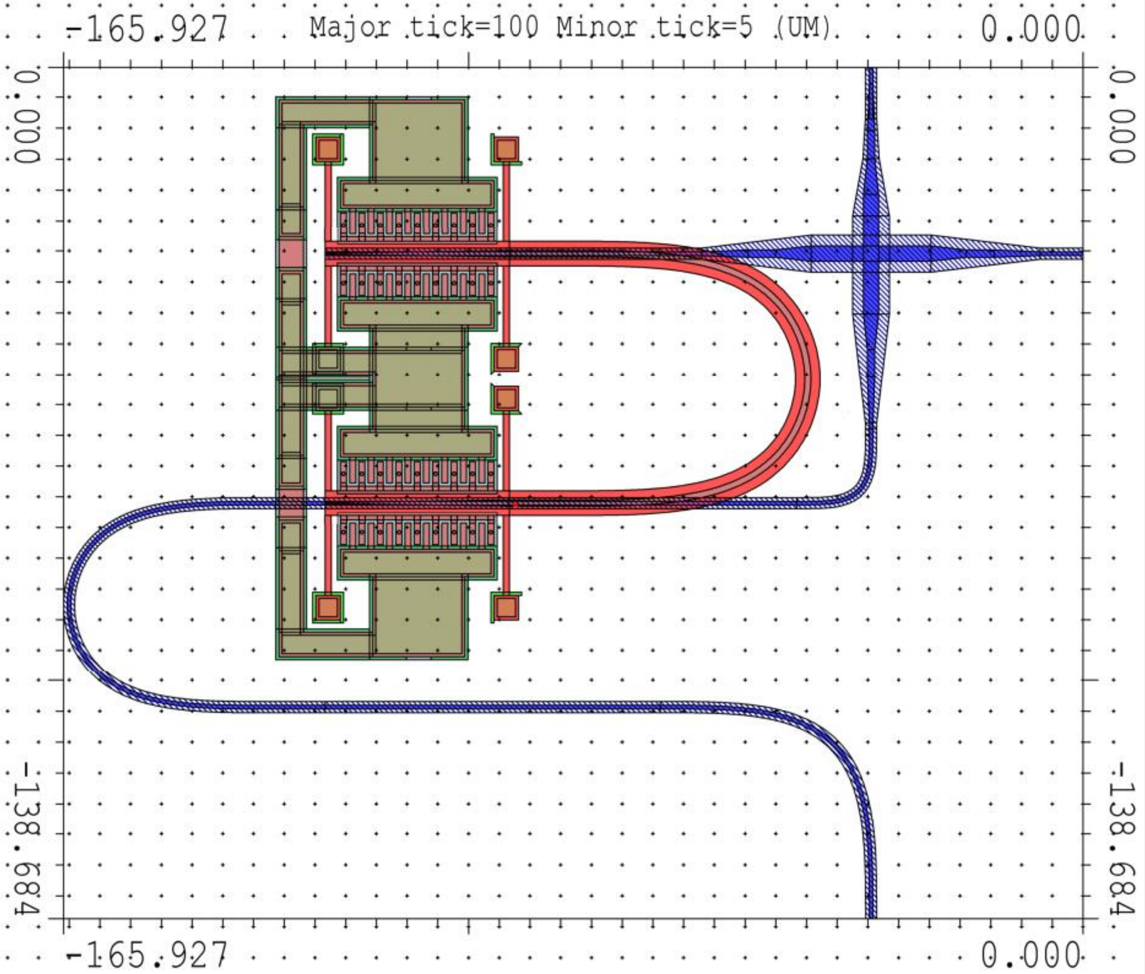
3.5 Design 1 - Conclusions



- 3rd order Bézier curves provide an **elegant solution** to the problem.
- The need for **fully etched** strip waveguides over a long distance is problematic for losses.
- Using sine-circle-sine constructions requires additional steps, but the tapering needed for the **rib-strip adiabatic transition** is possible.
- Simulations show expected behavior.

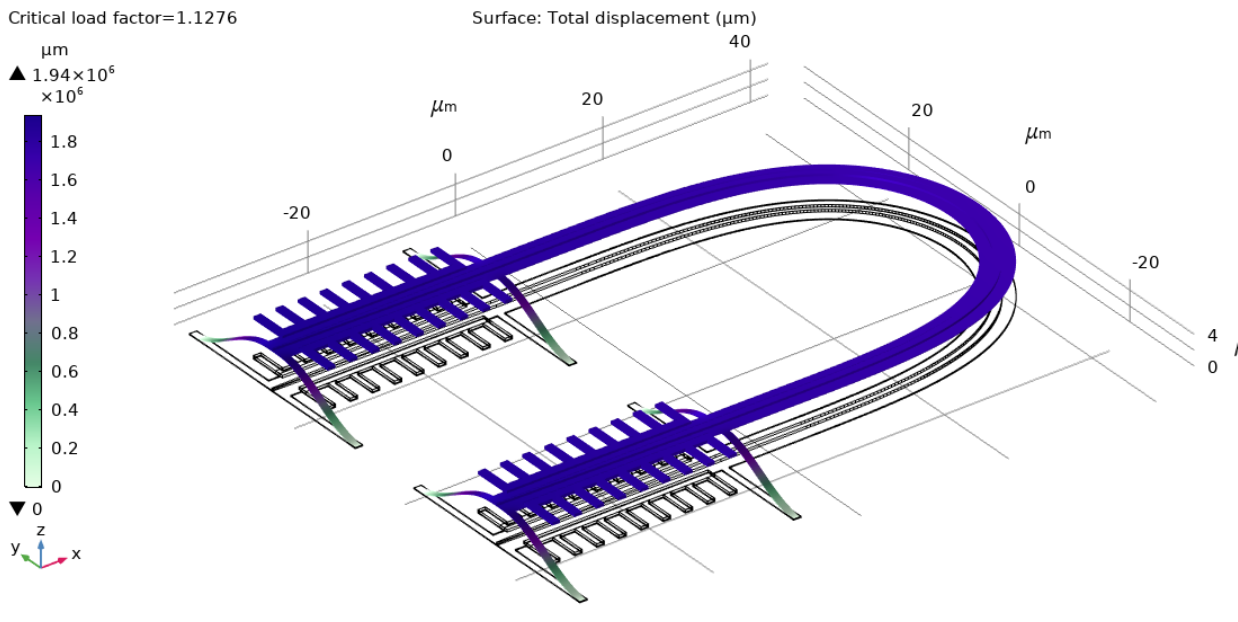
4.1 Design 2 : U-Turn coupler

- Coupler principle : U-Turn with suspended coupler.
- **Bottom waveguide** is deformed using sine-circle-sine methods.
- Minimum radius of curvature is **5 um (strip)**.
- Estimated loss : 0.038 dB

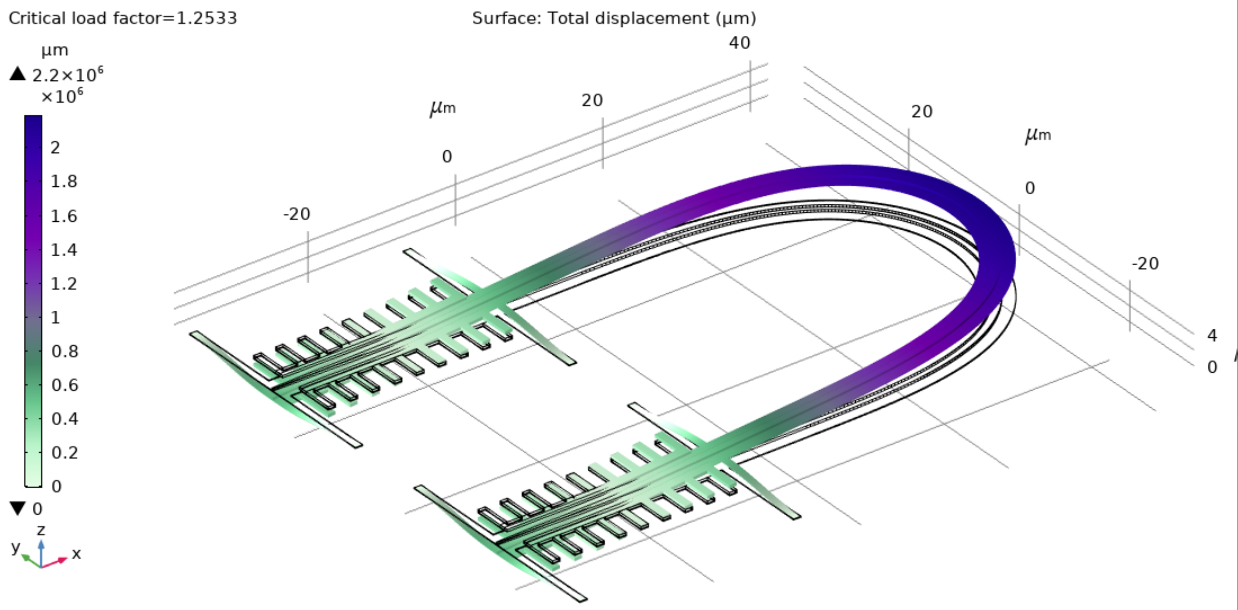


4.2 COMSOL simulations

- Compressive stress of 7.75 MPa is applied.
- Upwards buckling is seen for a critical load factor of $\lambda = 1.13$.
- Critical load factor for the third mode, $\lambda = 1.25$.



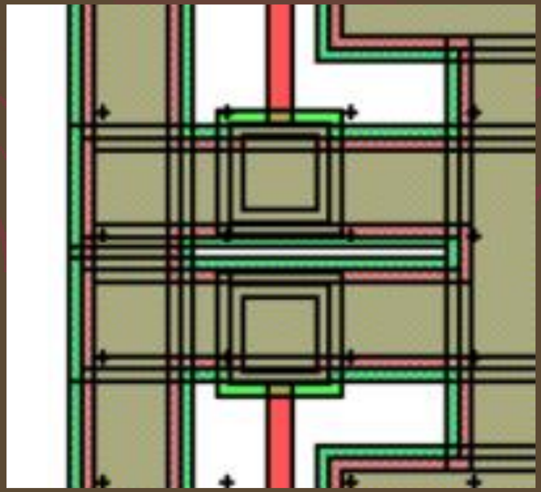
First mode, critical load factor = 1.13

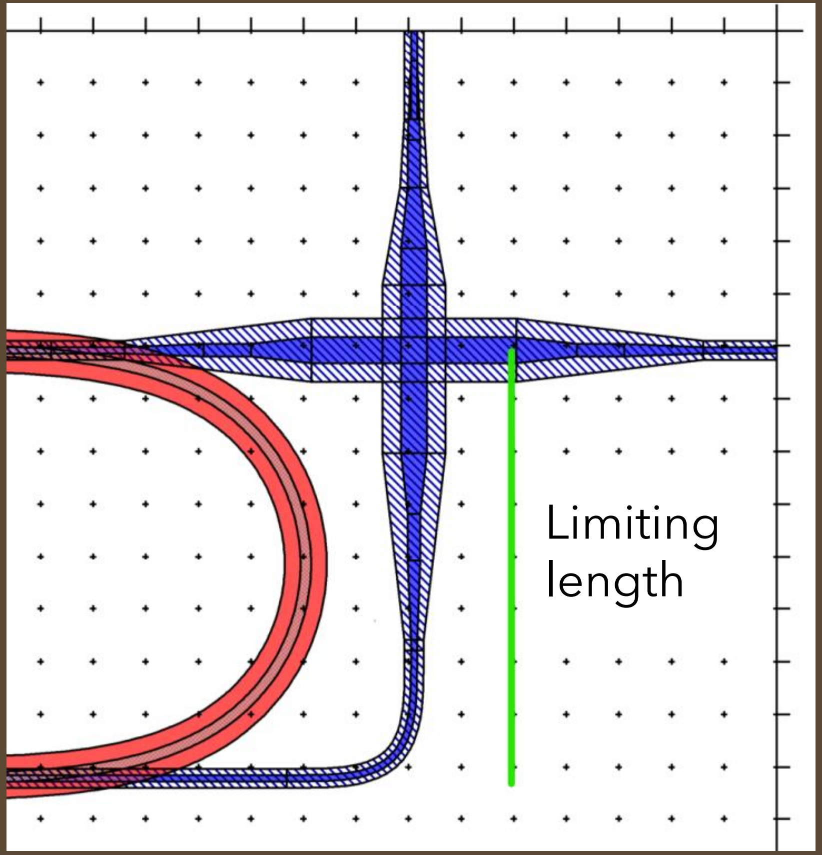


Third mode, critical load factor = 1.25

4.3 Limitations

- Trying to push the comb drives together creates an overlap of the suspension elements, and **limits the minimum radius** of the coupler.
- This can be improved by reducing the mode matching between adiabatic coupler and U-Turn.
- The curve matching of the bottom waveguide creates a **long optical path**.



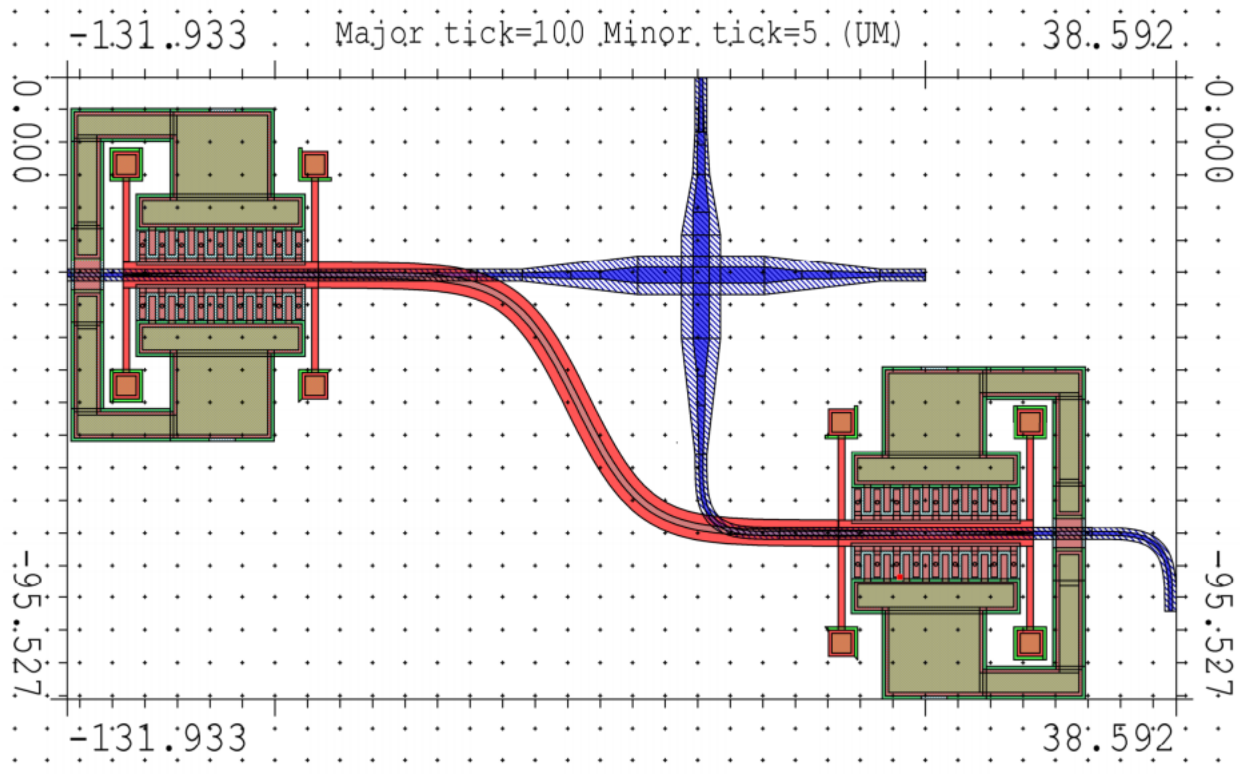


4.4 Design 2 - Conclusions

- The geometry's compactness is limited in part by the **low loss crossing's size** (good).
- A compact U-Turn requires a **redesign of the comb drives**.
- The system could potentially be driven by the **outer drives** only, and joint in the middle.
- Simulations show that the 3 first buckling modes are **close to each other** in critical load factor.

5. Other design idea : sigmoid

- Uses a **sigmoid logistic function** to model the coupler : 0 curvature at ends.
- Uniaxial stress, large curvature radii, compact, **but** long coupler length.
- The coupler can be **mechanically unstable !**



6.1 To do

1. Design the row/column addressing (all).
2. Design the tapering on Si FTE layer for strip-rib adiabatic transition (all).
3. Re-design the comb drive (U-Turn).
4. Simulate buckling for completeness purposes (Sigmoid).

6.2 Conclusions

- Linear coupler appears to be the easiest optimization solution.
- The U-Turn coupler needs a redesign of the comb drives but could be more compact.
- Comparable losses between all designs.

	Pros	**Cons**
Linear coupler	• Simple coupler design. • Uses tested components. • Small coupler.	• Large footprint (unused space). • Tight curves.
U-Turn coupler	• Potentially compact. • Limited by low-loss crossing.	• Requires redesign of some elements.
Sigmoid coupler	• Compact. • Low curvature. • All outputs on the same side.	• Mechanically unstable. • Large coupler length.

Thank you ! Questions ?

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