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Innovation Matters

256 x 16 SPAD Array and 16-Channel Ultrashort Pulsed Laser Driver for Automotive LIDAR

Patents Pending

09.06.2020 Dr. André Srowig | The International SPAD Sensor Workshop 2020

Expert in analog mixed signal solutions focused on automotive market

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35 years experience

- Development, production & marketing of **ICs & pressure sensors**
- Sales: ~85% **automotive** ~15% **non-automotive**
- **Main strength:** design of innovative products and specialized application know how

Worldwide leading products

- Elmos serves the **megatrends** (ADAS, EV…) & **attractive niches** with benchmark innovations
- **#1 positions:**
  - Ultrasonic Parking Assistance
  - Ambient LED Light
  - Climate Applications
  - Gesture Control
  - **Soon** Rear Light LED & more…

Ready for further growth

- **Global player for automotive** ASSPs and ASICs
- Significant addition to **design/application resources**
- **Fablite:** Flexible production strategy for Frontend and soon for Backend (Test)

From a statistical point of view: >**4 Elmos ICs** in every new car *…soon >5!*

IC = Integrated Circuit / ASSP = Application Specific Standard Product / ASIC = Application Specific Integrated Circuit

Optical Segment
Target Applications

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Proximity and Gesture

HALIOS® Technology

Control of Infotainment system
Simple Gesture recognition
Gestures in interior

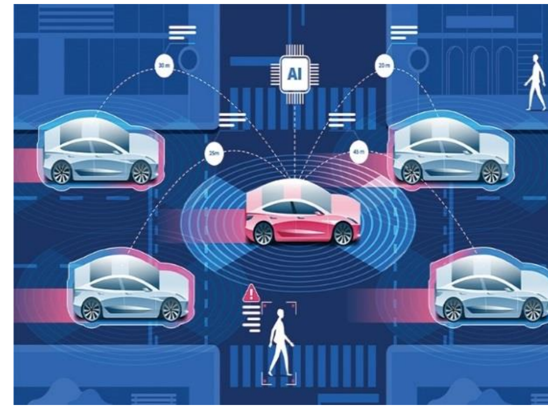
USPs
High light immunity
Best cost/low latency

Gesture and Object Recognition

ToF Imager

3D object recognition
Gestures in interior & exterior
Cliff detection

USPs
Low power consumption
Higher resolution than HALIOS®



Collision Warning

SPADs & SiPM

Autonomous Emergency Brake (AEB)
Pedestrian detection
Cross Traffic Alert (CTA)

USPs
Lower operation voltage
Embedded and compact solution

HALIOS®= High Ambient Light independent Optical System /ToF= Time of Flight/ SPAD=Single Photon Avalanche Diode/ LIDAR= Light Detection and Ranging

Agenda

- Solid State LiDAR System Considerations
  - Solid state scanning system comparison
  - Tradeoffs
- 256 x 16 SPAD Array and Readout IC
  - Architecture
  - Features
    - Multievent
    - Coincidence
- Solid State LiDAR Demonstrator
  - 16 Channel Laser Driver
  - Optical Components
  - System Assembly

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Solid State LiDAR – System Comparison

- Flash LiDAR
    - No spacial modulation of light source (illumination of entire scene)
    - Requires simultaneous operation of all pixels
- Solid State Scanning LiDAR
    - Spacial modulation of light source
    - Challenge of scanning transmitter and receiver simultaneously
  - Beam steering
    - Phased array (photonic IC)
    - Solid state
    - Scanning of both axes
  - MEMS Mirror
    - "Moving part"
  - Rolling Shutter SPAD array + solid state laser scanner
    - Scanning of transmitter and receiver by two independent mechanisms
    - No moving parts
    - CMOS implementation
    - Standard optical components
    - Scanning of one axis (parallel operation on other axis)

Trade-Offs in LIDAR Systems

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- LIDAR is an active system, so the performance is **equally** determined by the performances of transmitter and receiver
- Eye safety regulations limit the maximum **average** power density that can be provided
- Trade-Offs of range, resolution, frame rate, and object reflectivity

$$\text{Signal} \propto \frac{\mathit{Transmitter\ Power\ Density} \cdot \mathit{Transmitter\ Aperture}^2 \cdot \mathit{Object\ Reflectivity} \cdot \mathit{Receiver\ Aperture}^2}{\mathit{Pulse\ Width} \cdot \mathit{Resolution} \cdot \mathit{Frame\ Rate} \cdot \mathit{Distance}^2}$$

- (yellow) driven by application / market
- (orange) driven by application / market
- (blue) limited by eye safety regulation

- Major parameters to impact on performance:
  - Sender aperture
  - Optical pulse width
  - Receiver aperture

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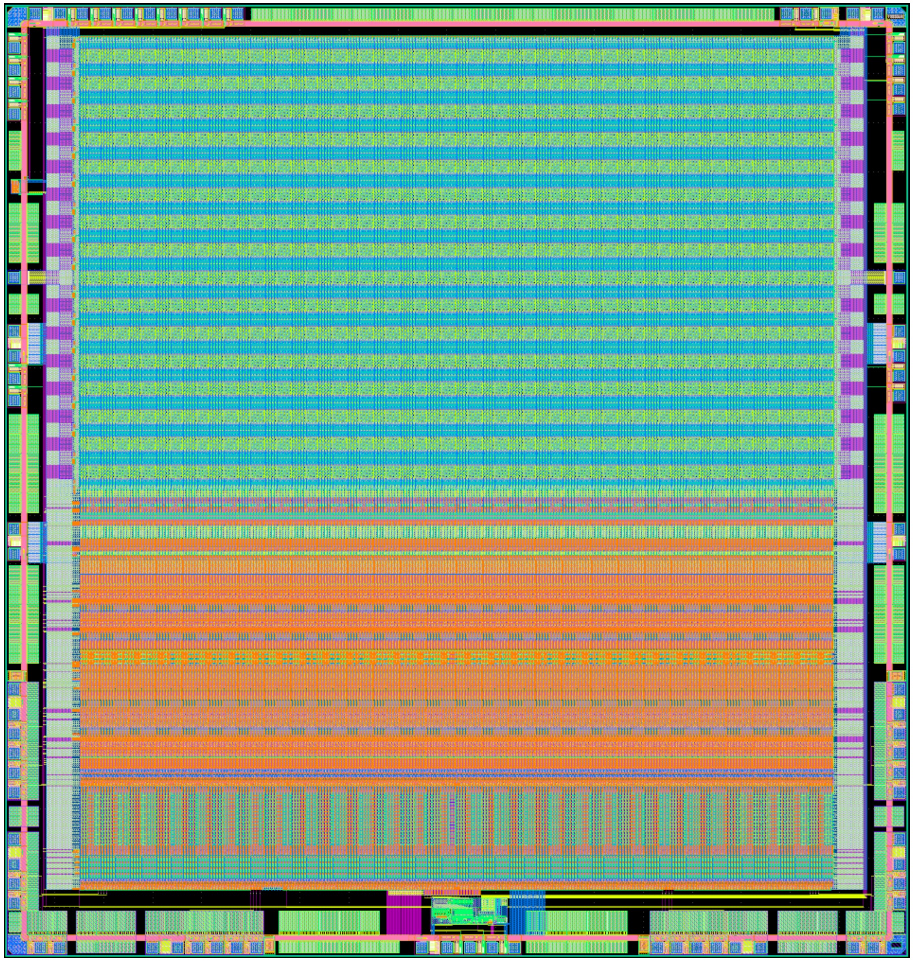
Elmos 256 x 16 Rolling Shutter CMOS SPAD Array

- 256 x 16 SPAD Array
- Elmos L035
- IMS SPAD architecture
- “Rolling shutter” architecture for improvement of fill-factor
- Photon counting mode for ambient light detection and 2D imaging
- Ready for auto-adjustment of photon coincidence
- Multi-event detection mode (up to 4 events per pixel and laser pulse)
- Column integrated TDC with 312.5 ps resolution (~5 cm resolution)
- 1.28 µs full range (192 m max. theoretical range)



Elmos 256 x 16 Rolling Shutter CMOS SPAD Array

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Total Chip Size: 9200 x 9700 µm²

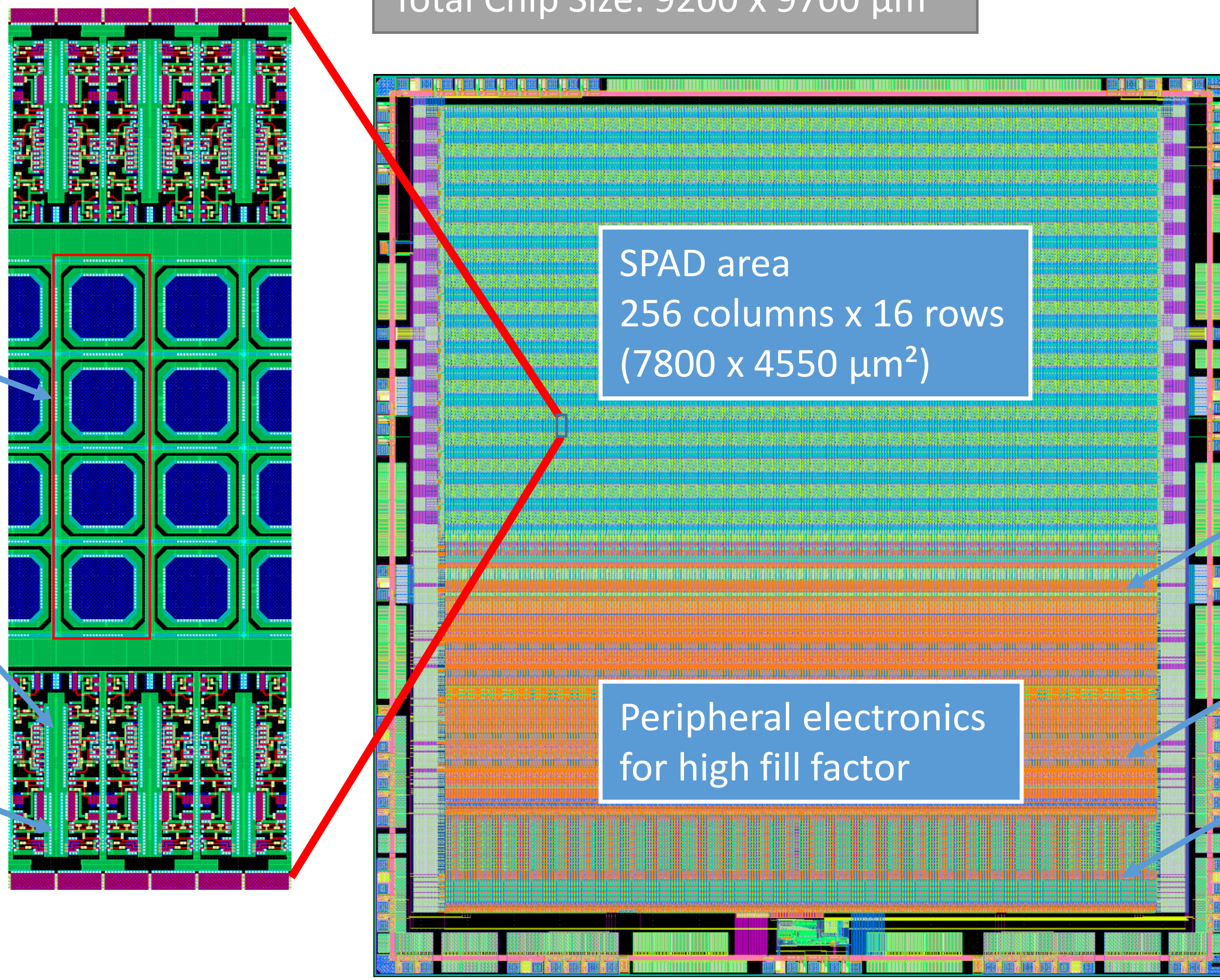
120µm SPADs
160µm Electronic
280µm Line Pitch

30µm SPAD
Active: 21.6µm

4 SPADs per Pixel

Active Quenching

Pulse Shaping



Coincidence Circuits

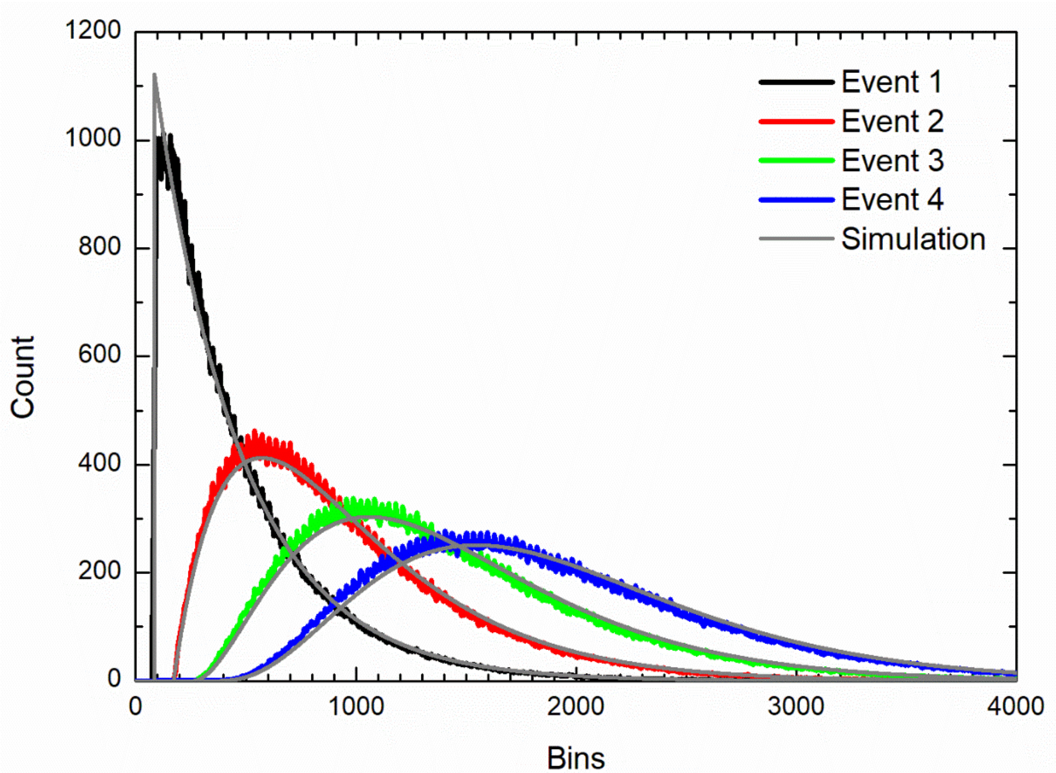
Time-to-Digital Converters

Output:
2 x 12 bit digital

Multi Event Detection: 2nd /3rd /4th Photon Detection

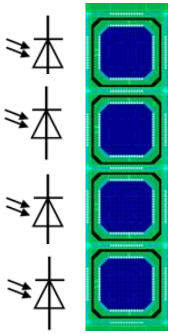
- For high background rate the Probability Density Function (PDF) of 1st / (i+1) photon in given by a modified Erlang distribution

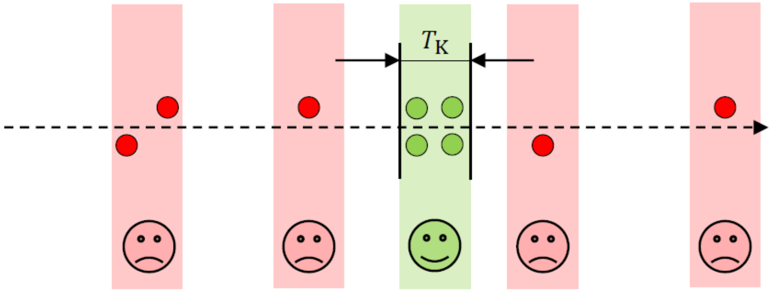
- Multi Event Depth of 4 is good compromise between signal improvement and complexity increase

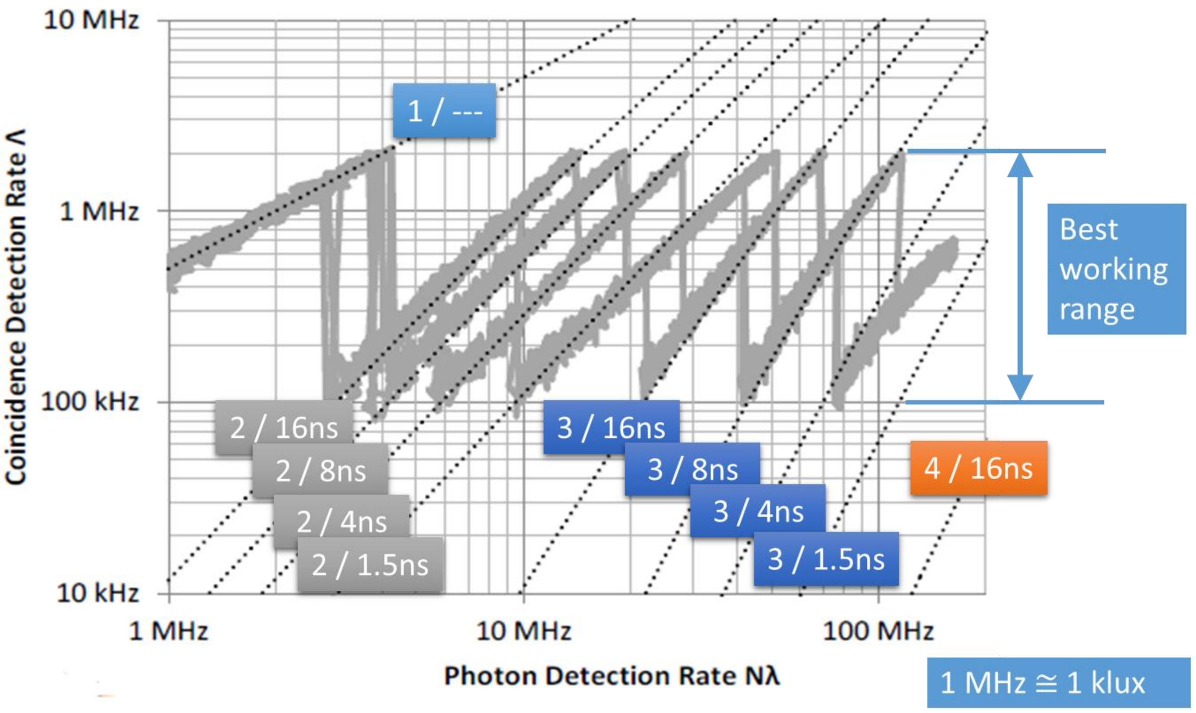


Temporal Photon Coincidence

- Statistical model with 4 SPADs per pixel
  "x out of 4"
- Parameters
  - Coincidence depth
  - Coincidence time
- Improvement of signal-to-background ratio (SBR)
- "Background" can be
  - Light
  - Noise (Rain / Snow)
  - Temperature (DCR)
- Keep sensor in ideal signal range
  - High count rate: dead time becomes dominant
  - Low count rate: poor histogramming

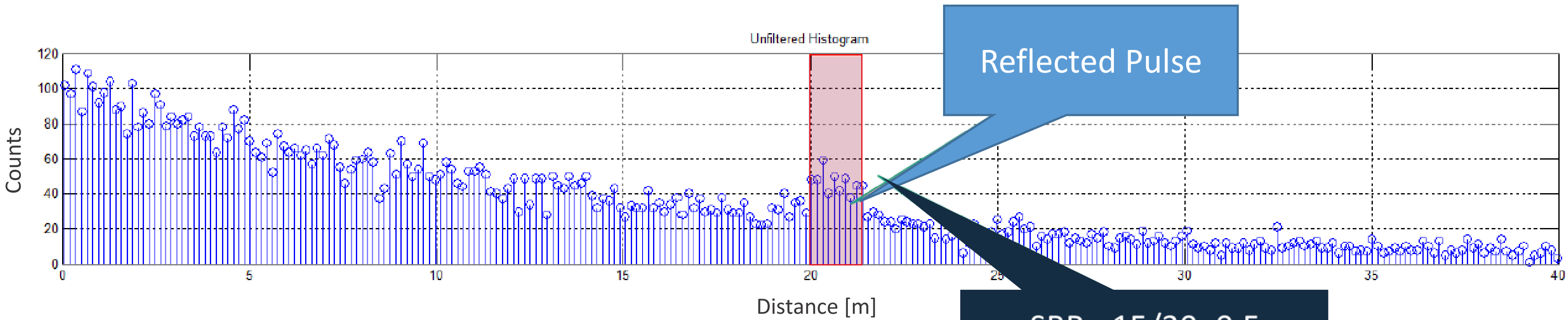




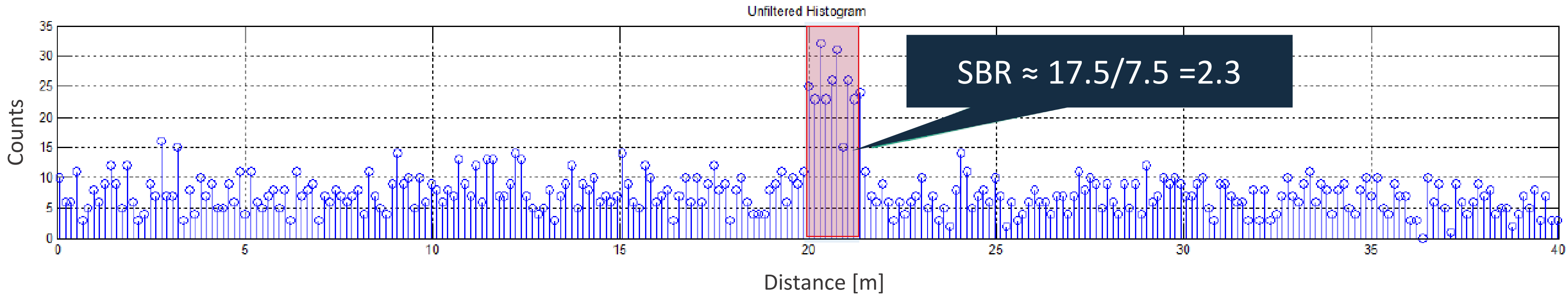


Temporal Photon Coincidence

Without Coincidence

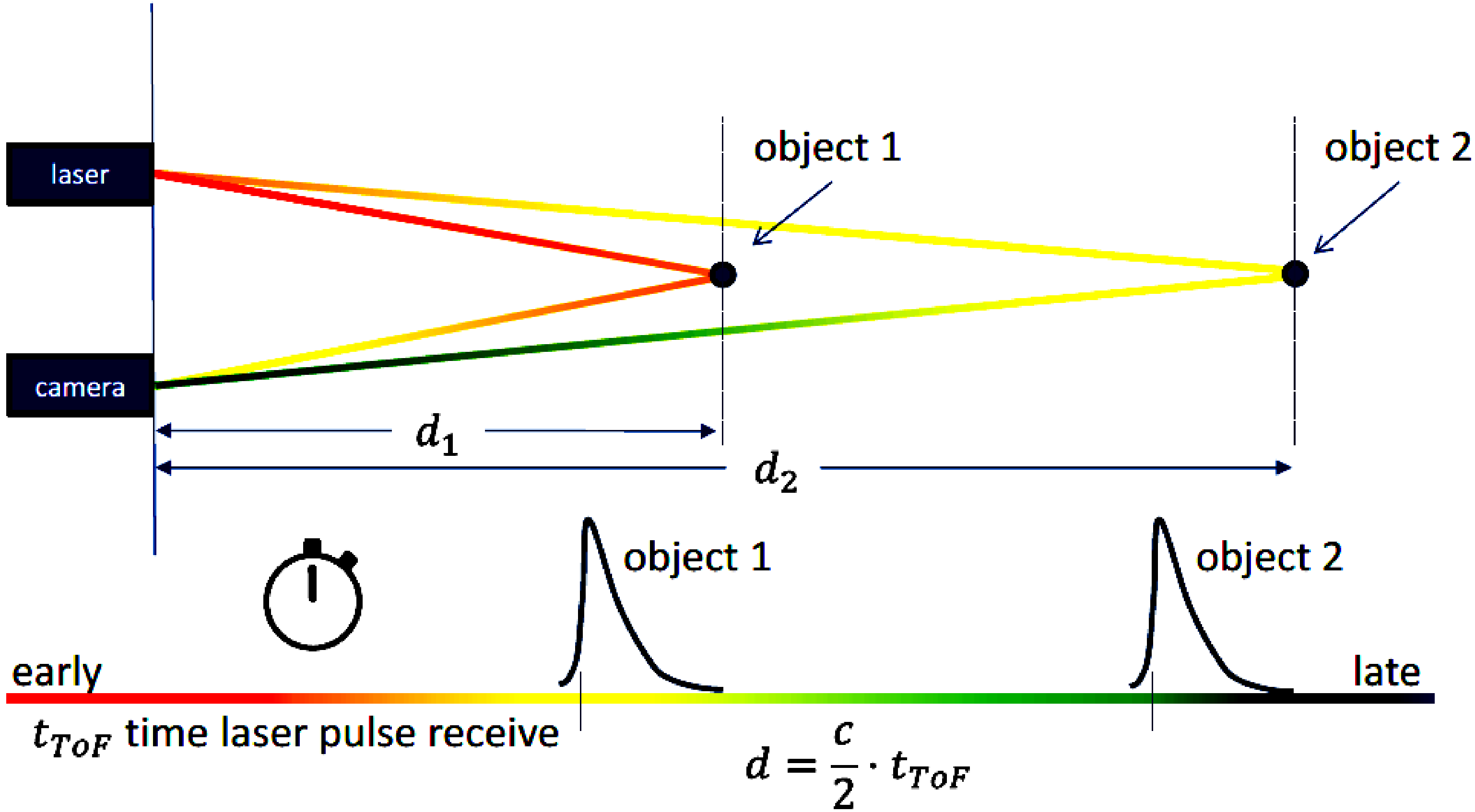


With Coincidence



Multi Object Detection

- Improved detection of small objects
- Improved detection of transparent objects



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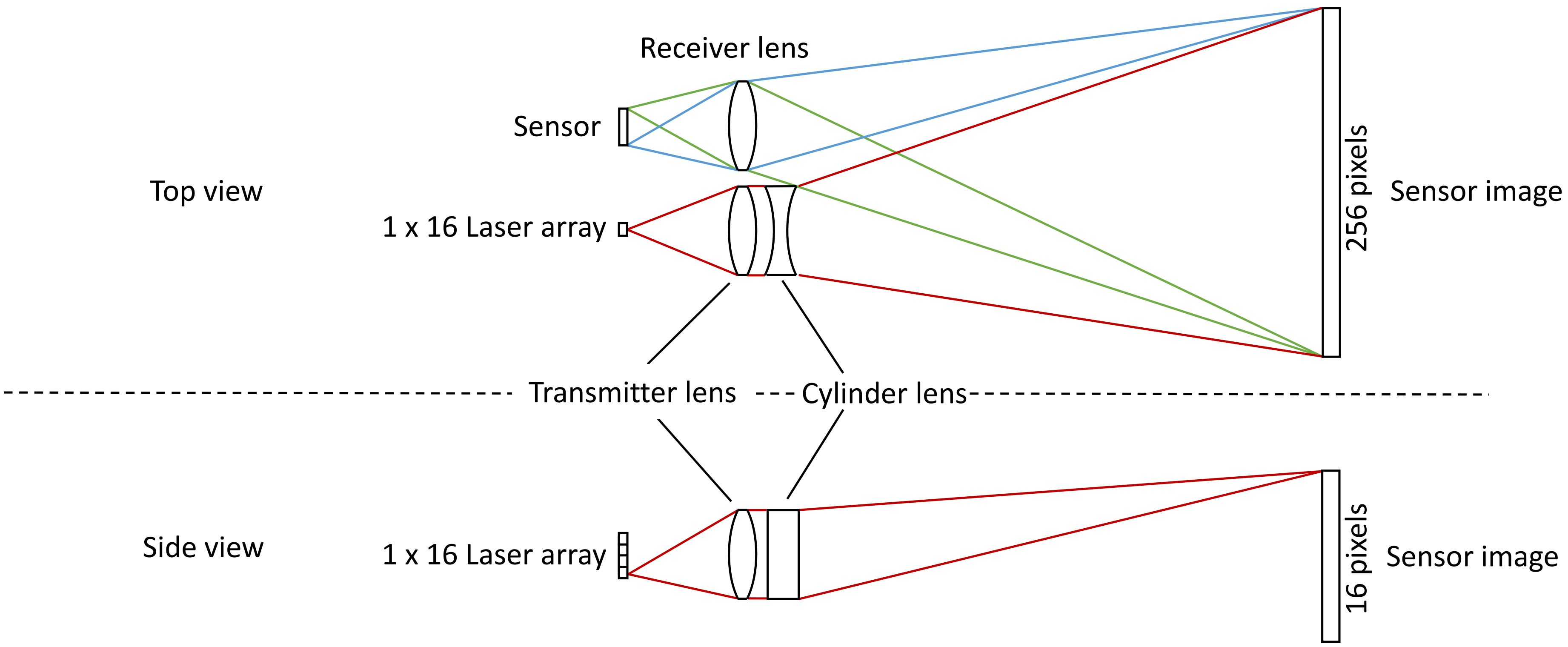
Elmos – Rolling Shutter + Solid State Laser Scanner

- No moving parts on either the macro or the micro scale
- Highly efficient and scalable
- Energy is only emitted into the observed field of view (1 x 16 laser array)
- Observed field of view is only extending over illuminated area (rolling shutter)



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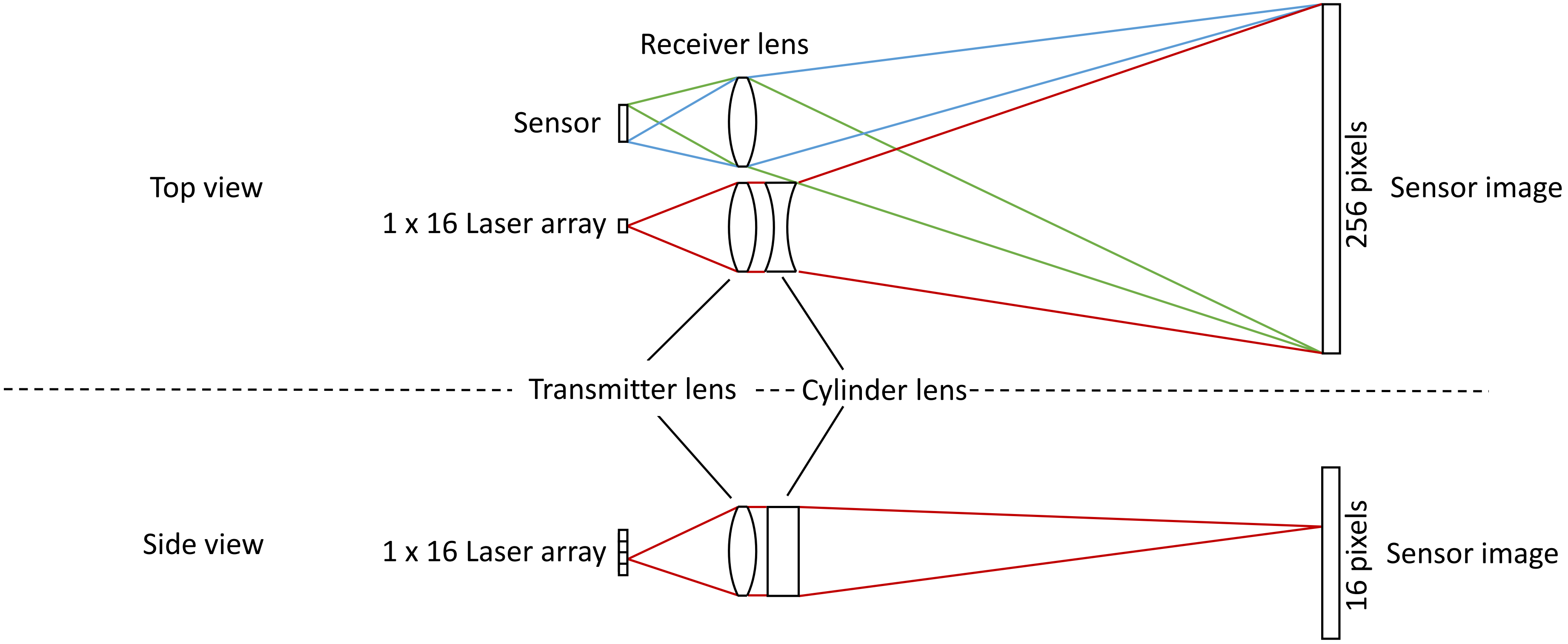

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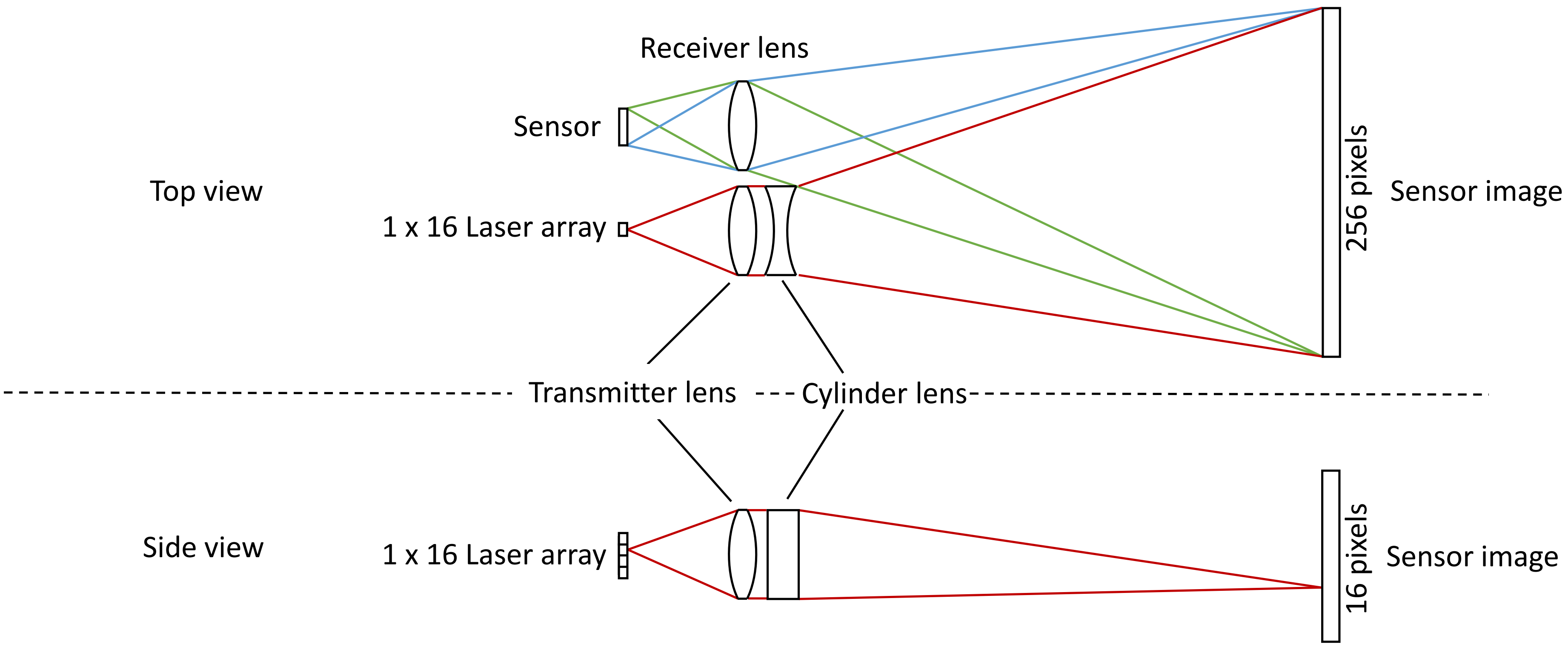

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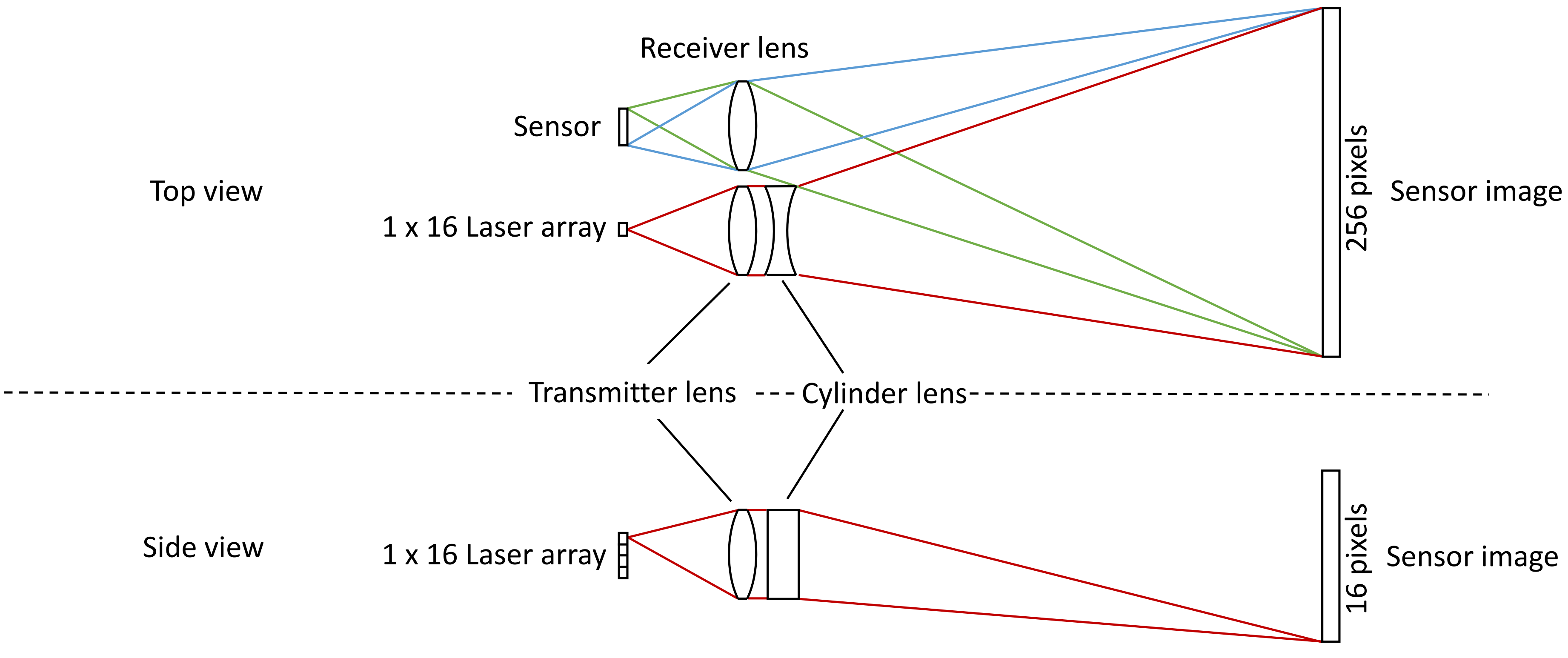
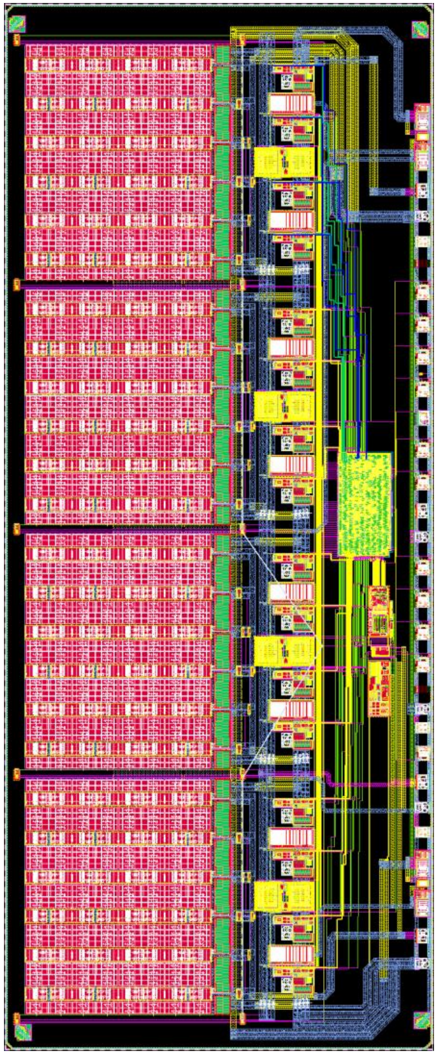
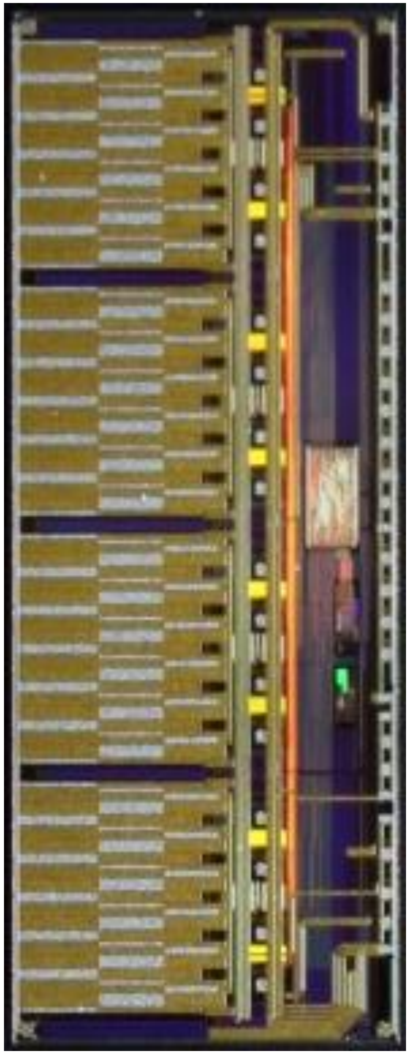


T914.25 – Features

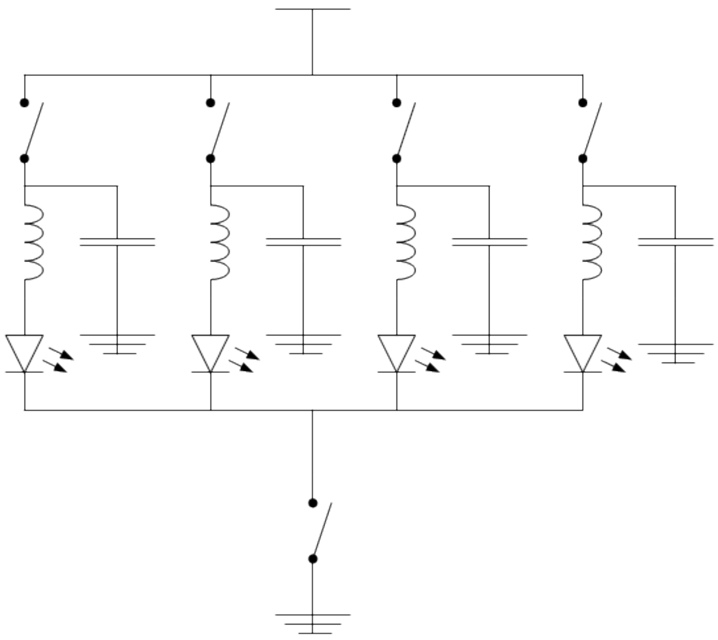
- 16 channel laser driver
- 4 x 4 common cathode switching
- 1 ns pulse width @ 50 A peak current
- Configurable pulse width and delay 1-15 ns
- 10 ps resolution
- HV charge and discharge function per channel
- Digital readout of laser pulse energy by detection of residue charge on capacitors (switched capacitor)
- Control of average laser power
- Monitoring of eye safety
- 10 temperature sensors with digital readout
- 100MHz SPI interface
- On-chip channel sequencer matching SPAD array T955510
- D035 with thick metal option T
- Metal 5 RDL layer for die stacking
- Die size 10 x 4 mm^2





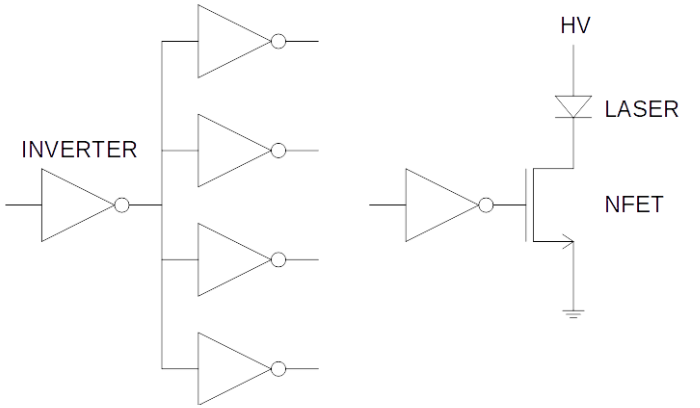
Laser Driver – Basic Driver Architecture

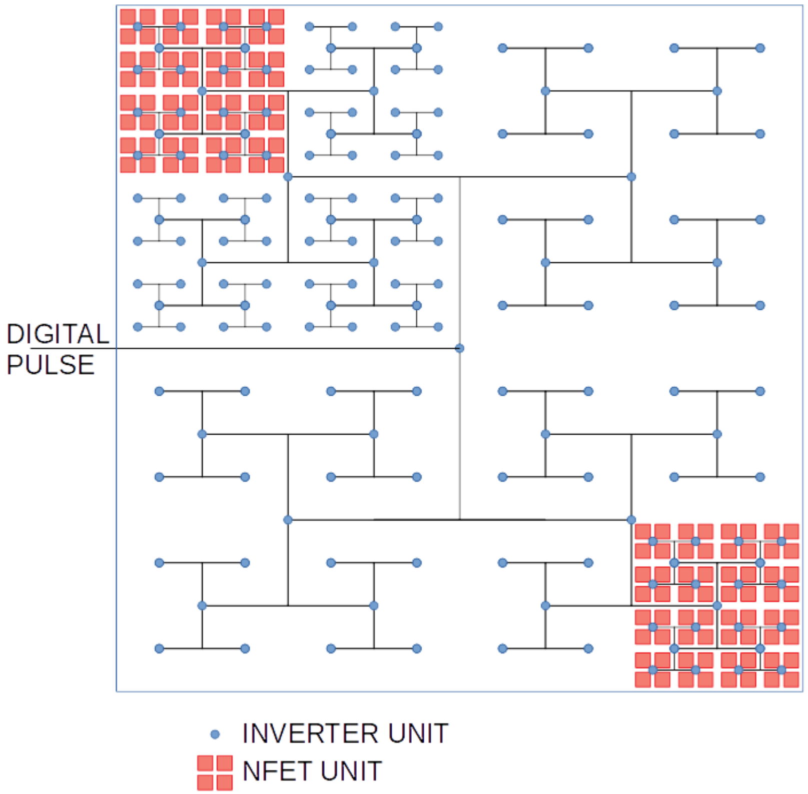
- 4 x 4 Channel common cathode switching
- Full integration of pre-driver, output FET, HV switches and digital control



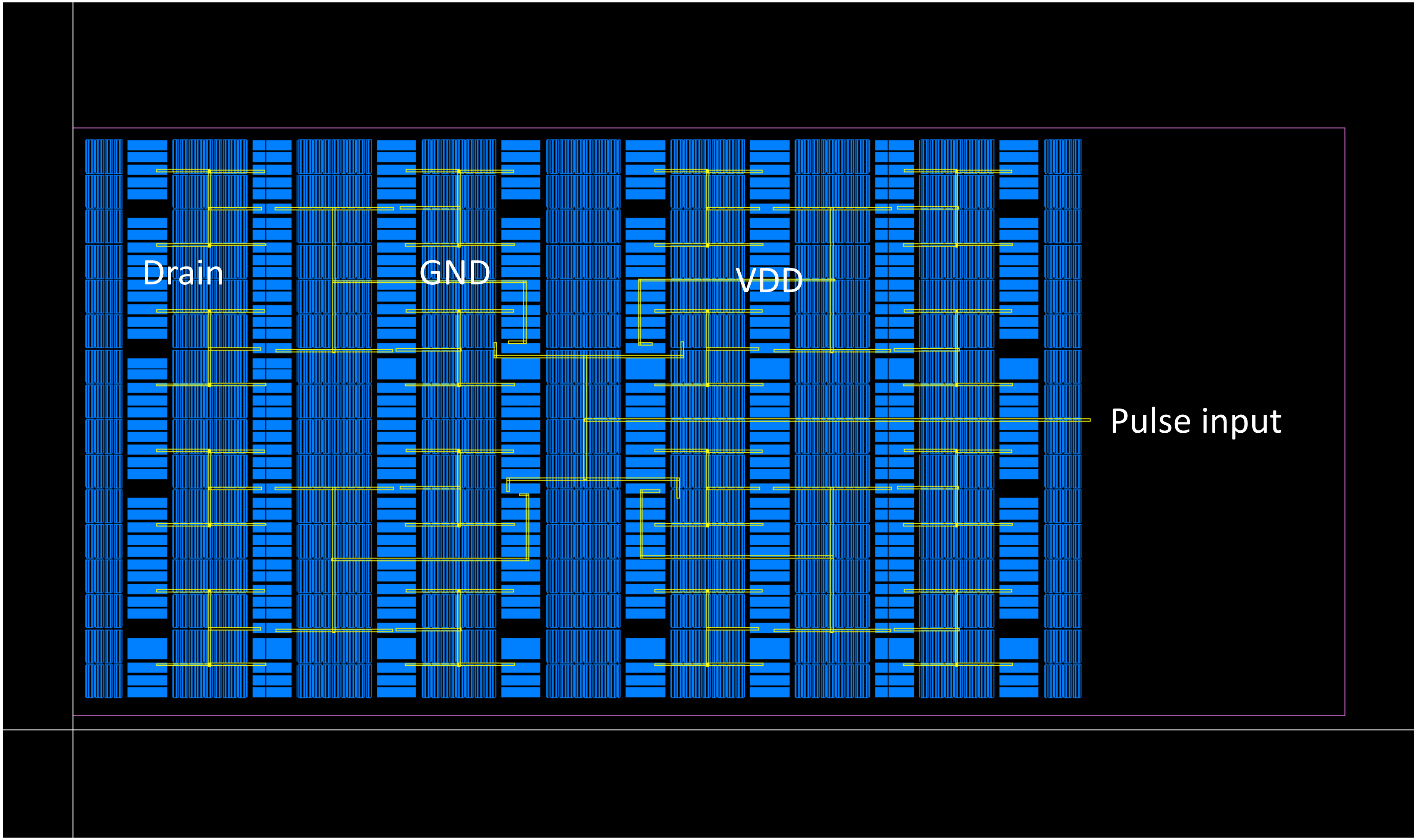
Pulsed Laser Driver Architecture

- Ultra-short high current pulse generation
- Self-similar driver structure
- 4 distributed inverter stages in series
- Fanout 4 per stage
- Balanced propagation delay on all sub-structures
- Signal shaping in every stage
- Signal routing requires only one metal layer



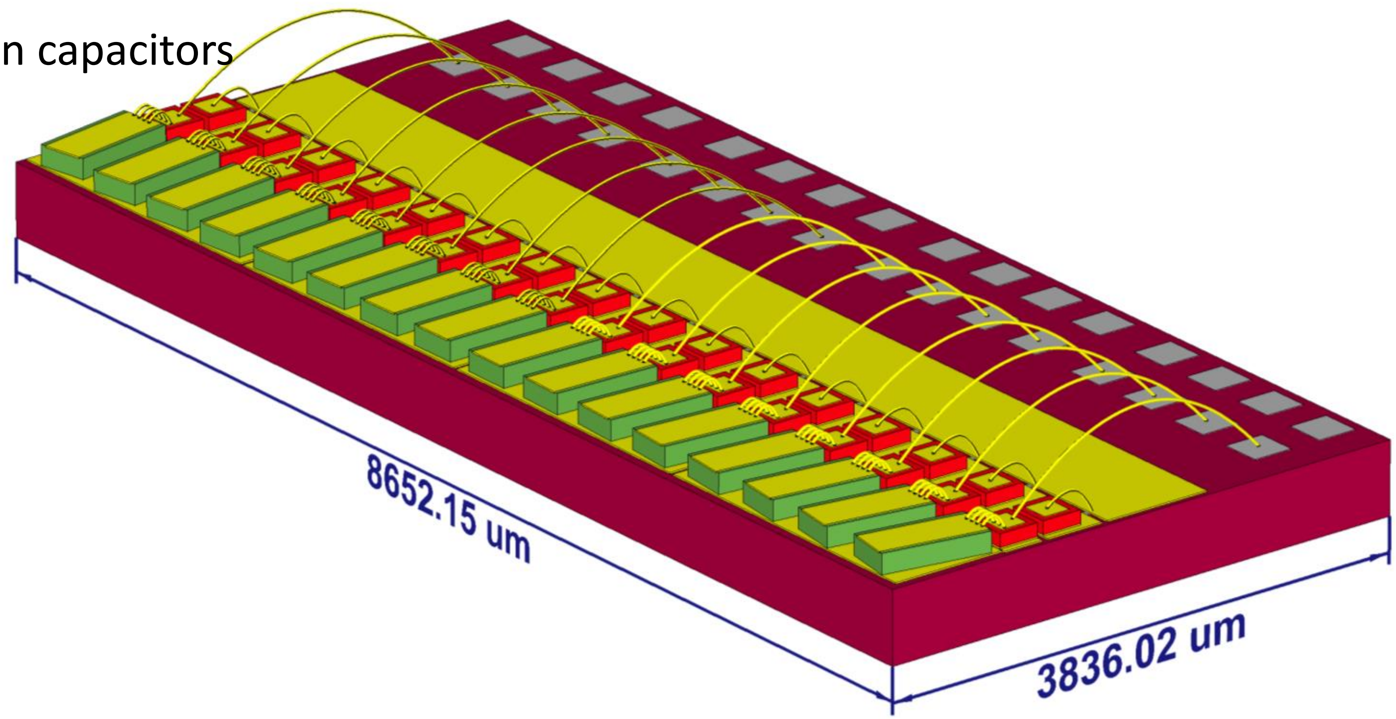


Interleaved Structure of Gate Driver and NFET

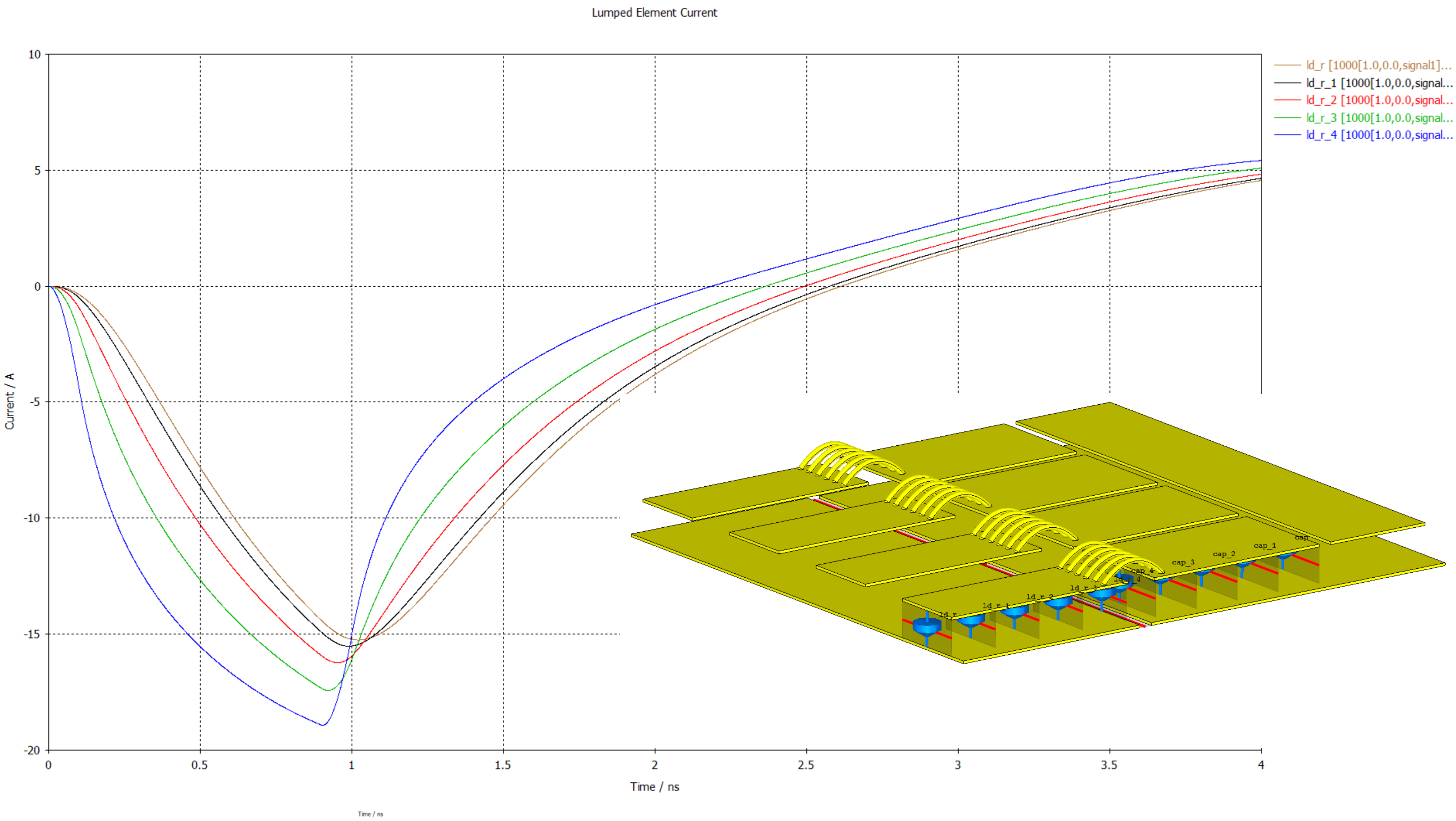


ALIS16 – Automotive LIDAR Illumination System

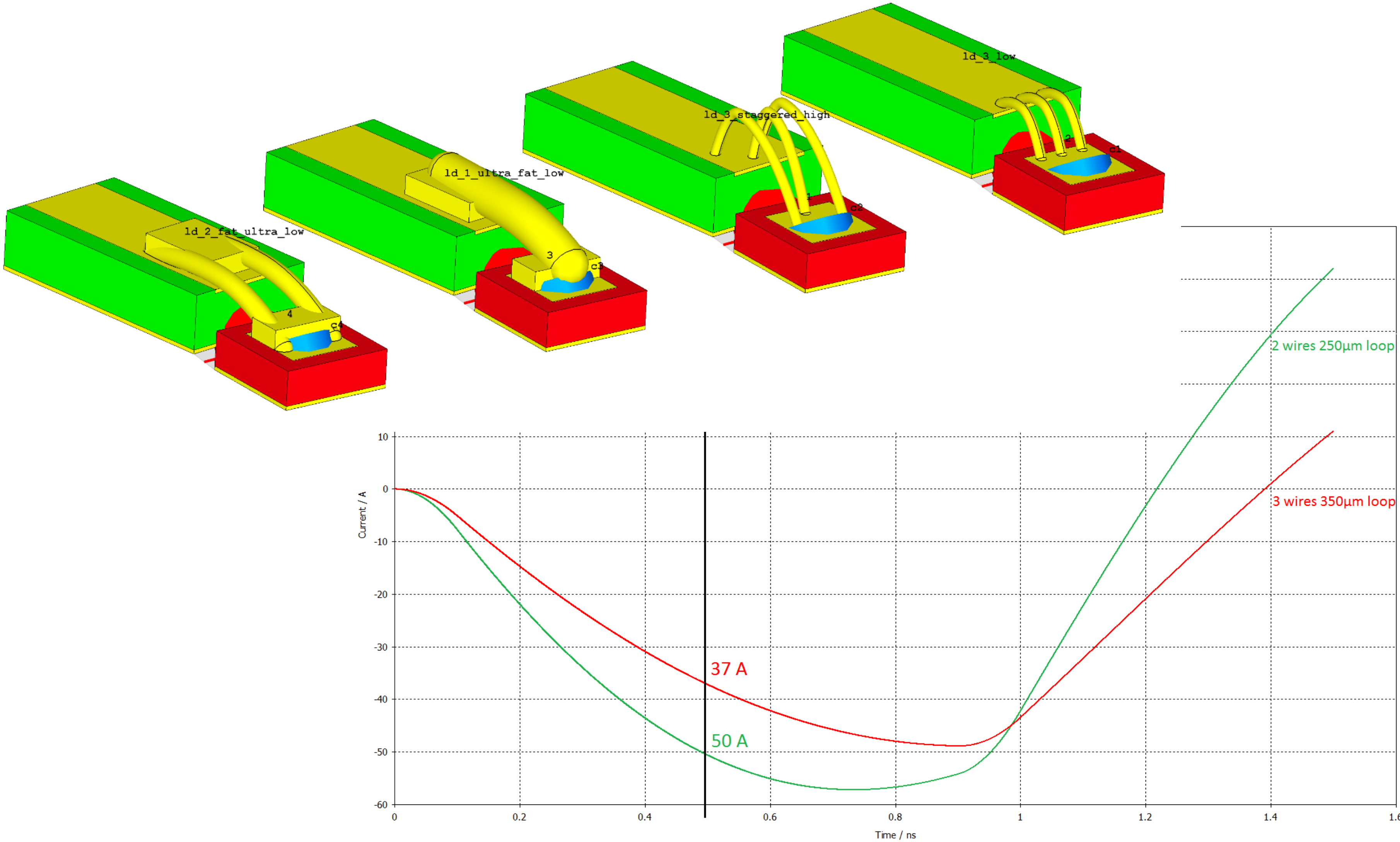
- 16 channel module
- Single-channel edge emitting lasers gradually rotated up to ±10° for massive simplification of optics
- Compact single lens design for vertical focusing and horizontal de-focusing
- 32 x 1nF 50V silicon capacitors



Laser Diode – Inhomogenious Current Distribution

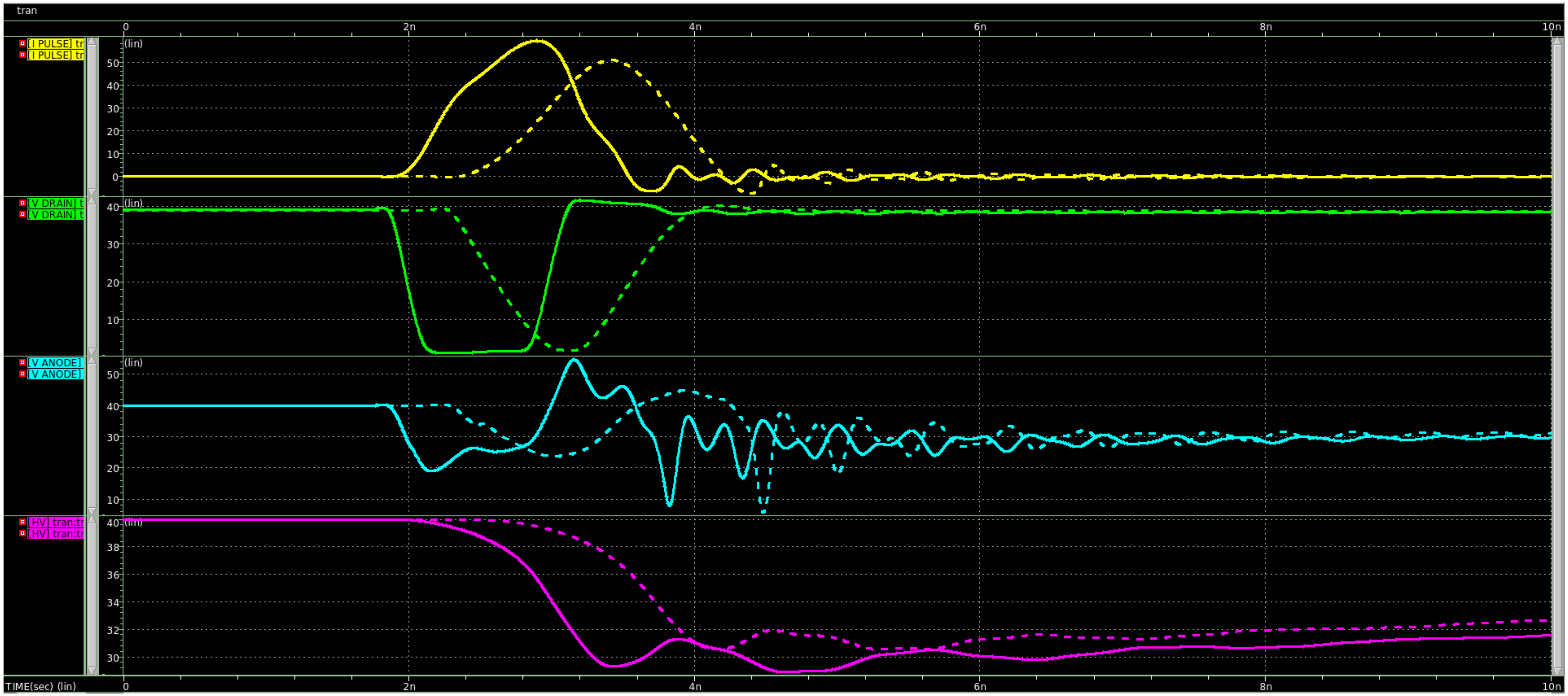


CST Simulation – Influence of Bondwires on Inductance



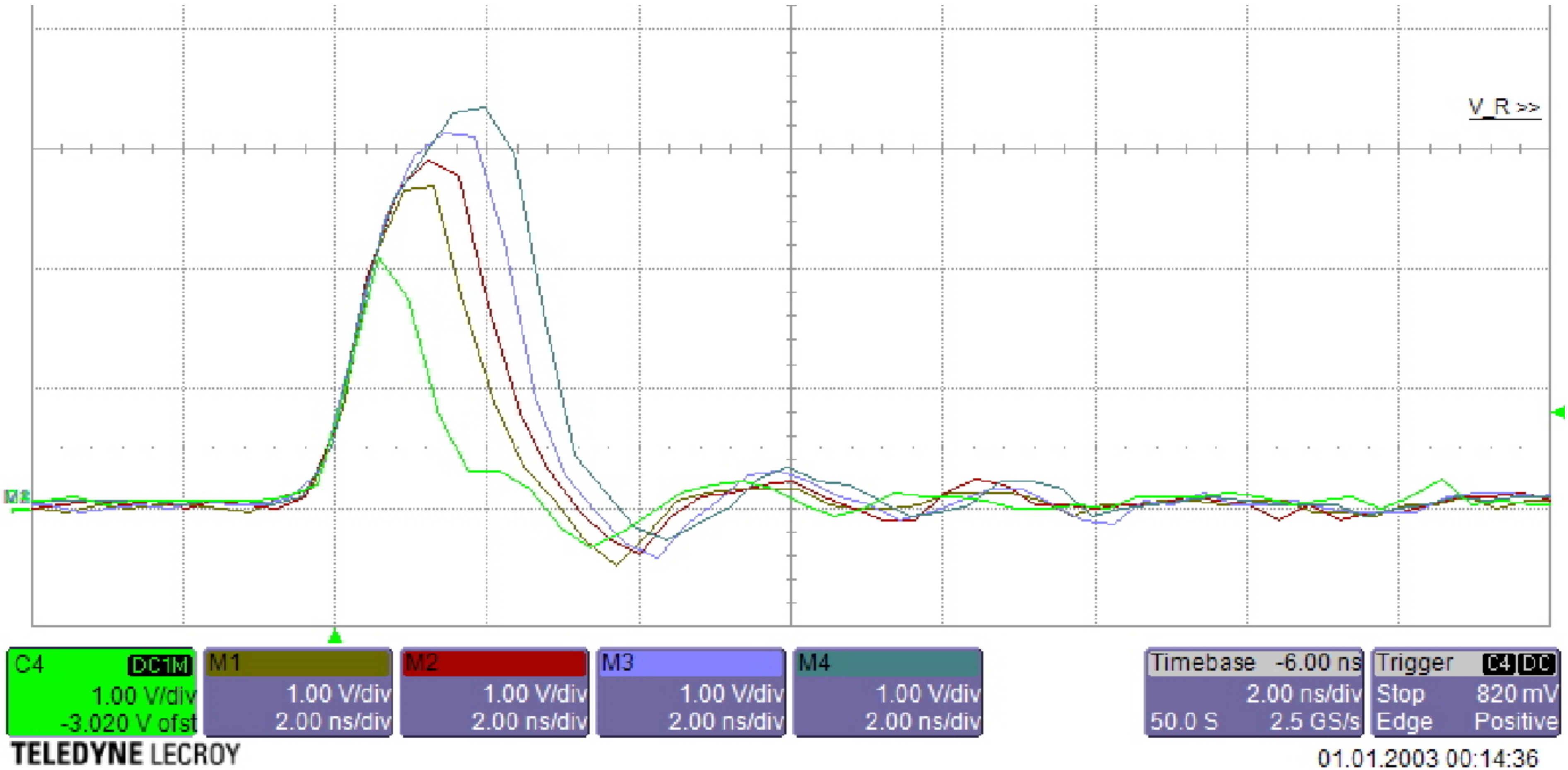
Pulse Driver Simulation – Back Annotation

- 4nF capacitance per channel
- 300pH total inductance per channel
- 1 ns FWHM pulse width @ 50 A peak current (starrc back annotation)
- „Active Off“ Switching: Self inductance generates negative voltage on laser for fast falling edge

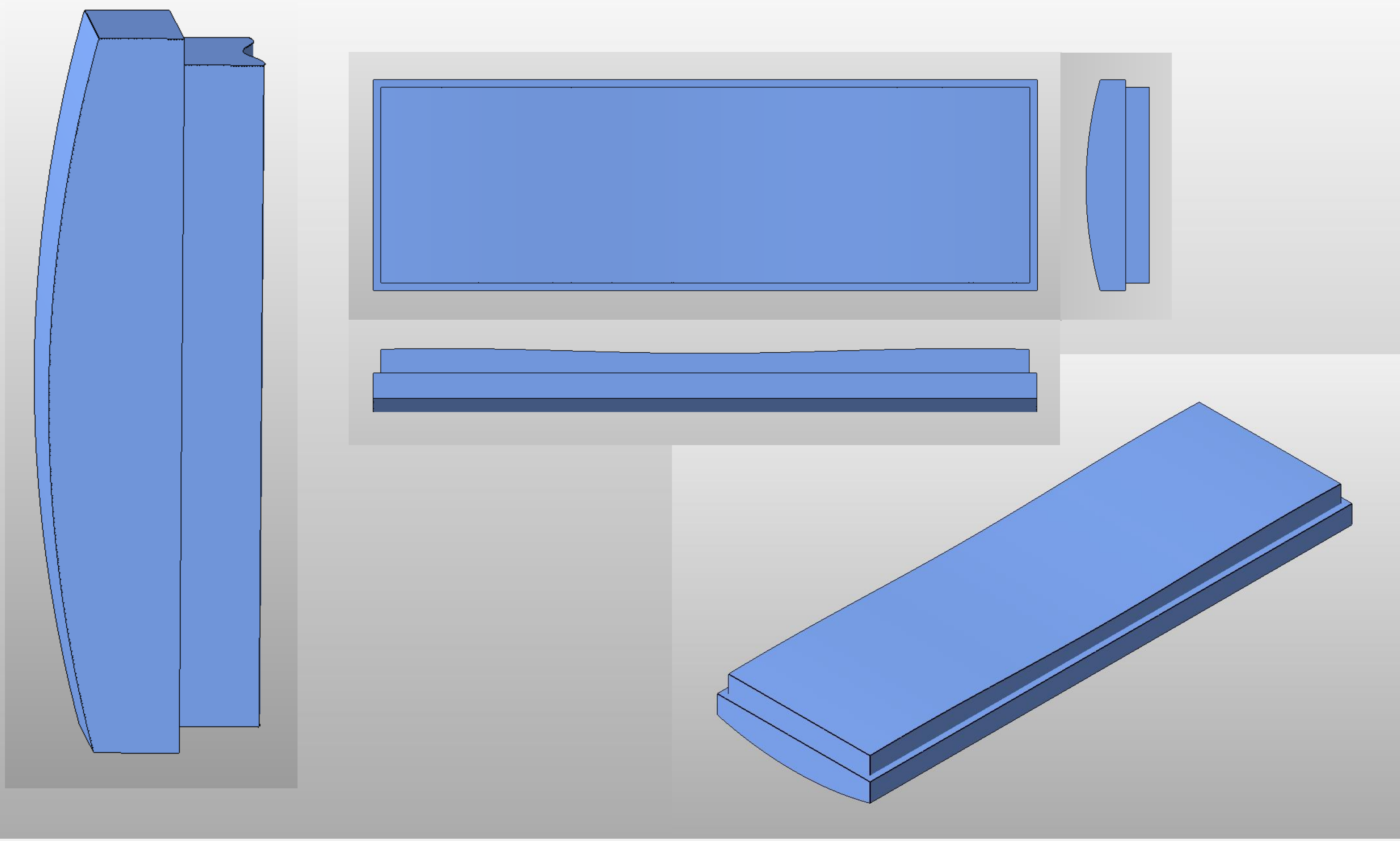


ALIS16 – Pre-Driver Pulse Width Sweep

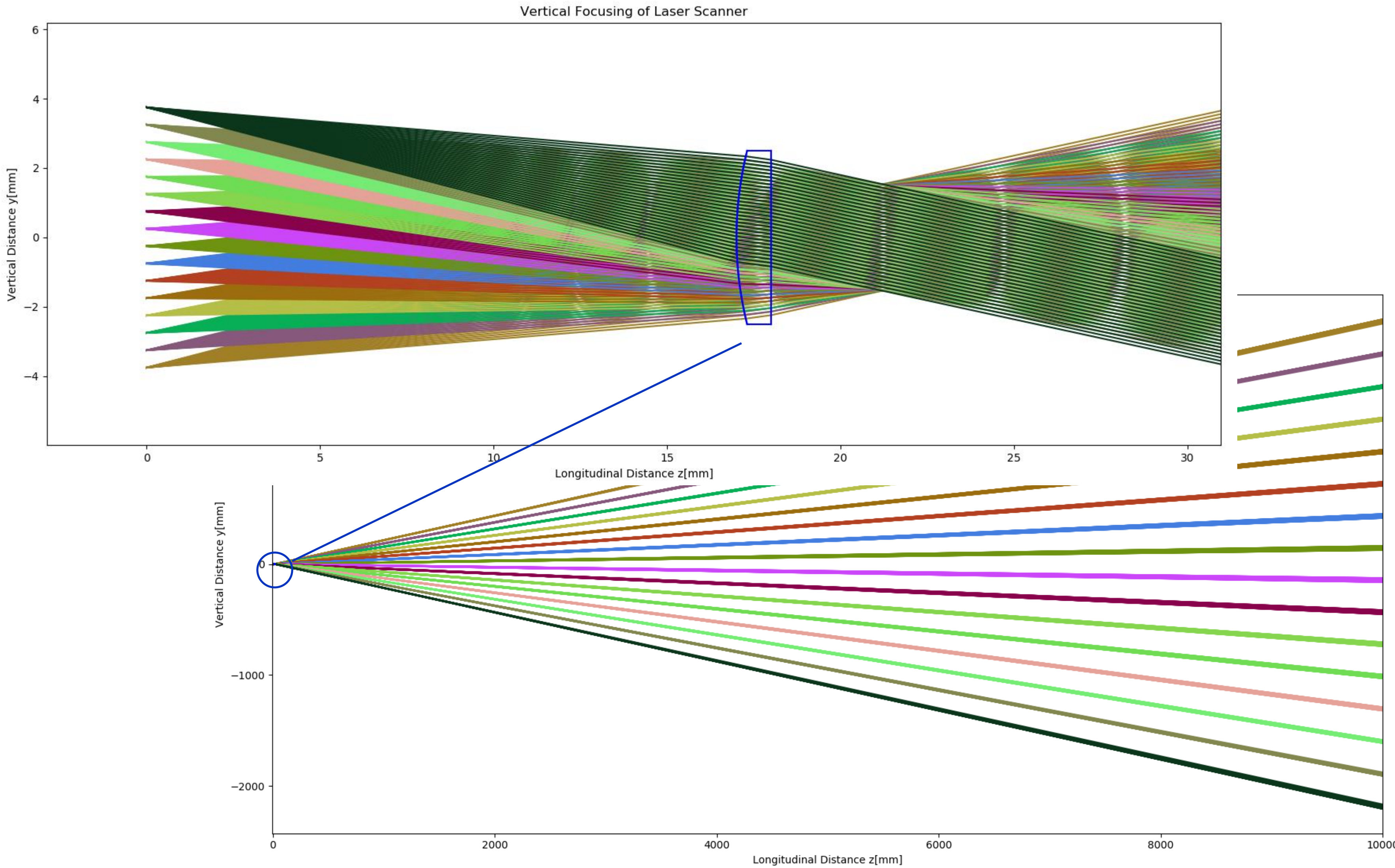
- Time resolution limited by 600 MHz oscilloscope
- Coarse pulse width setting 1, 3, 4, 5, 6



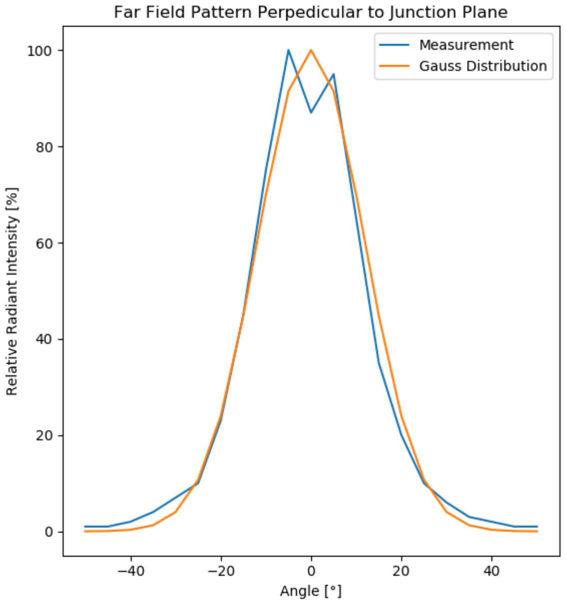
Transmitter Lens – 3D Model – 16.5 x 5.5 x 1.5 mm^3

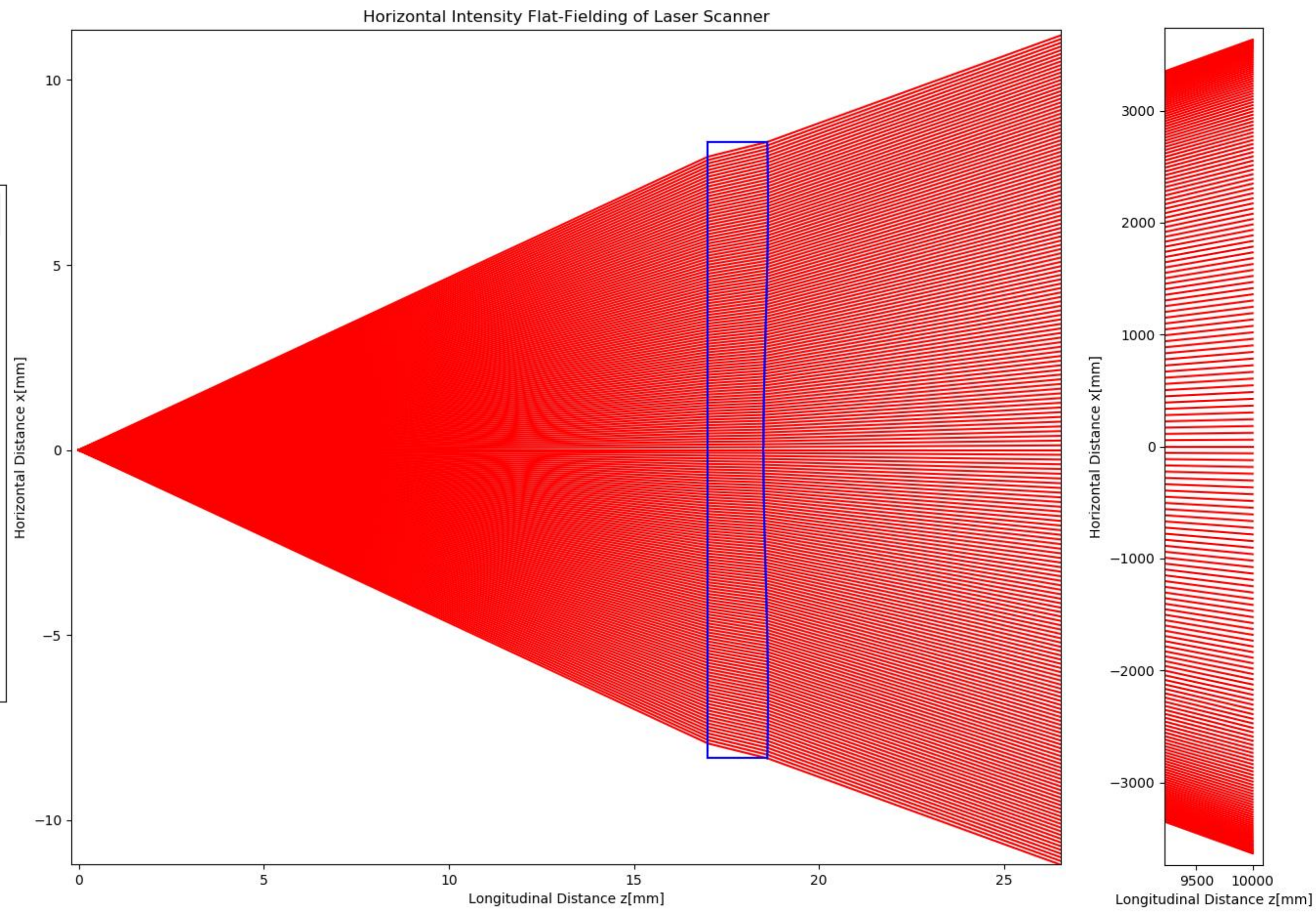


Laser Scanner – Vertical Focusing by Cylinder Lens

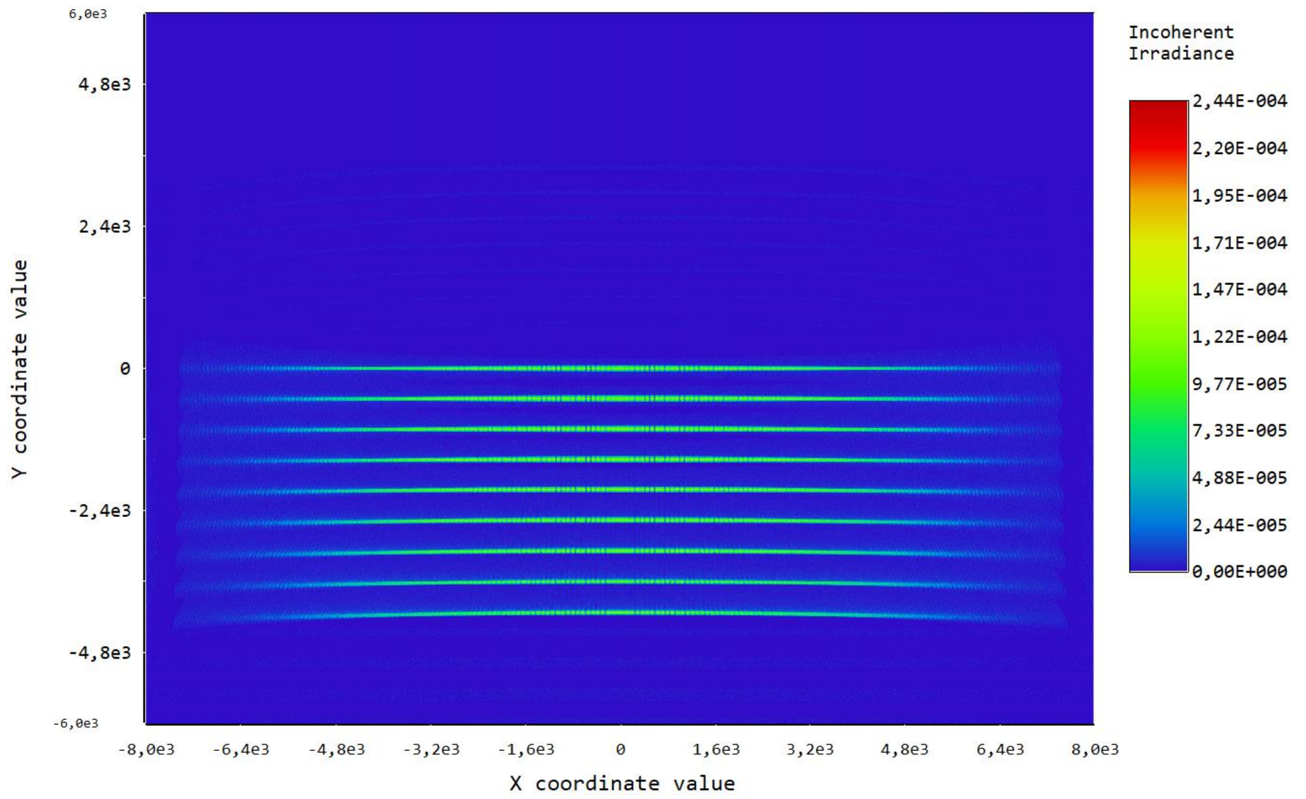


Laser Scanner – Horizontal Flat-Fielding by Powell Lens



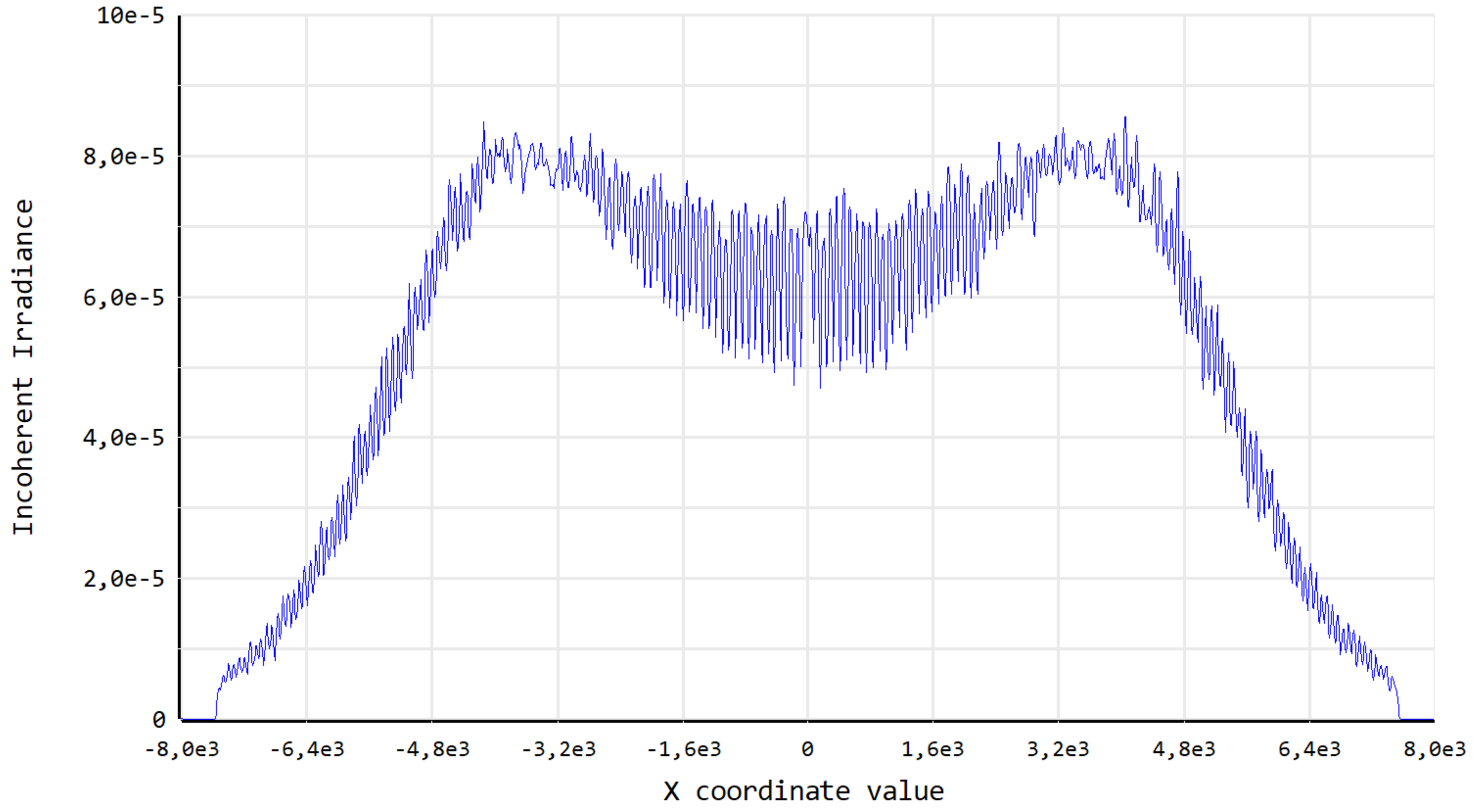


Illumination Pattern @ 20m Distance



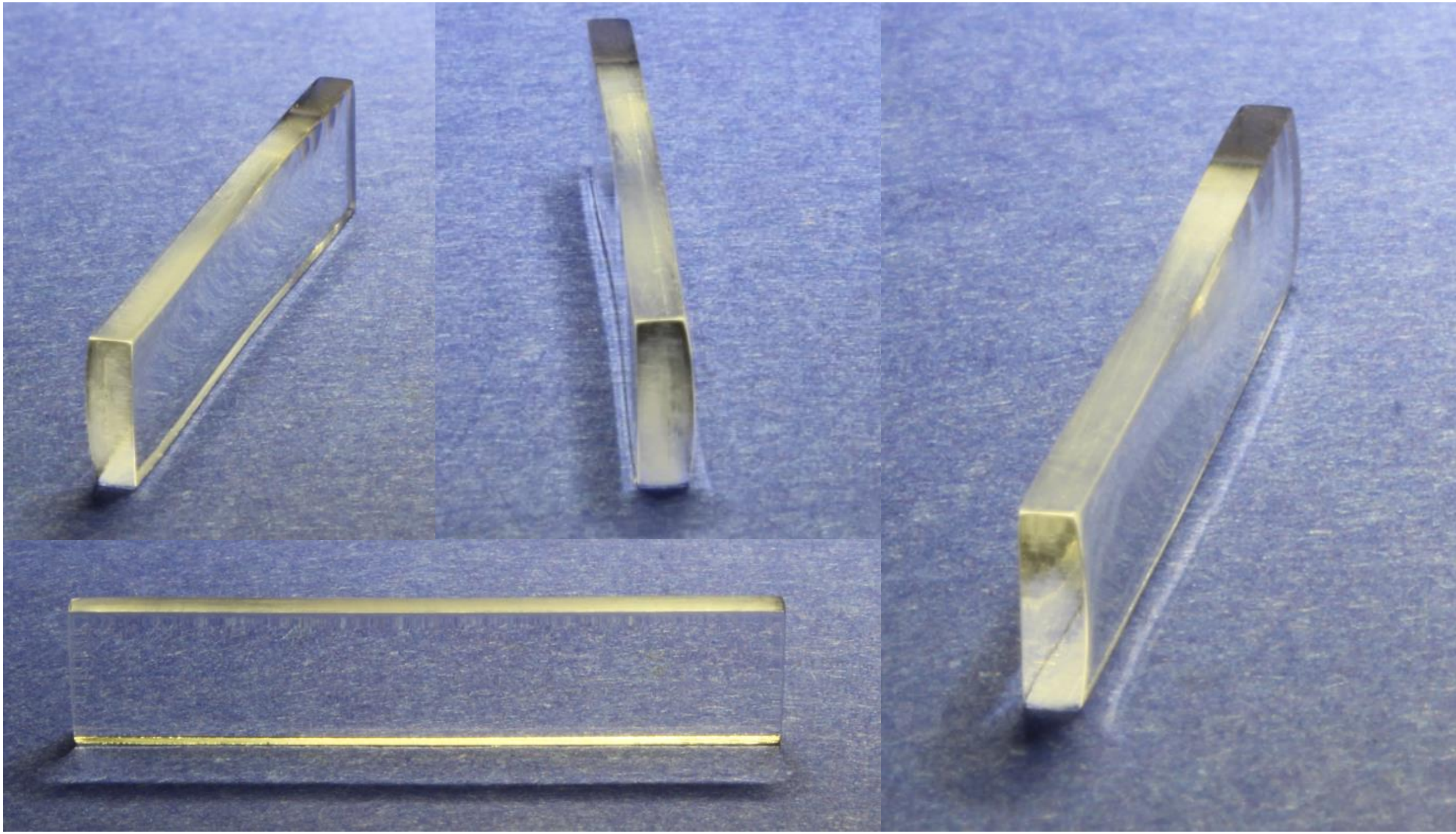
Detector Image: Incoherent Irradiance	
27.05.2019 Detector 8, NSCG Surface 1: Detector@20m Size 16000,000 W X 12000,000 H Millimeters, Pixels 6000 W X 6000 H, Total Hits = 15887279 Peak Irradiance : 2,4422E-04 Watts/cm^2 Total Power : 7,3522E+00 Watts	Zemax Zemax OpticStudio 18.9 ALIS16_Scanlens_Laser_SourceDiode.zmx Configuration 1 of 1

Horizontal Intensity Distribution of Laser Line

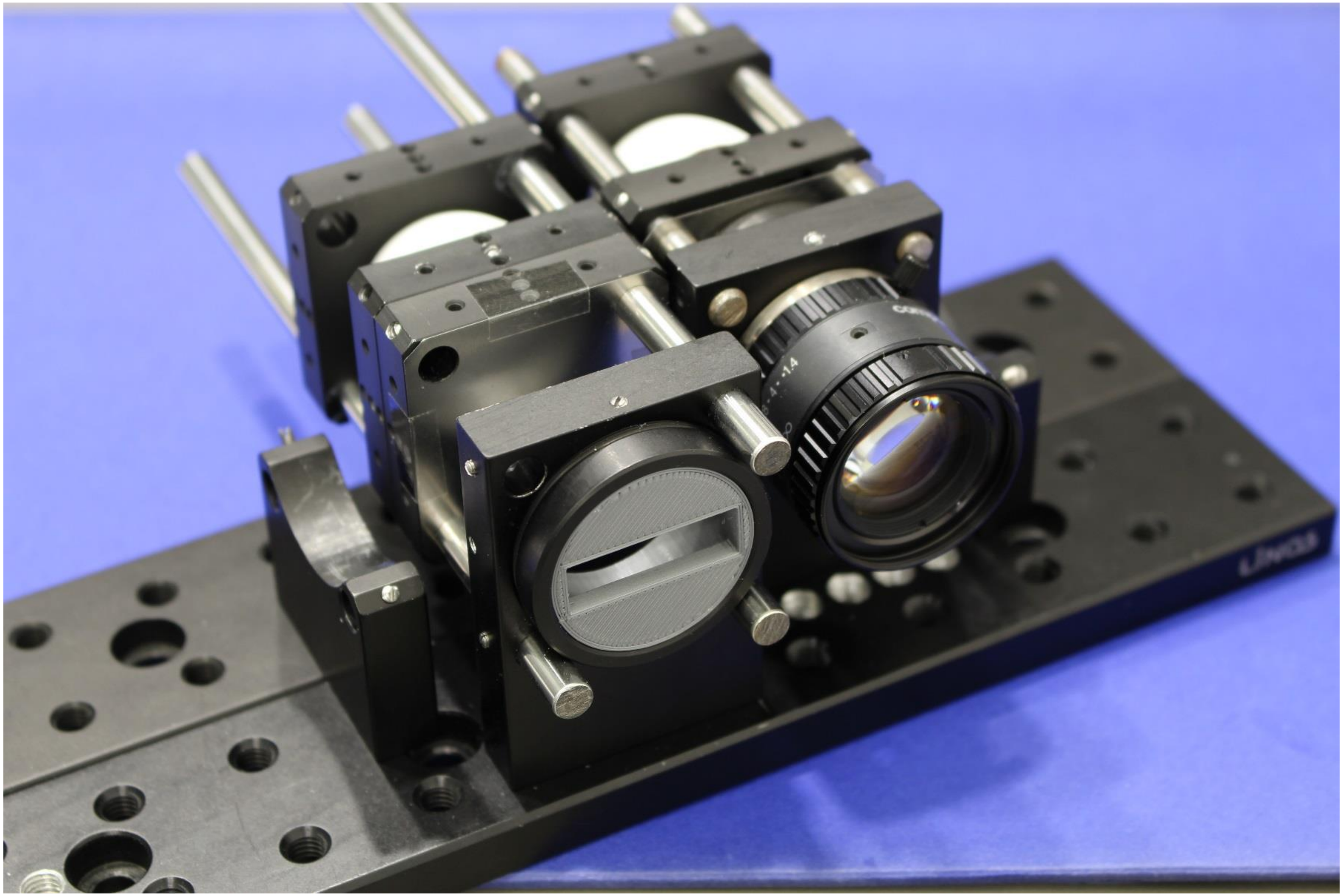


Incoherent Irradiance	
28.05.2019 Detector 8, NSCG Surface 1: Detector@20mRow Center, Y = 0,0000E+00 Size 16000,000 W X 12000,000 H Millimeters, Pixels 1600 W X 1200 H, Total Hits = 7967379 Peak Irradiance : 9,6783E-05 Watts/cm^2 Total Power : 7,3731E+00 Watts	Zemax Zemax OpticStudio 18.9 ALIS16_Scanlens_Laser_SourceDiode.zmx Configuration 1 of 1

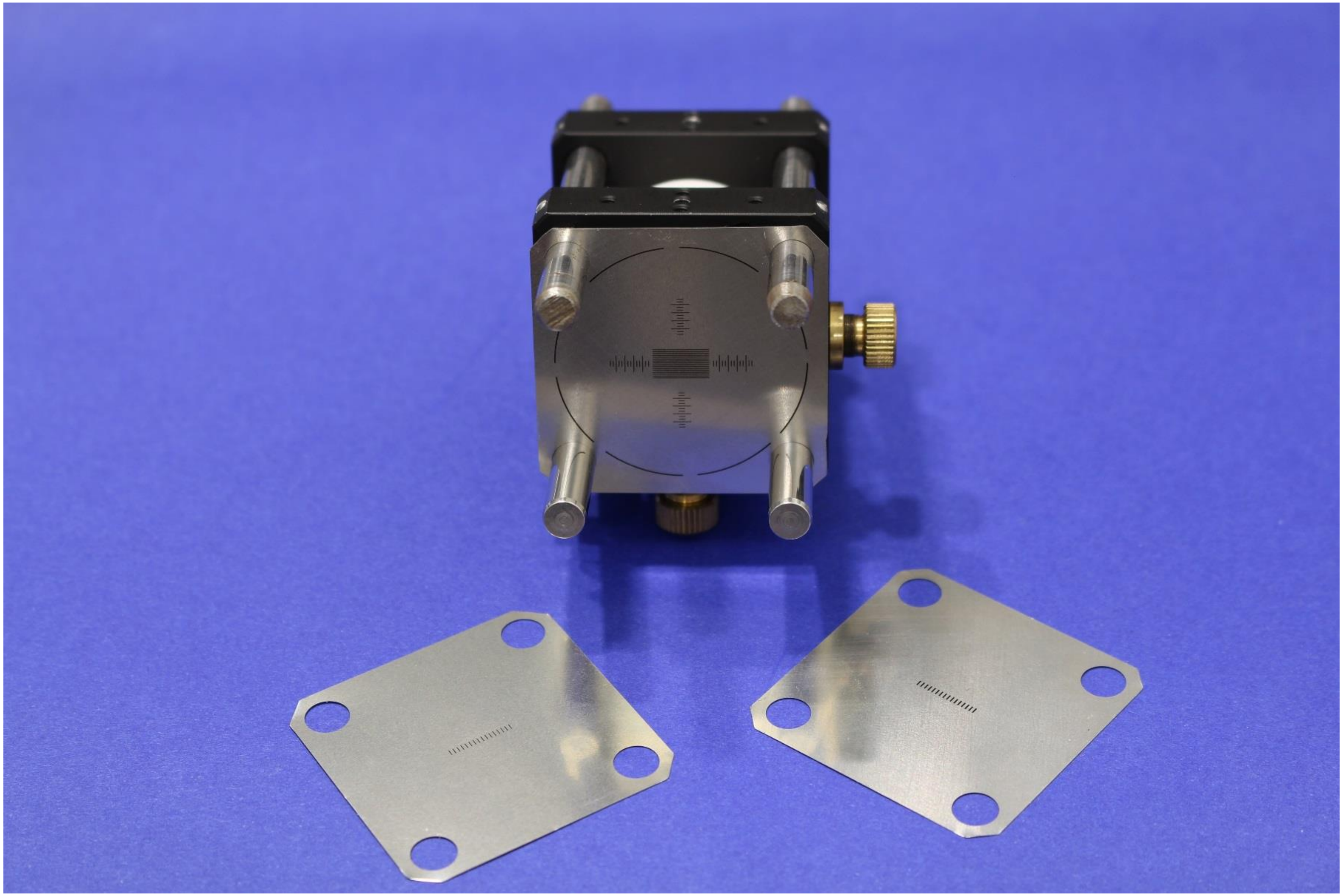
Scan Lens V1



Optical Test Setup

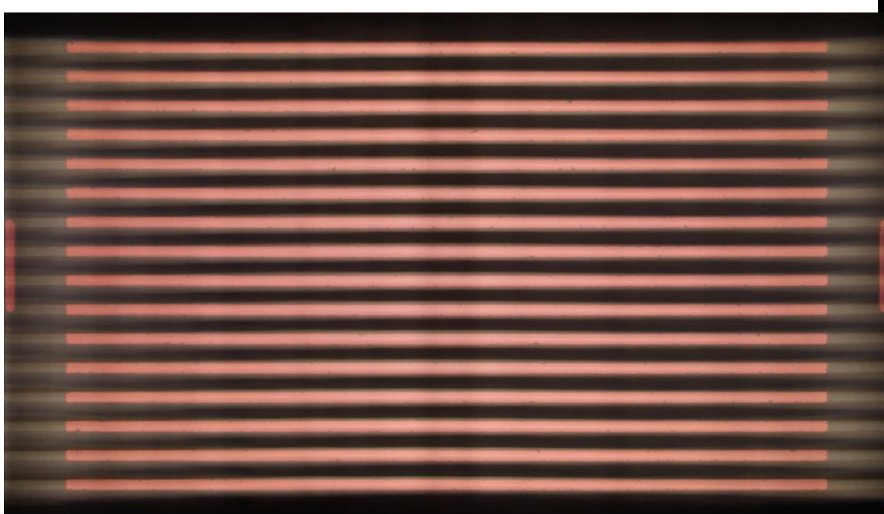


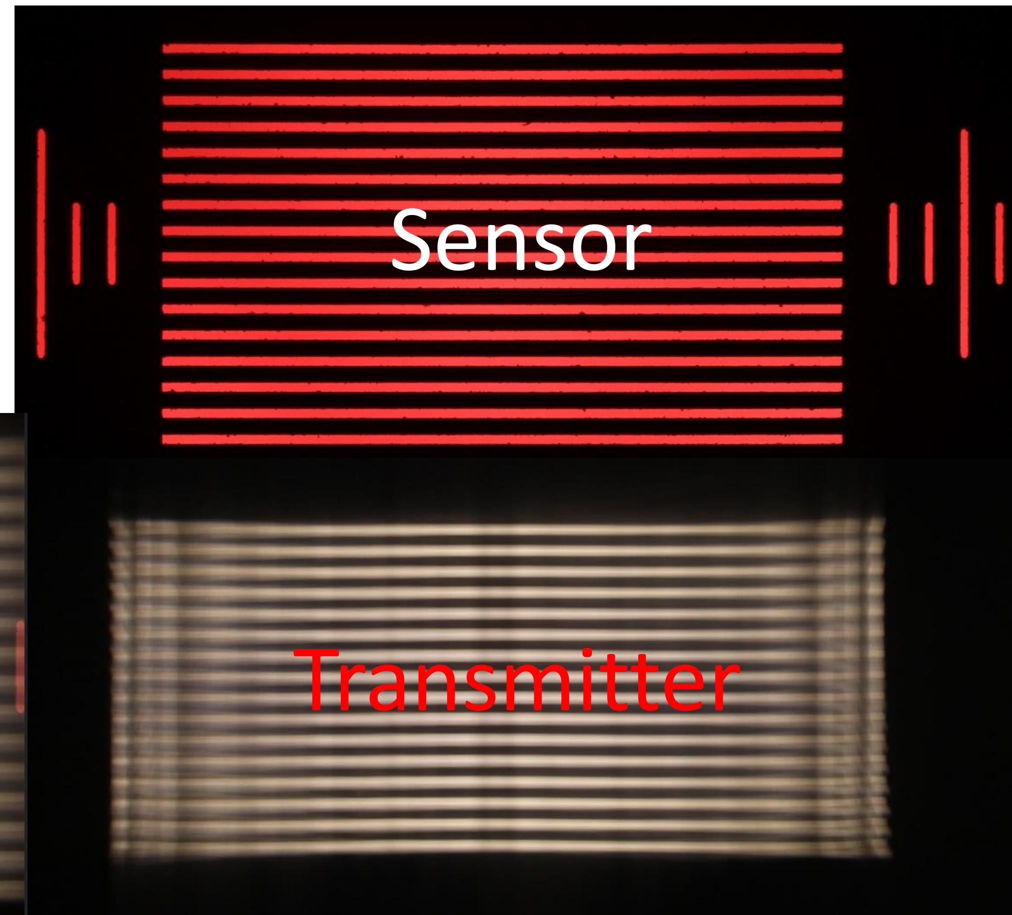
Scale Images of Transmitter and Receiver Array



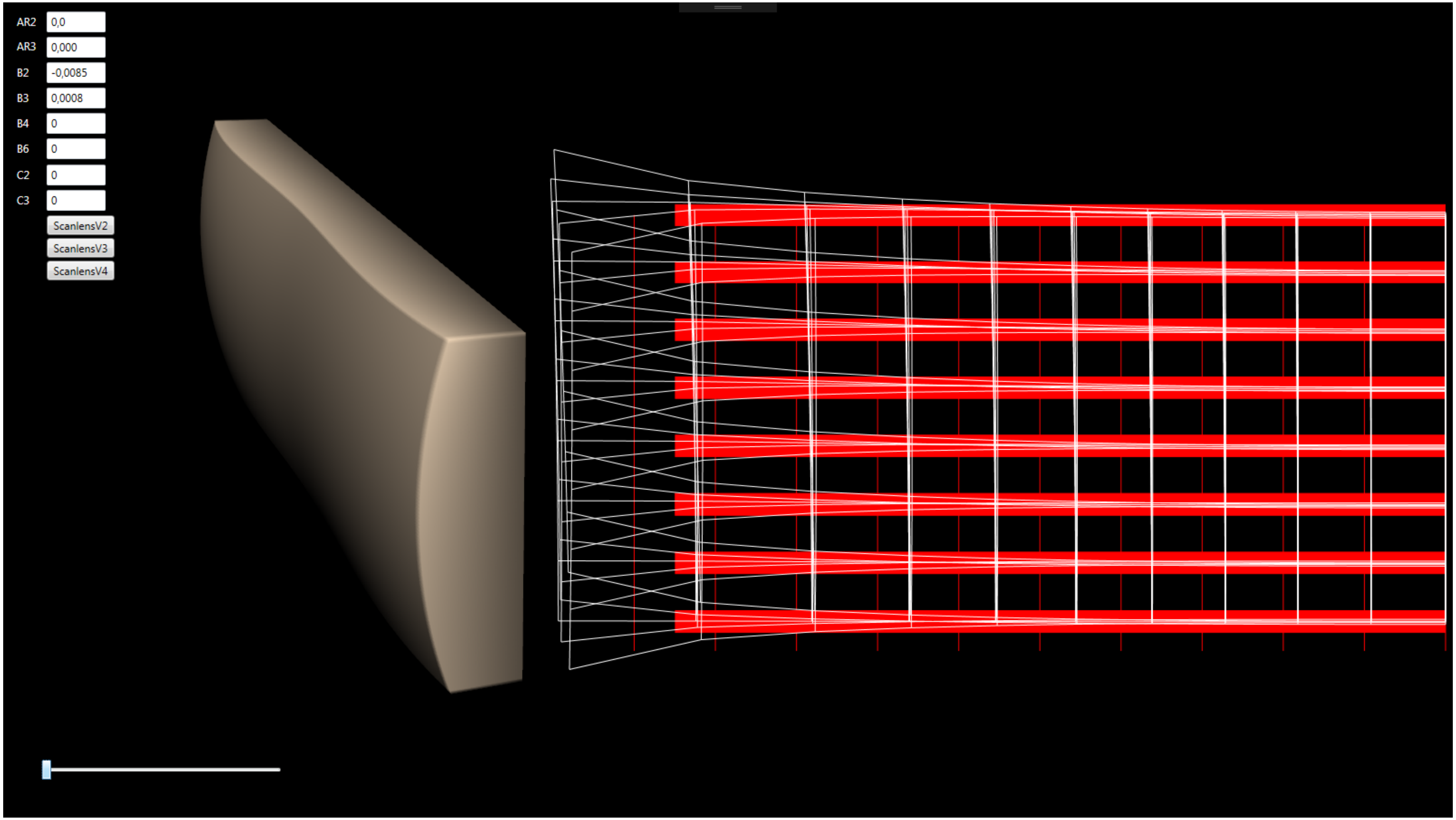
Scan Lens V1 – Test Results

- Proof of prciple
- Good vertical focusing
- Constant line spacing
- Slight fabrication errors
- Cushion distortion
- Defocus at end of lines

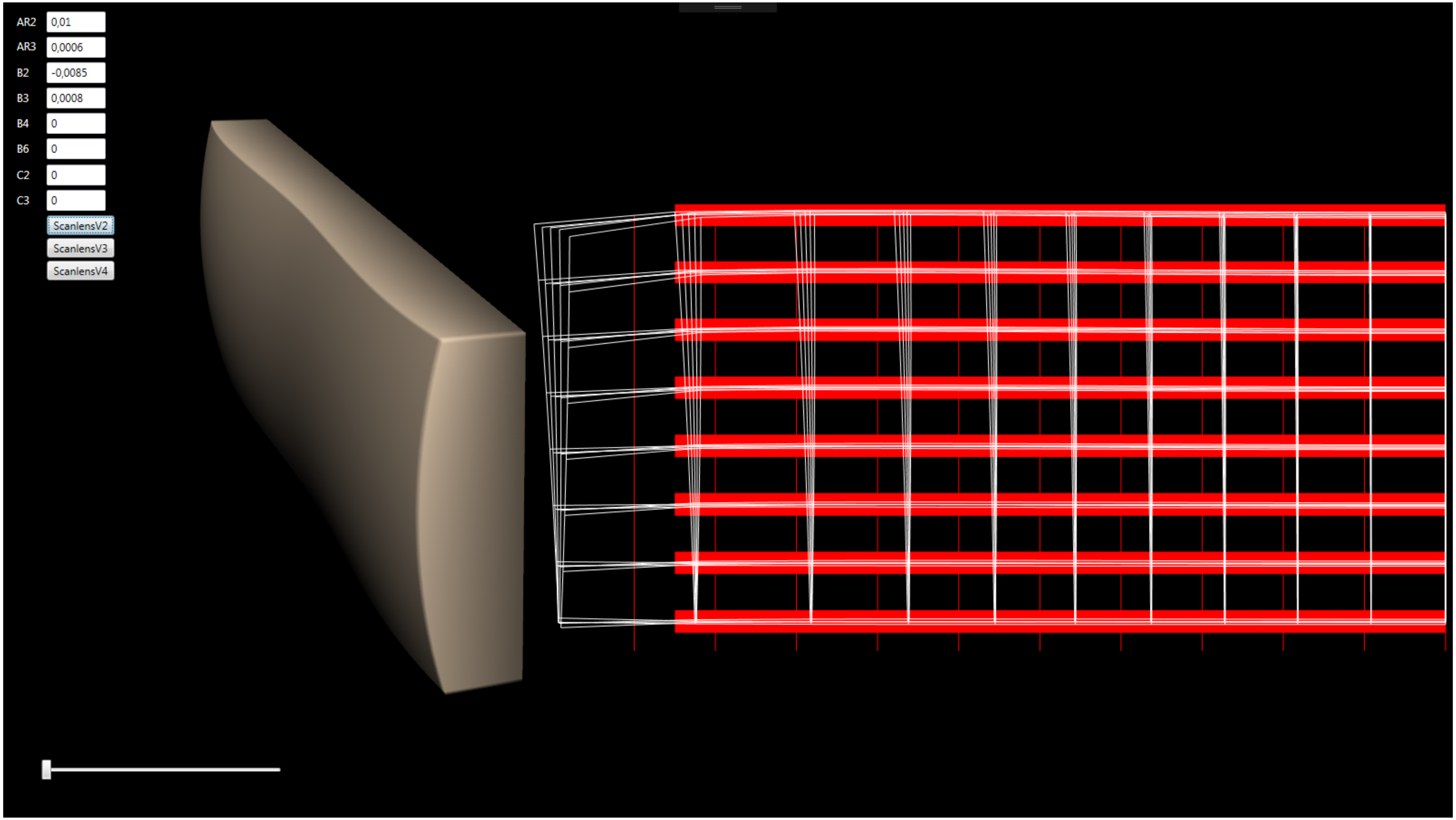




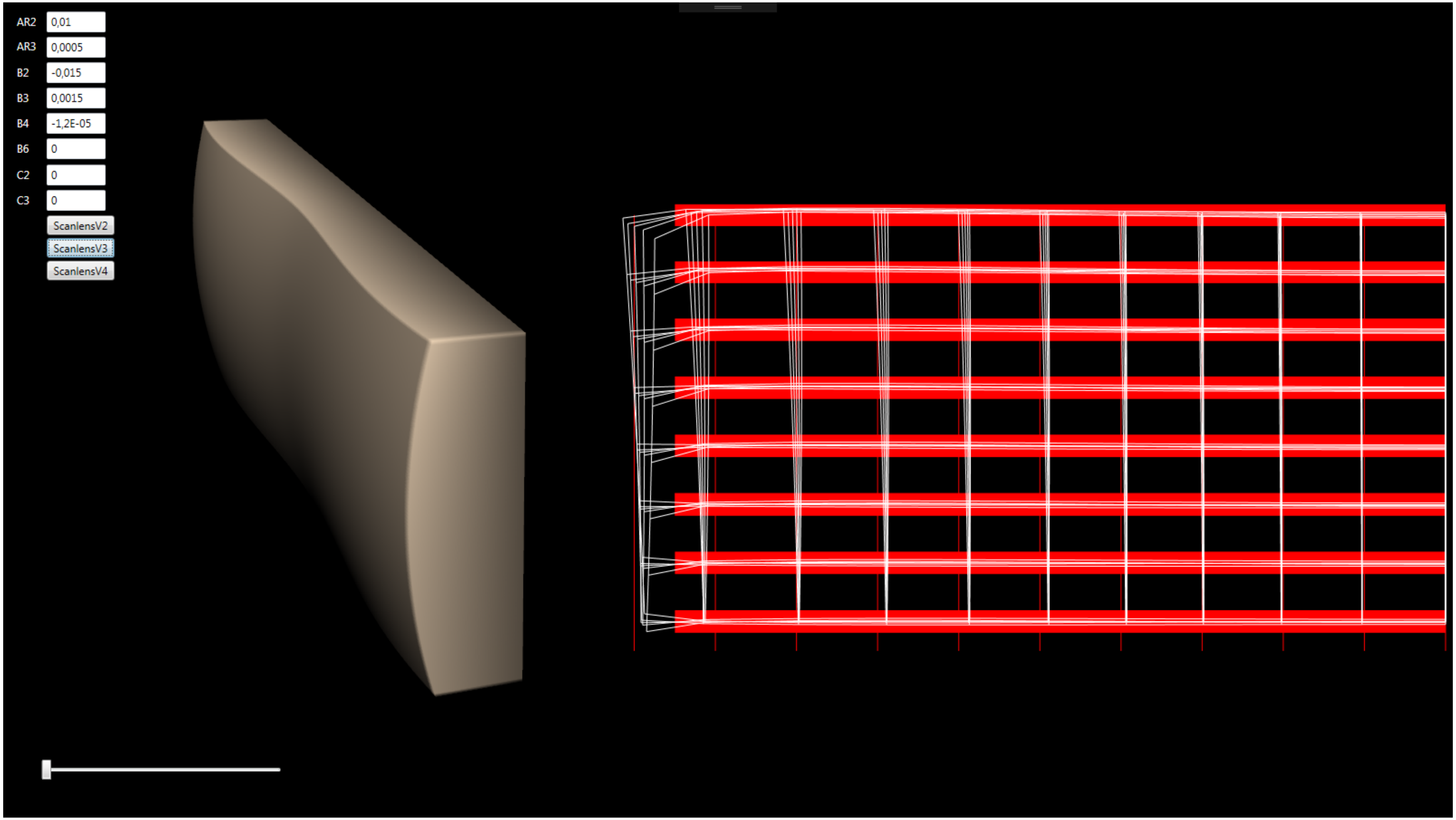
Scanlens V1 – Simulation



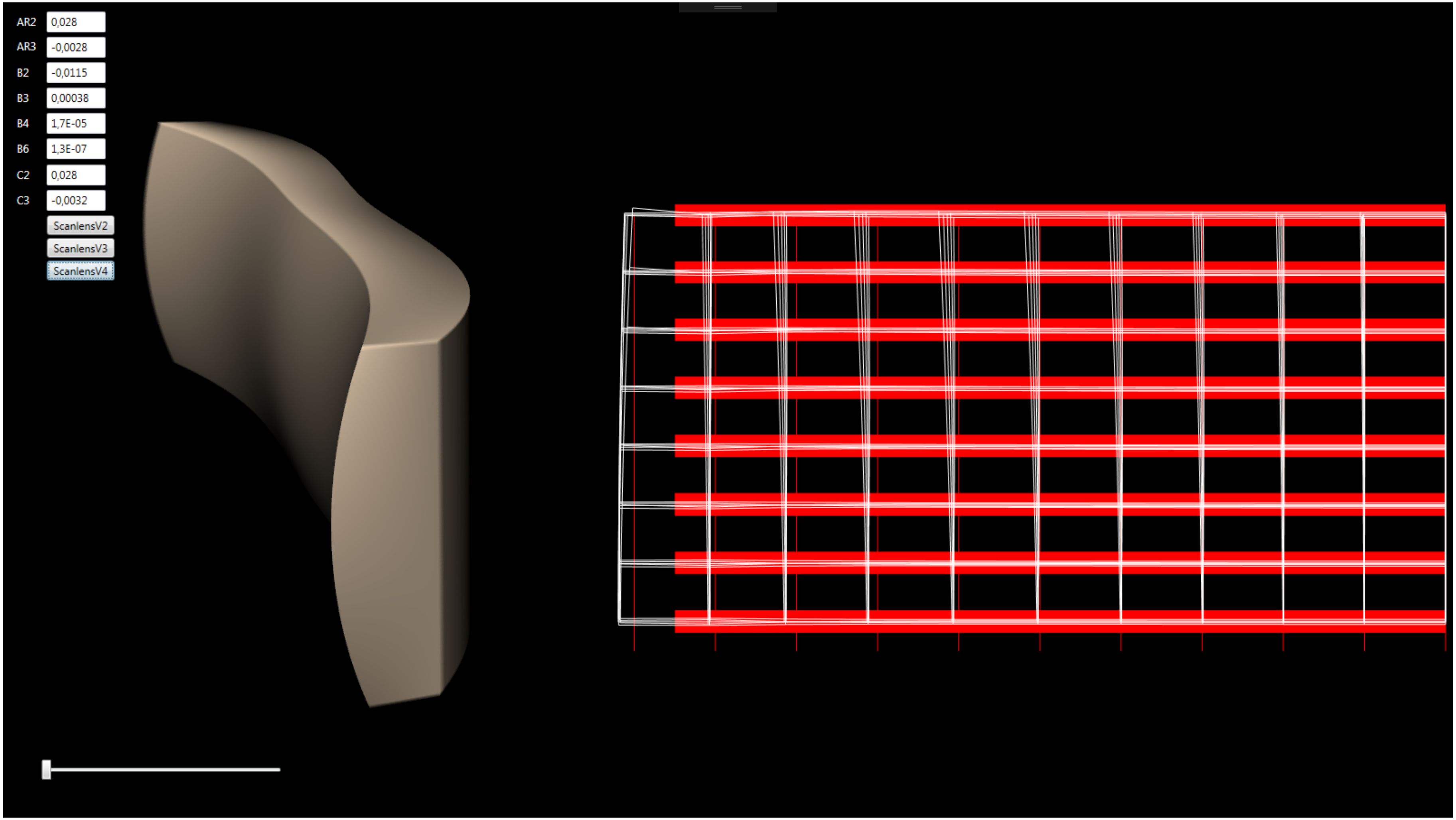
Scan Lens V2 – Focal Correction



Scan Lens V3 – Brightness Correction



Scan Lens V4 – Distortion Correction



Solid State Scanning LIDAR Camera

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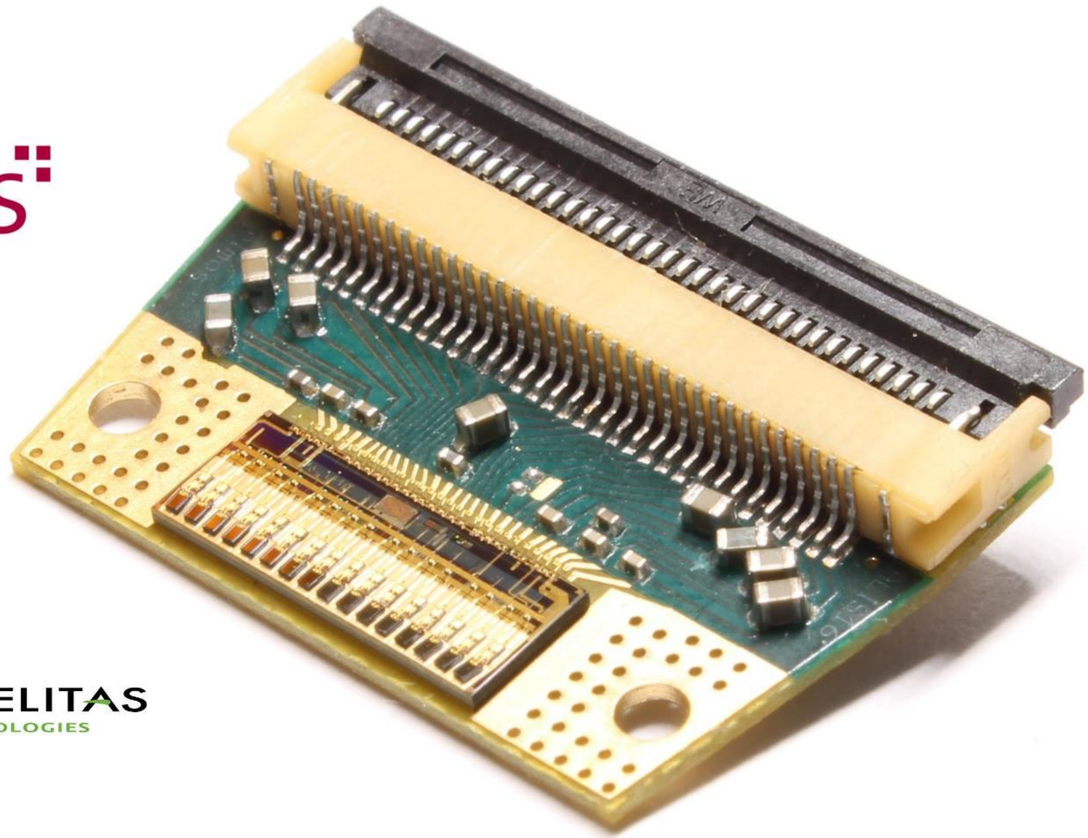
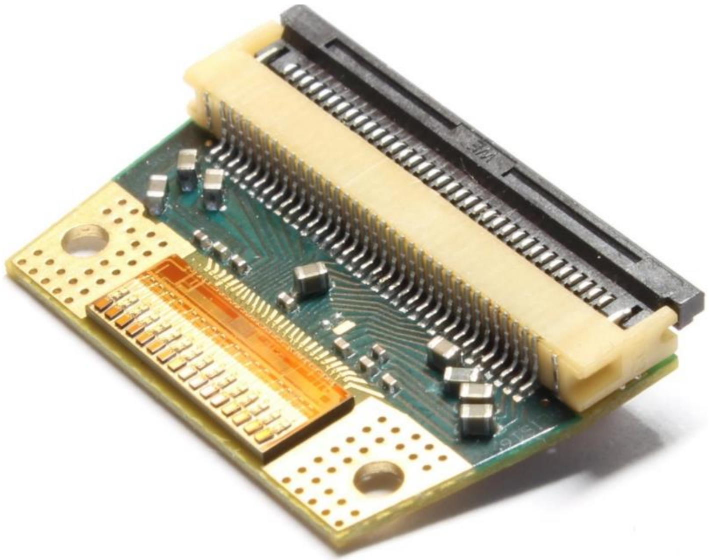
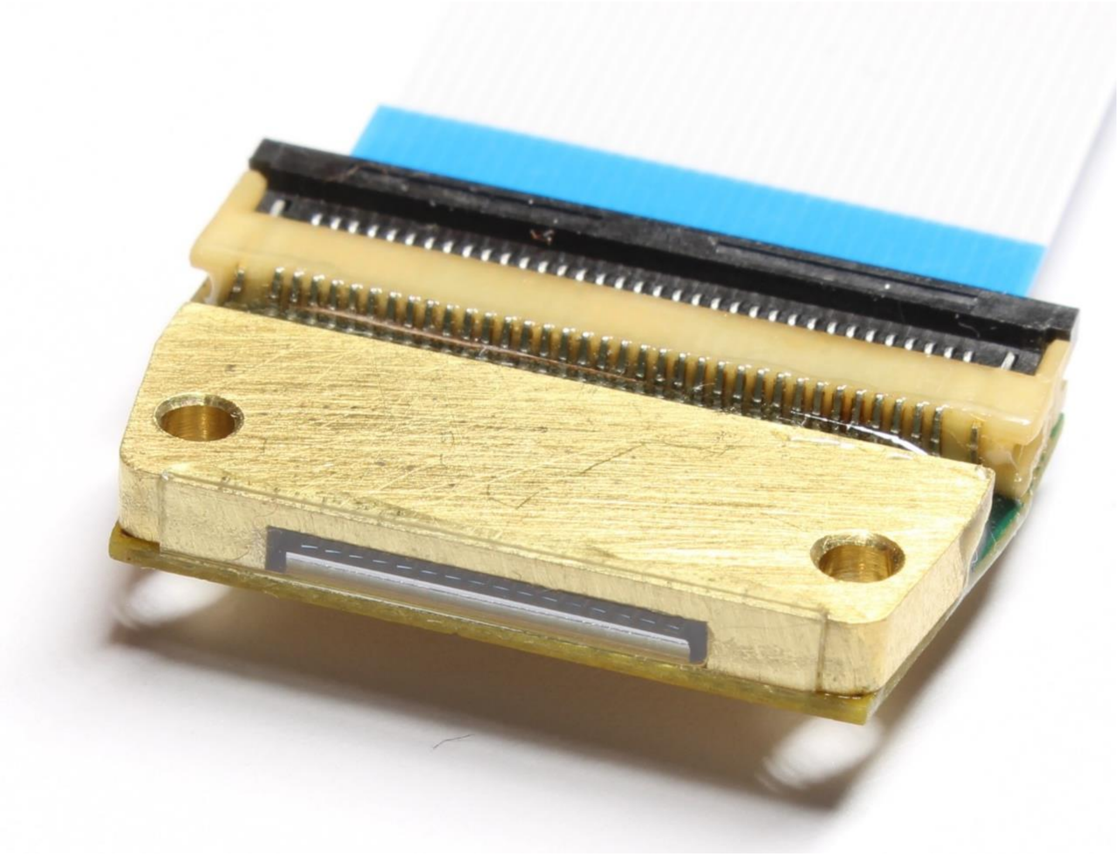
EXCELITAS
TECHNOLOGIES

16-Channel Pulsed Laser Driver Module – Multi Chip Stack

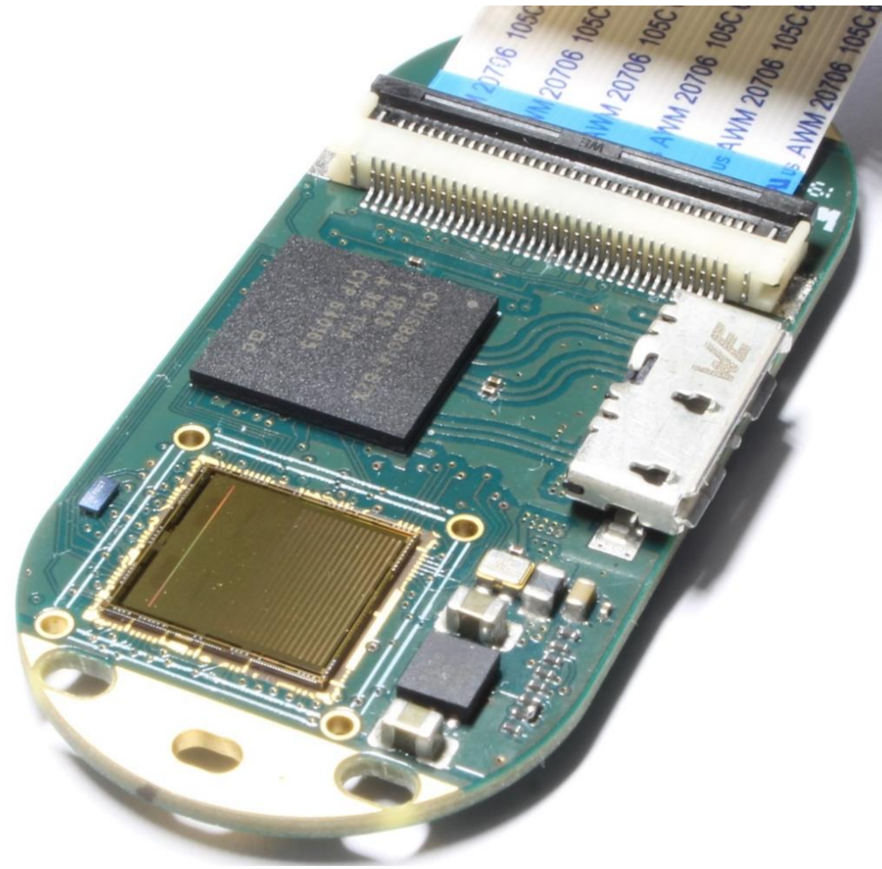


16-Channel Pulsed Laser Driver Module – Camera Package

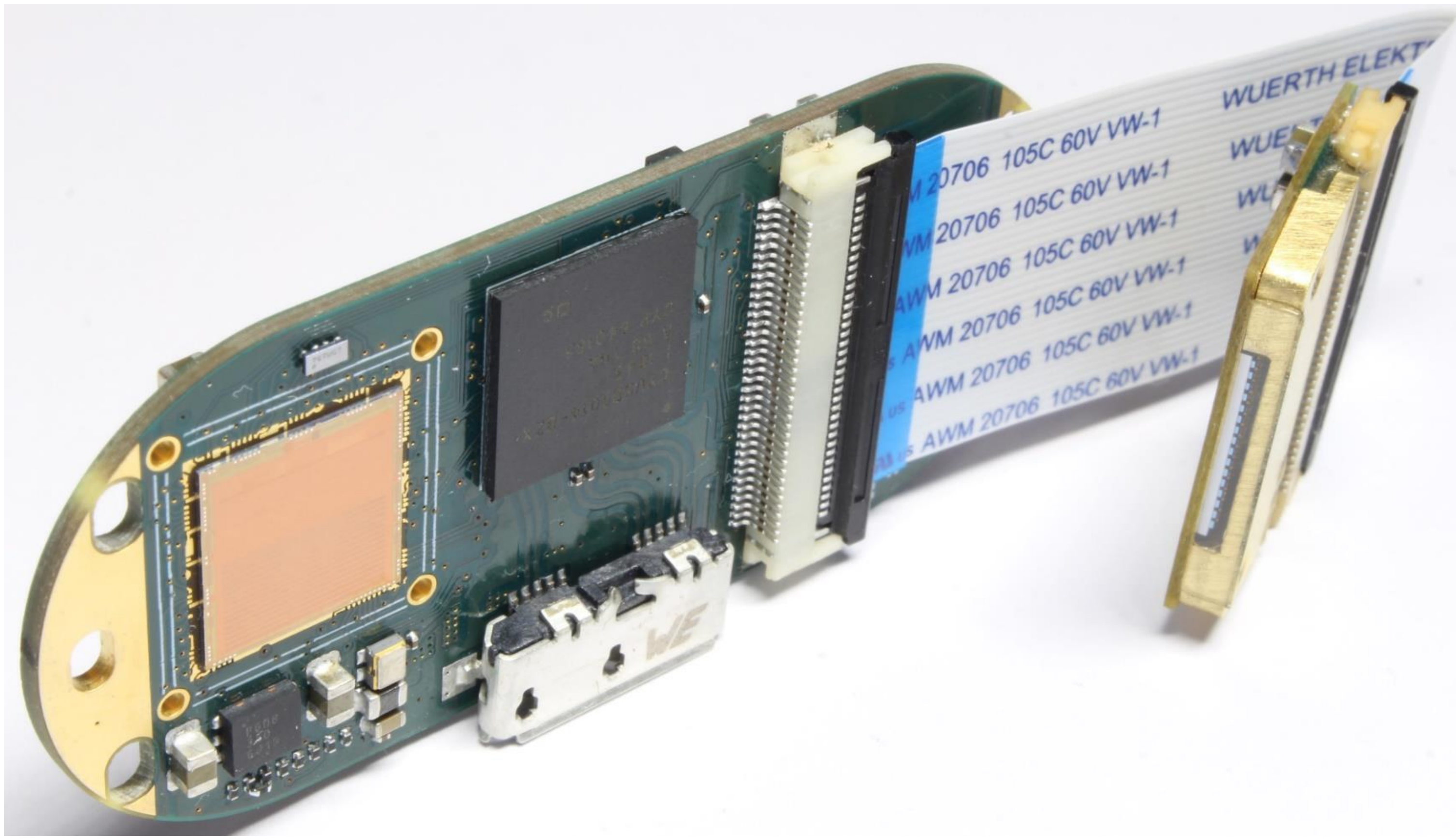




256 x 16 SPAD Array Sensor Board – USB 3.0 SuperSpeed Connectivity



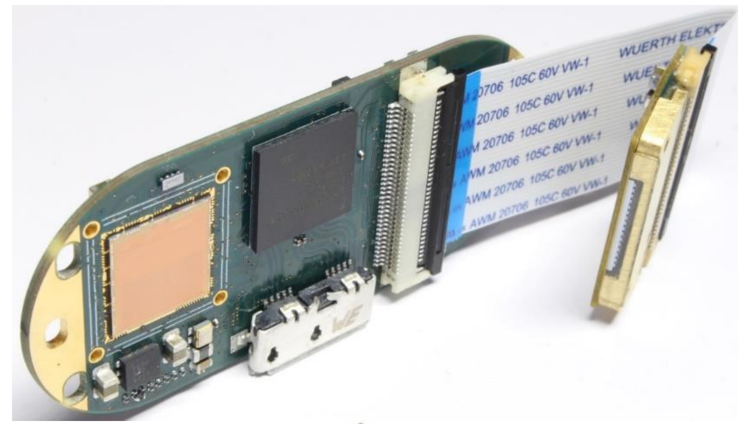
Solid State Scanning LIDAR Camera – System Assembly

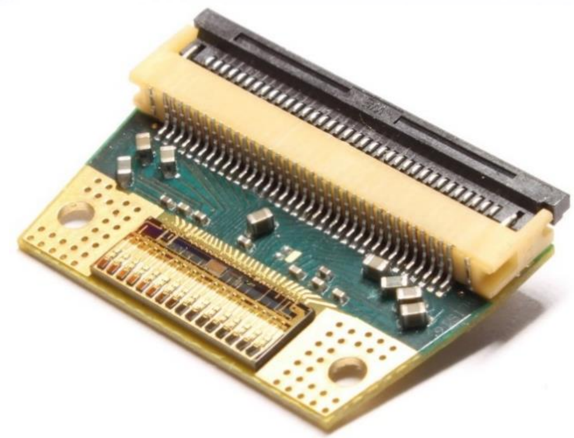


Solid State Scanning LIDAR Camera – Features I

Solid State Scanning LIDAR Camera

- 16 channel pulsed laser module
- Rolling shutter 256 x 16 pixel CMOS SPAD array
- USB 3.0 SuperSpeed connectivity
- Ultra short laser pulse width 1ns
- Up to 3Gb/s raw data rate
- No moving parts
- Bus powered





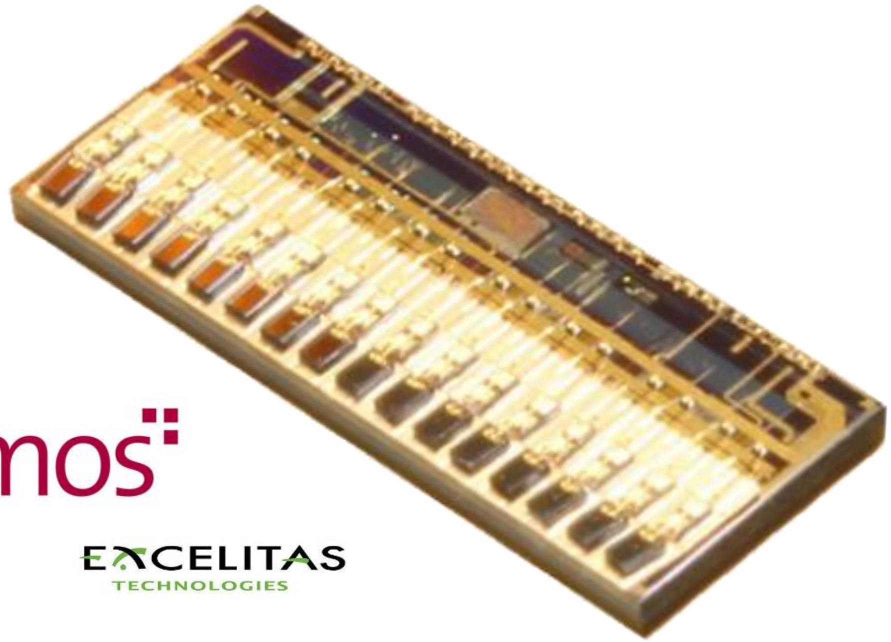
Solid State Scanning LIDAR Camera – Features II

1st Generation Multi-Channel Laser Driver Module

- 16-channel configurable laser driver IC
- 16x Excelitas edge emitting 905nm pulsed laser diodes
- 32x Murata 1nF UWSC caps
- **1ns pulse width @ 50A peak current**
- HV charge & discharge function/channel
- Lowest inductance stack-up multi-channel driver
- Scalable building block approach for high channel count
- Build on robust & automotive qualified process

Special Features

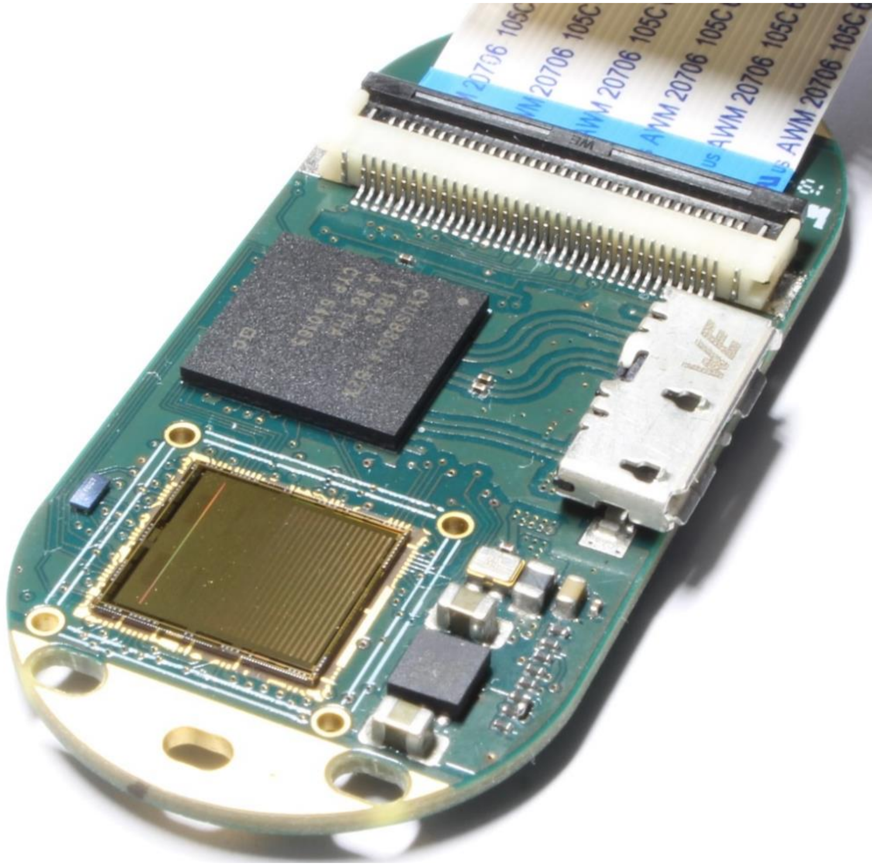
- **Configurable pulse width & delay 1-15ns**
- **10ps resolution**
- Integrated diagnostics & measurement
- **Control average laser power**
- **Monitoring of eye safety**
- 10x temp sensors w/digital readout
- 100MHz SPI interface
- On-chip channel sequencer



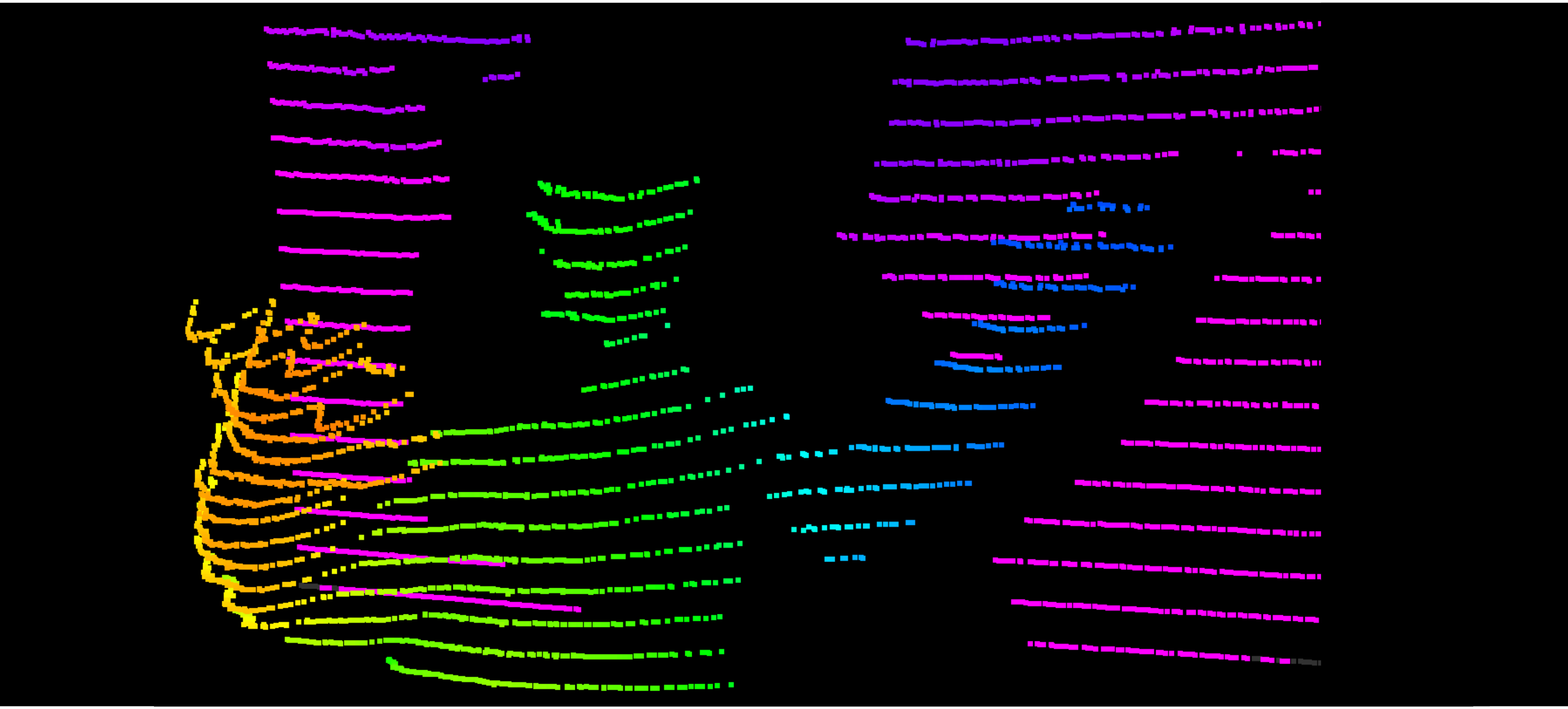
Solid State Scanning LIDAR Camera – Features III

2nd Generation SPAD Array

- 256 x 16 CMOS SPAD Array
- Massive parallel data processing with multi-channel TDC
- 3mm distance resolution by interpolation
- 192m full range
- Rolling shutter operation
- Build on robust & automotive qualified process
- Active quenching circuit for SPAD dead-time variation
- 4x vertically arranged single SPADs
- Multi-event detection mode
  - Up to 4x event/px & pulse
  - Increased Range & Noise Immunity
- Auto-coincidence circuit for high ambient light rejection
- Statistical evaluation offers rich analysis of raw data
  - Distance
  - Brightness / ambient light
  - Visualization of multiple reflections
  - Rain and fog detection



Solid State Scanning LIDAR Camera – 3D Image Data



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Contact:
Dr. André Srowig
System Development Engineer
Email: andre.srowig@elmos.com

Thank you for your attention!

Elmos Semiconductor AG

Heinrich-Hertz-Str. 1 | 44227 Dortmund | Germany
Telephone: + 49 231 75 49 0 | Telefax: + 49 231 75 49 149
info@elmos.com | www.elmos.com

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True Solid State Scanning LIDAR System

elmos

- System features
  - 3mm distance resolution
  - 40 fps framerate
  - 192m range
- 16 channel pulsed laser module
  - 1ns pulse width @ 50A peak current
  - Integrated diagnostics & measurement
  - Control of average laser power
  - Monitoring of eye safety
- 256 x 16 pixel CMOS SPAD array
  - Rolling shutter
  - Auto-coincidence circuit
  - Multi-event detection