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European Commission

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# MEMS Spatial Light Modulators for Real Holographic 3D Displays

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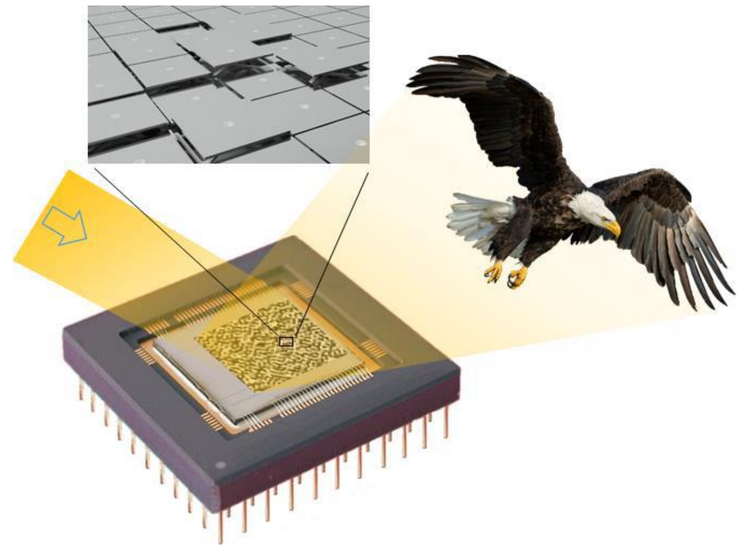
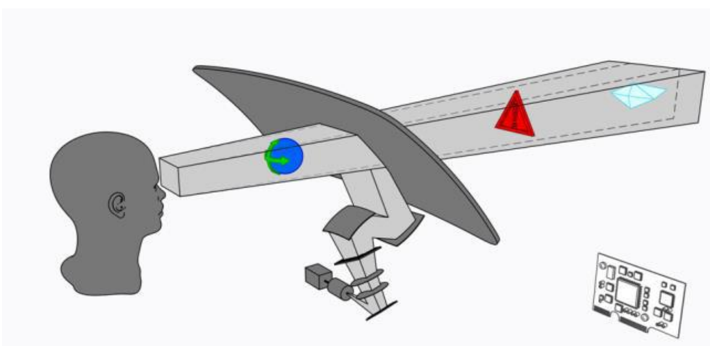
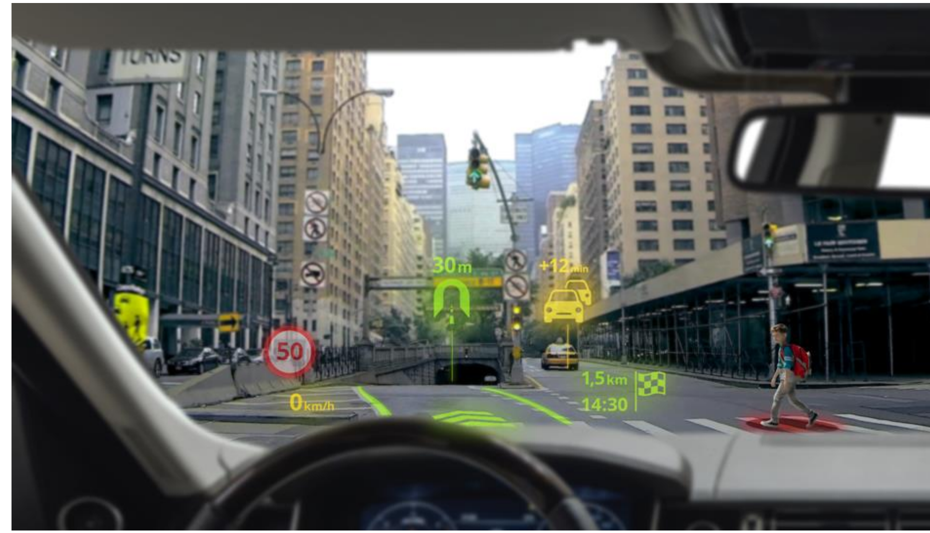


# Development of Holographic 3D Display Proof-of-Concept

## EU Horizon 2020 Project 'REALHOLO', Jan. 2021 … Dec. 2024

- holography has been a fascinating prospect for a long time
- the data volume is generally huge
- by restriction to small viewing windows real holography becomes feasible
- light modulators need to be developed





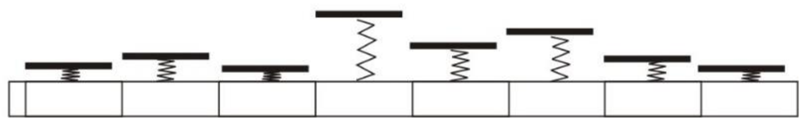

- REALHOLO main target: real time holographic automotive 3D head up display
- only real holography can provide a fully natural viewing experience with the image content correctly placed in 3D

# Challenges for SLMs in Holography

- very many pixels
- pixels as small as possible for large diffraction angle (→ low drive voltage)
- phase modulation is better than intensity modulation
- analogue modulation of light
  - binary modulation is inferior, pulse width modulation not feasible

→ DLP-SLMs are sub-optimal

- high frame rates
- high precision, stable deflection, low cross-talk

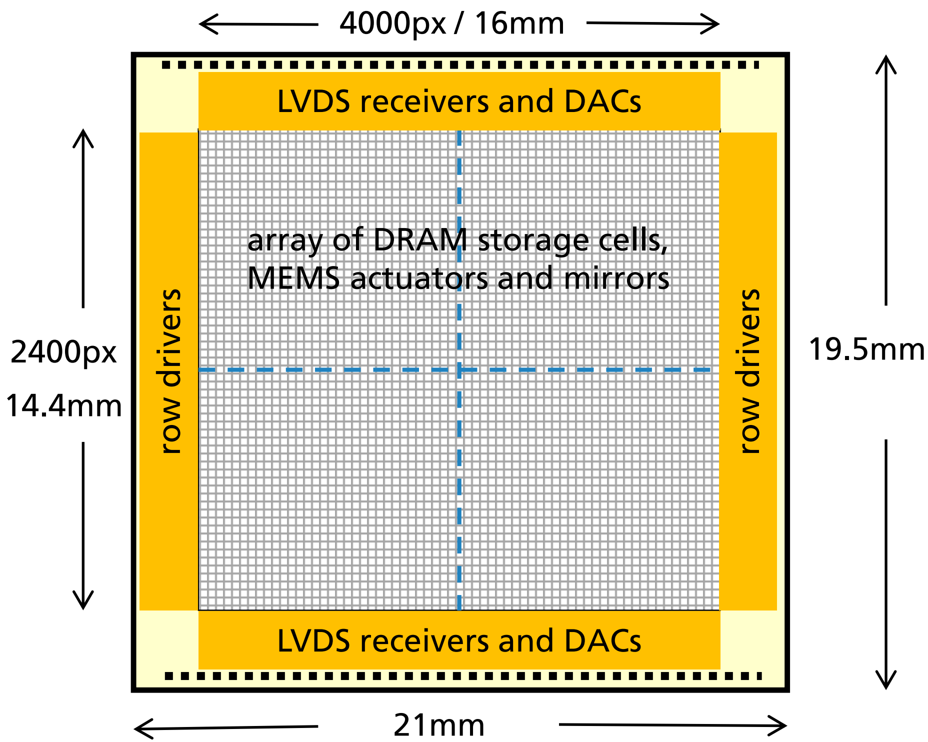


→ LCoS-SLMs are sub-optimal

- additional advantage: micro mirrors are independent from polarization
- low power dissipation

→ analogue piston mirror SLMs are perfect for holography, but development is needed

# RealHolo MMA Key Parameters




| Parameter | Target |
|---|---|
| pixel size | 4µm x 6µm |
| pixel count | 4000 x 2400 |
| active area | 16mm x 14.4mm |
| vertical deflection | 0 … 350nm |
| tilt error | < 0.1° (< 1.75mrad) |
| frequency | > 1kHz |
| duty cycle | > 20% |
| power consumption | < 2.5W |
| pixel voltage | ≤ 3.6V |
| deflection precision | 8bit |

- the pixel area is divided into 4 subareas which are addressed from the edges

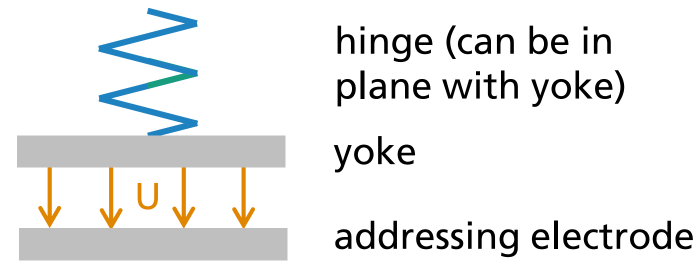
# Parallel-Plate Actuators Need Large Actuator Gaps

- Analytical model with linear spring and plate capacitor
- Force equilibrium between mechanical force and electrostatic force

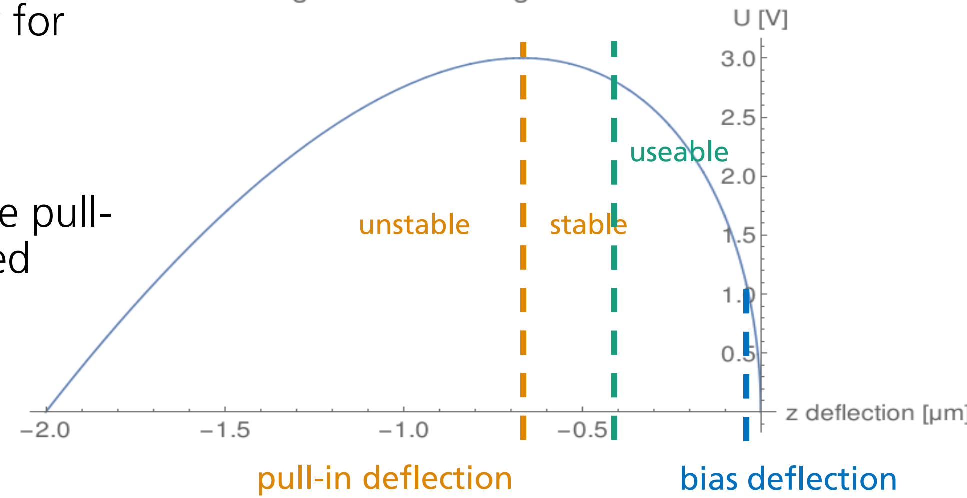
$$F_m = -k \cdot z$$

$$F_{el} = \frac{\varepsilon_0 A U^2}{2(g-z)^2}$$

- Force equilibrium can be solved analytically for deflection curve
- Electrostatic pull-in happens at gap/3
- a maximum deflection of about 60% of the pull-in deflection or 20% of the gap can be used
  - non-linear response curve
  - small margin in voltage
  - possible dynamic overshoot

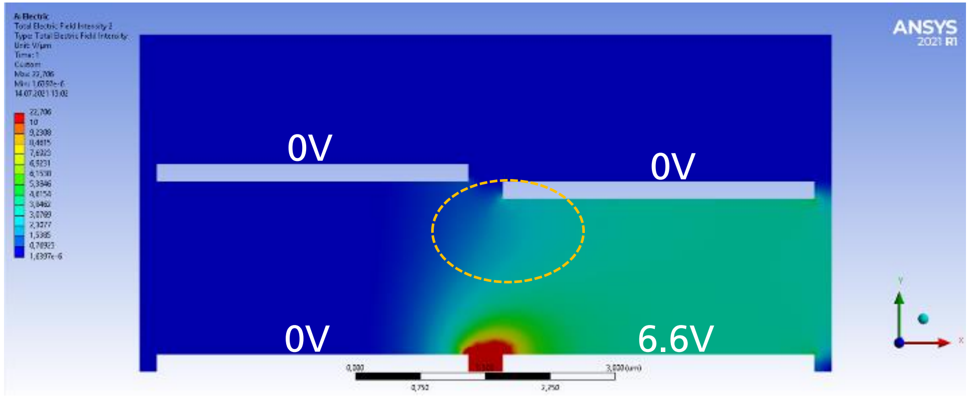


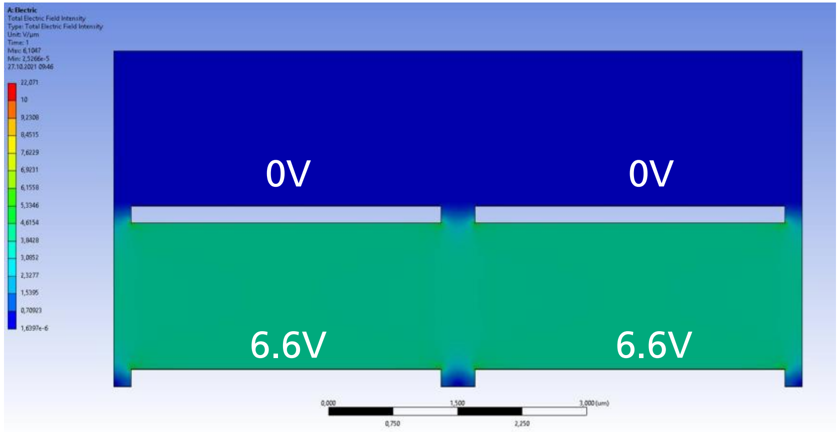

Voltage deflection diagram



# Parallel-Plate Actuators

- deflection needs to be $\lambda/2 \approx 350$nm for red light
- the actuator gap needs to be at least 1.8µm, which is only twice the pixel width
- due to the large gap the total electrostatic force is small
- and the electrostatic cross-talk is large
  - simulated cross-talk of ~3.5% at one edge
  - would be ~14% for 4 neighbor pixels





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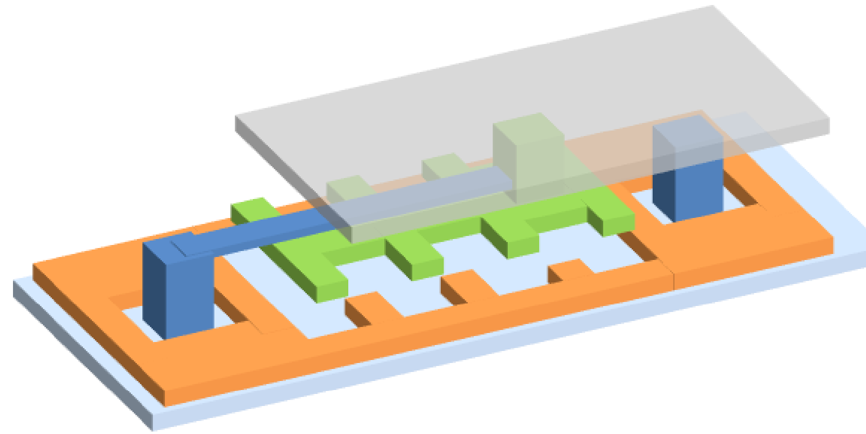
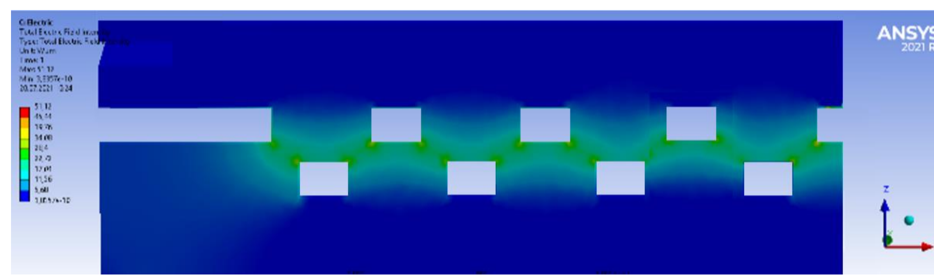
# Novel Comb Drive Actuator Concept

- comb-drive actuators have no pull-in effect (in direction of intended deflection)
- the actuator gap may be very small → ~10x larger electrostatic forces in spite of electrode small area
- the cross-talk may be very small due to the concentrated electrostatic field around the fingers

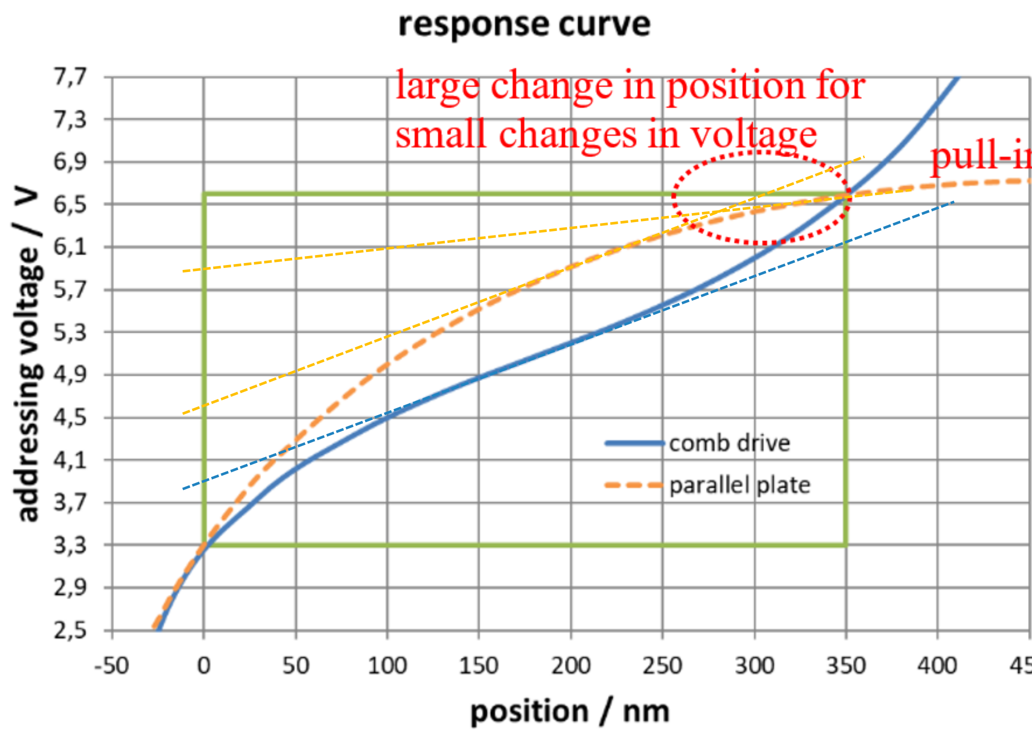




# Novel Comb Drive Actuator Near Linear Response

additional advantage :

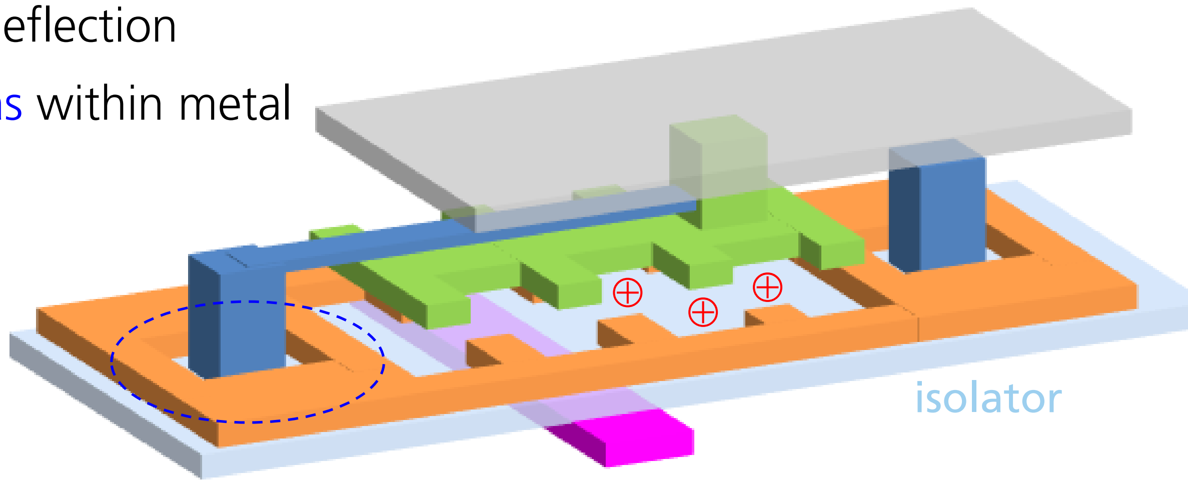
- the response curve can be much closer to linear than for parallel plate actuators
- this gives more deflection precision for given voltage uncertainty
- optimizing parameters are
  - finger thickness
  - zero-voltage vertical comb distance
  - horizontal finger distance
  - bias voltage




the parallel plate actuator needs to have a much weaker hinge than the comb drive actuator for the same deflection

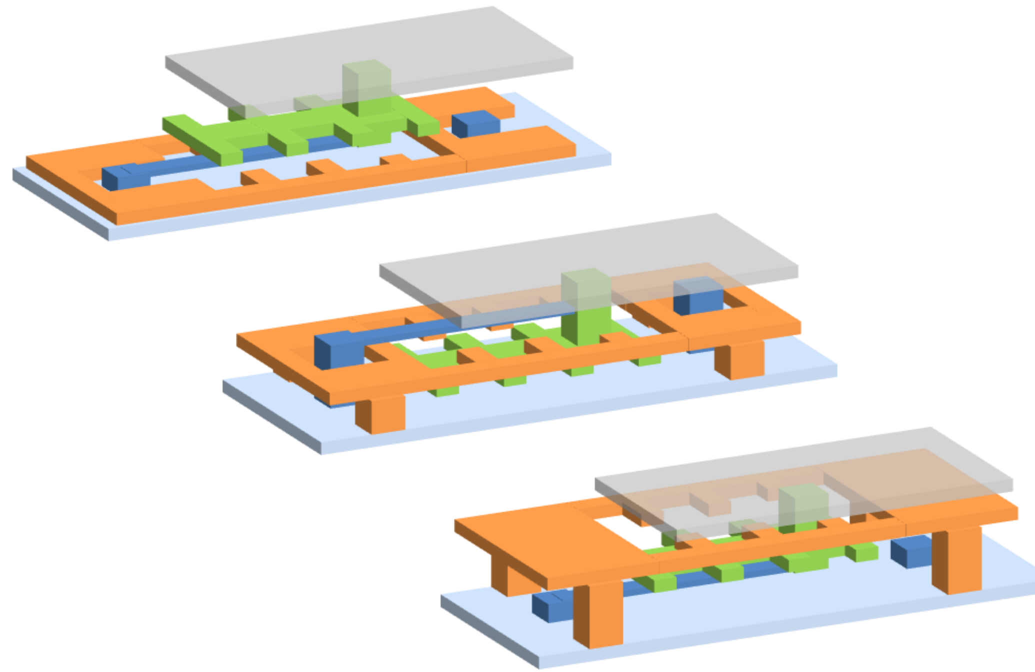
# Possible Issues with Comb Drive Actuator (I)

- the underlying circuitry may directly attract the yoke
  → deviation from desired deflection
  - an electrical shield could again cause pull-in
- isolators may have trapped charges
  → deviation from desired deflection
- small defects in critical areas within metal layers may cause short cuts
  → pixel defect
- small area for connection MEMS to backplane



# Possible Issues with Comb Drive Actuator (II)

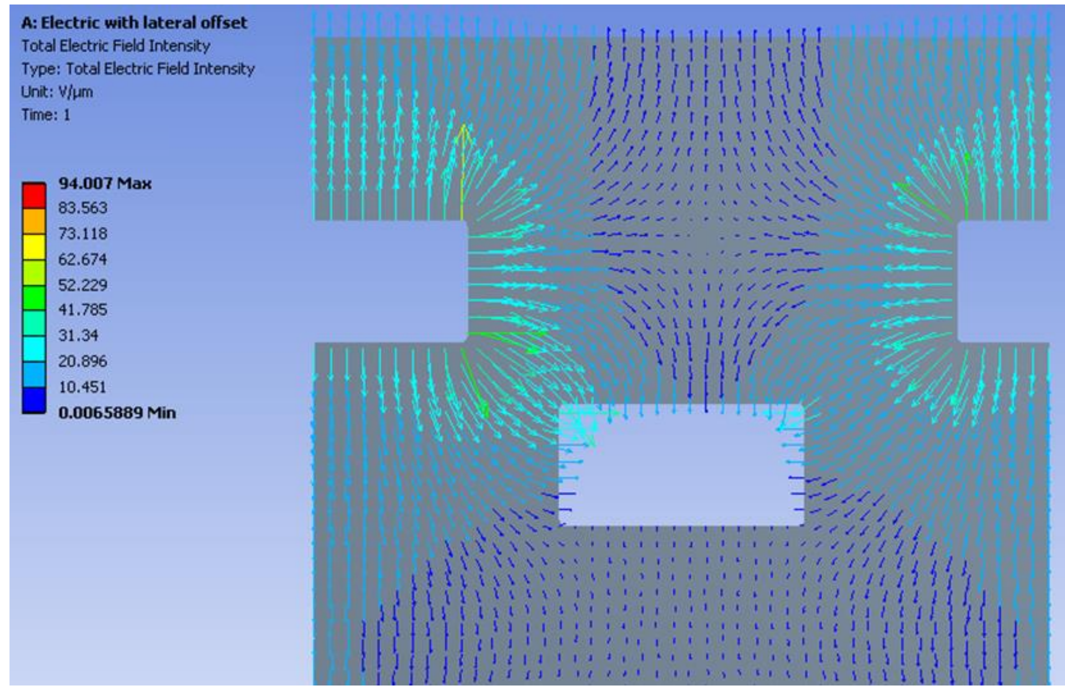
- high aspect ratio posts are difficult to fabricate
- for high stator the field between stator and mirror may counteract the deflection
- with pixel voltage on stator an isolation distance is required between pixels → smaller comb circumference and force
- with pixel voltage on yoke floating mirrors or electrostatic cross-talk between mirror edges



some actuator variations that have been considered

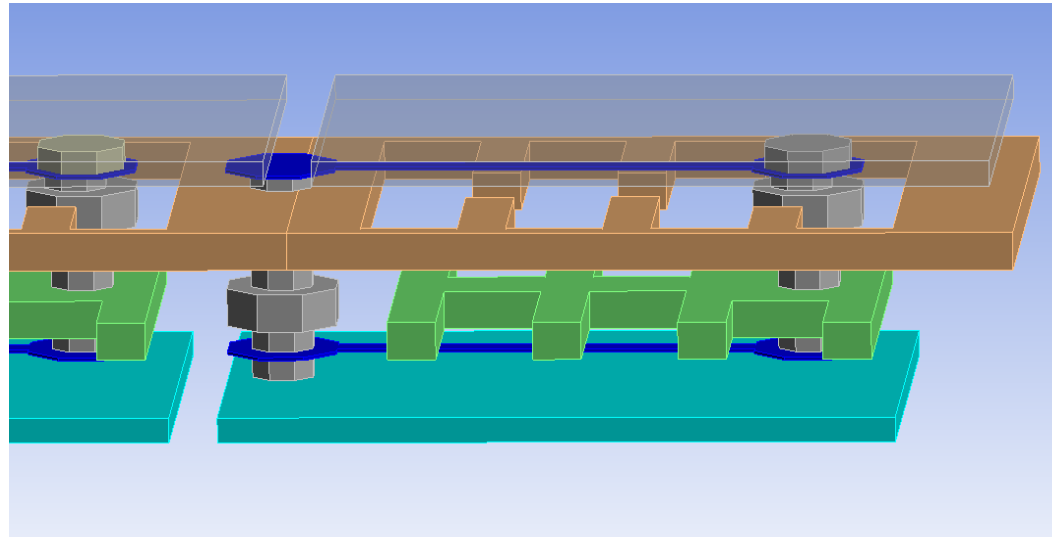
# Possible Issues with Comb Drive Actuator (III)

- an overlay error or other asymmetry of the combs causes large horizontal force
  → tilting mirror or even horizontal pull-in
- a stress gradient in the hinge may cause tilted actuators and mirrors and changes the finely tuned actuator response



# Optimized Comb Drive Actuator for Holography

optimized basic concept of the comb drive actuator



- two hinges make for a parallelogram guidance mechanism for tilt suppression
- baseplate, lower hinge, and yoke are on the same electrical potential
  → no charging expected here
- stator, upper hinge and mirror are on the same electrical potential
  → no charging and no cross-talk at mirror edges
- low risk of shortcuts in insulating posts





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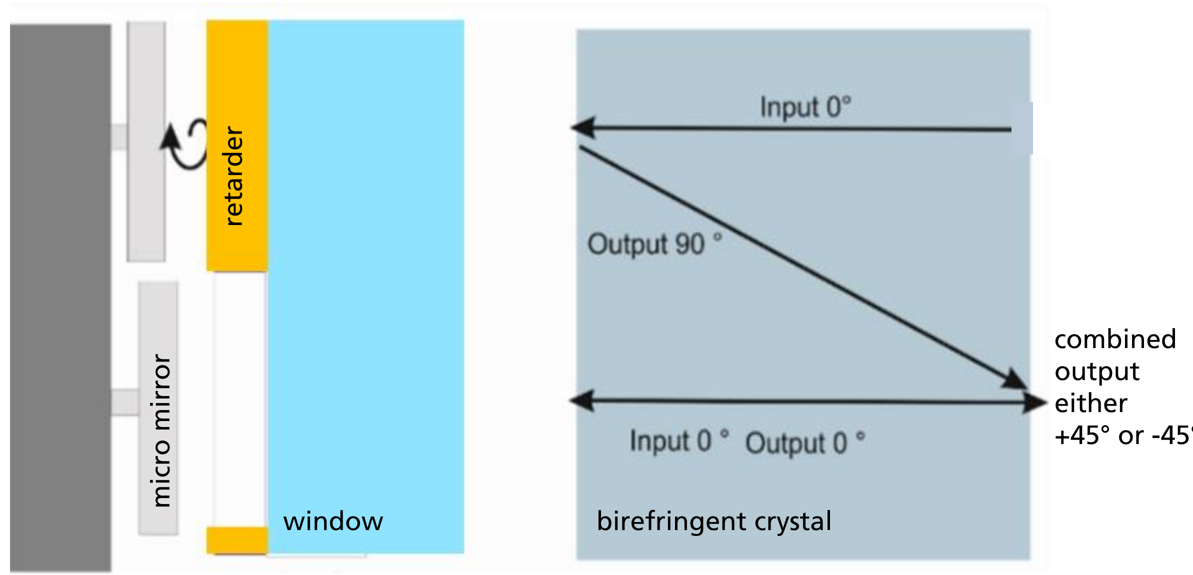
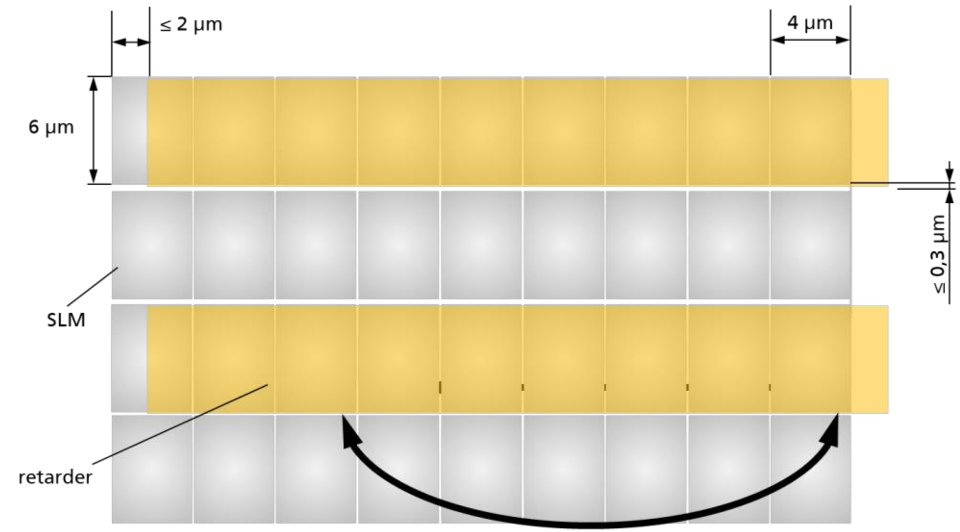
# Complex-Valued Light Modulation

- a birefringent crystal can combine polarized light from two phase modulating pixels
- the combined light can thus be set to any desired phase and amplitude
- the computation is direct (not iterative), the effort is small and suitable for real time

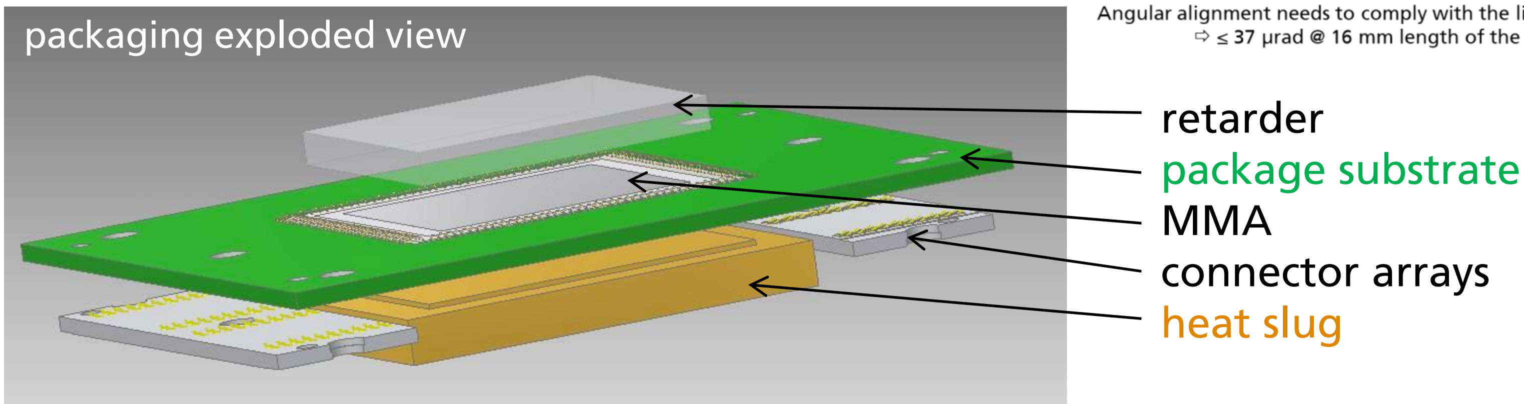


# Retarder and Packaging

- a very precise alignment of retarder stripes to pixel rows is required
- the retarder will be mounted directly on the SLM
- this additionally protects the micro mirrors

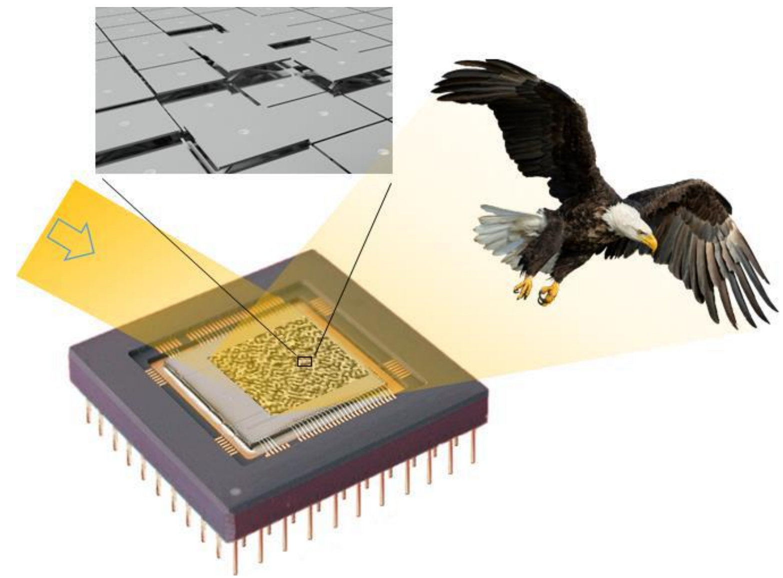



Angular alignment needs to comply with the linear ≤ 0,3 µm criteria
⇨ ≤ 37 µrad @ 16 mm length of the active area



# Summary

- Fraunhofer IPMS, SeeReal, and partners are developing an MMA-based SLM optimized for real holographic displays
- the SLM features millions of comb-drive actuators for precise positioning of micro mirrors
- the SLM will exhibit optical properties superior to existing alternatives
- the high quality of the modulated light will allow a natural viewing experience in AR, VR, and MR applications



# Acknowledgement

further RealHolo Project Consortium Partners:

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