DLP650LNIR

200 W / 1064 nm Field Lens Optical Reference Design Using Off-the-Shelf Optics

July 2022

Rev. 2.0

Prior to design integration – Laser Safety

The Lumics fiber coupled diode laser provides a convenient controlled light source with a numerical aperture (NA) that can easily be coupled with standard DLP optical components. This fiber coupled laser eliminates the difficulty of aligning and collimating individual laser diodes for easier and more effective light coupling into the projection system.

US standards require a class 4 laser lab with trained individuals for these power levels.

In addition to the class 4 laser lab facility, TI enclosed the optics inside a metal box so that any stray light from optical misalignment/reflections would be contained.

An IR camera, was used to observe the 1064 nm image;

Edmund optics; 34-176 Basler ace acA2040-90 um NIR USB 3.0,
86-574, 50 mm Focal Length lens

Always use safe practices appropriate for the laser wavelength and optical power level when operating, handling, and aligning laser systems.

Content

- Why off-the-shelf optics
- Example requirements
- DMD and laser source matching
- DMD diffraction efficiency vs wavelength
- Optical design layout
- Off-the-shelf optics
- Design details
- Architecture options

Off-the-Shelf Optics Prototype Design

- Why use off the shelf optics?
  - Ease to reproduce by DLP customers
  - Prototype quickly for experimentation / feasibility assessment
  - Low cost / quick turn around optics
  - Platform for electronics / thermal solution development
- Disadvantages of off the shelf optics
  - Coatings not optimized
  - Optical design not fully optimized for application needs
  - Some components may need be custom to meet basic functional requirements
- TI created both an off the shelf version of design (built) and a custom design (simulation) for reference

Example Requirements*

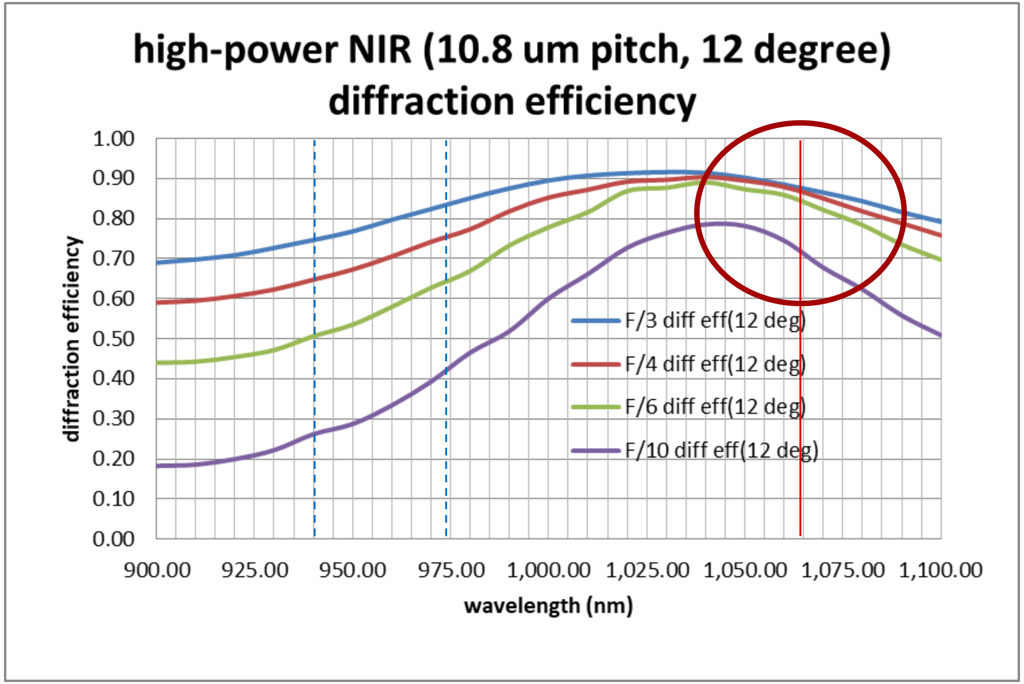
Parameter	Requirement	Comments
DMD	DLP650LNIR	
NIR Laser		160 - 200 W high power NIR laser *low power “Red” laser / LED for optical alignment.
DMD Laser Illumination Power	~160 Watt CW at DMD array	0 % overfill per DMD data sheet
NIR Laser wavelength	950-1150 nm	200 um core diameter 0.22NA - 975 nm , 400-600 um core diameter 0.22NA - 1064 nm are options being explored
DMD Illumination uniformity	>95%	Tradeoffs can be made to use DMD speed with multi-patterning to achieve improved power uniformity but at a system throughput cost.
Optical Alignment. Illumination	Eye-safe Red	For unit alignment only. Can be fiber coupled and use the same fiber input path as the high power NIR laser
NIR power @ projection surface	100 W minimum	
Projection MTF	50% at Nyquist	Typical display target. Possible trade-off for laser processing application.
Image size at projection surface	128 mm x 80 mm	100 um per pixel feature size – still to be finalized with customers
Contrast Ratio	300:1	Checker board
Image uniformity @ print surface	>90%	
Optical path loss vs exposure time	10% @ 5000 hours	Reduction in optical path efficiency (DMD and laser source not included)

* Values can be optimized

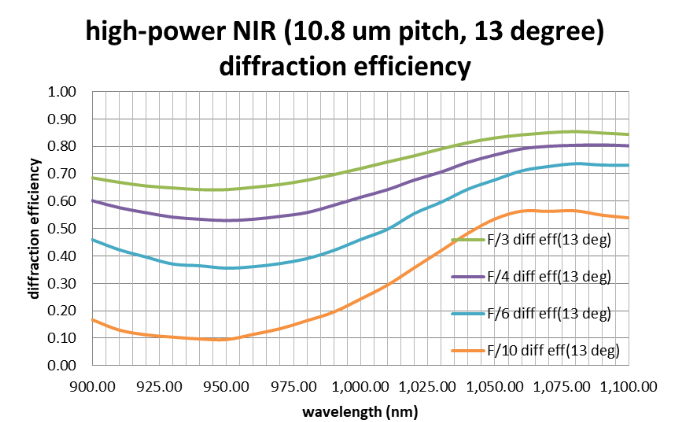
Laser Source Matching

- DMD capability (at f/2.4):
  - # of micro mirrors: 1280×800.
  - Pixel pitch: 10.8 um. Mirror tilt: 12 +/- 1°. Array size: 13.824 mm by 8.64 mm.
  - Width direction capability : 13.824×sin(12°) ×(cos(24°))^0.5 = 2.75 mm.
  - Height direction capability : 8.64×sin(12°) ×(cos(24°))^0.5 = 1.72 mm.
- Laser capability:
  - Laser of choice: Lumics laser, 1064 nm, 0.2 mm fiber (or 0.4/0.6 mm), NA 0.22. P/N LU1064C200-N30AT
  - Width/Height direction capability: 0.2 × 0.22 = 0.044 mm.
  - Slowest f/# with geometric matching: 1.72/0.044*2.4 = 93.8
- f/# consideration:
  - Illumination: a wide range between f/2.4 and f/93.8, design choice based on specific application trade-offs.
  - Projection: slightly faster than illumination to accommodate tilt angle and alignment variation. Also consider cost, size, and imaging performance. Too slow f/# will cause MTF, tilt angle, and alignment sensitivity related issues.
  - Choice of f/#: f/7. The projection lens is designed for f/3 with a removable aperture to control the f/#.

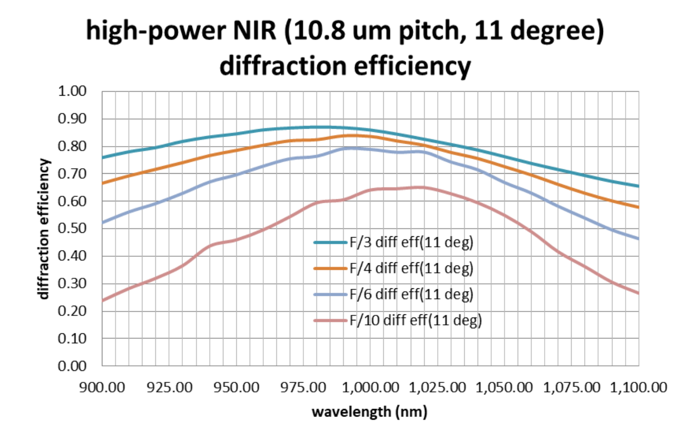
DMD 10.8 um Mirror Pitch Diffraction Efficiency vs Wavelength



Efficiency of DMD peaks near @ 1064nm

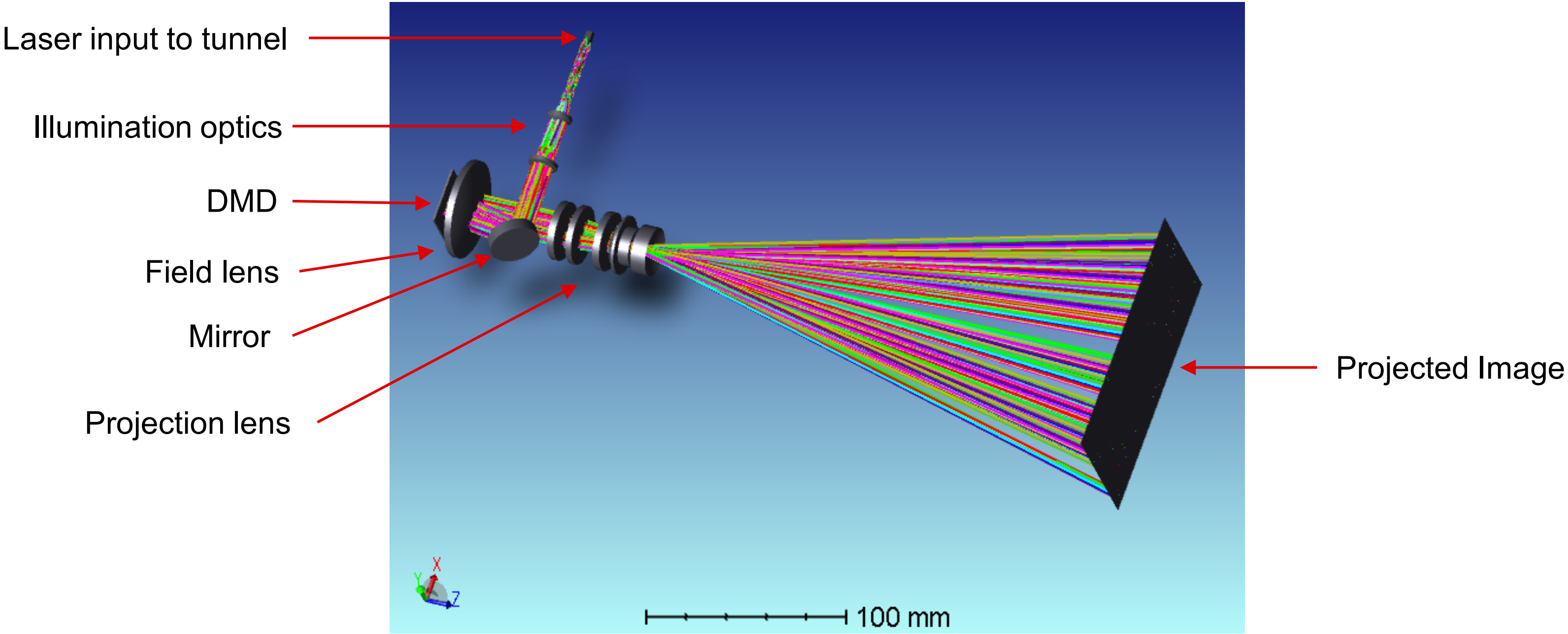


Mirror tilt angle +1 deg tolerance



Mirror tilt angle -1 deg tolerance

Design Layout



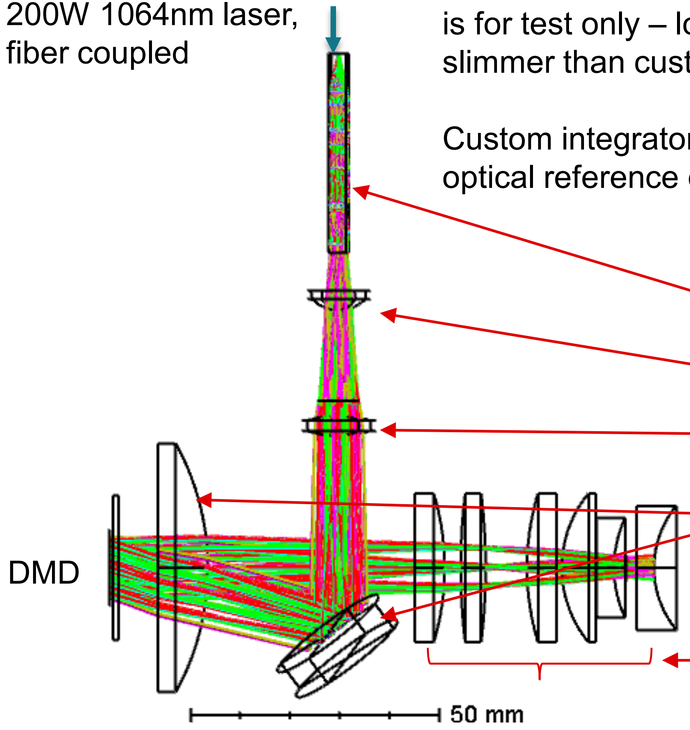
- 1064nm laser fiber output coupled to the integrator rod.
- Design file: FieldLensIllumf7-PrototypeWithCatalogLenses-RefDesign.zar

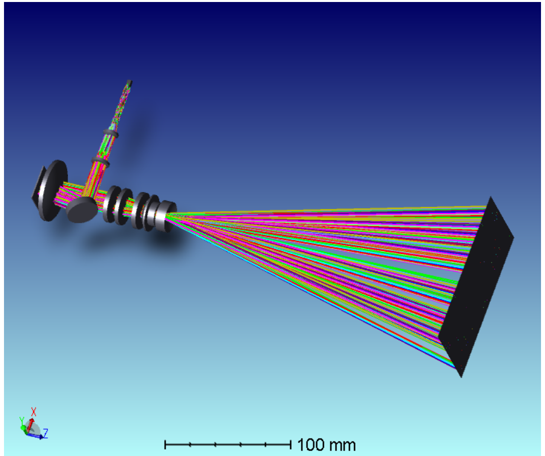
Off-the-Shelf Optics

200W 1064nm laser, fiber coupled

The off-the-shelf integrator rod is for test only – longer and slimmer than custom rod.

Custom integrator rod: see optical reference design.





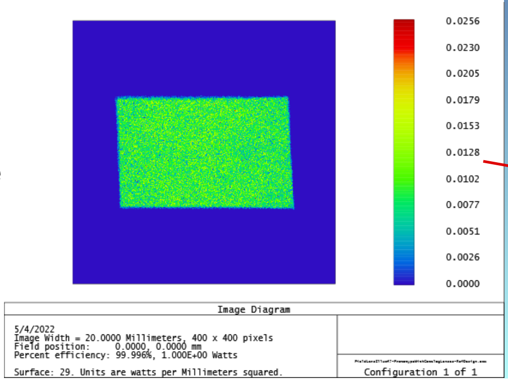
Items	EO Stock#	Specs	Single Unit Cost ($)
Integrator rod	63-080	2*2*50 mm, BK7	114
Relay lens 1	67-509	D12.7*4 mm, BK7	40
Relay lens 2	67-633	D15*4 mm, BK7	40
Folding mirror	34-830	D25.4*6.35 mm, BK7	125
Field lens	67-583	D50*10 mm, BK7	60
P-lens-1	48-786	D30*6 mm, BK7	50.5
P-lens-2	67-664	D30*5 mm, BK7	50.5
P-lens-3	67-572	D30*6 mm, BK7	50.5
P-lens-4	67-567	D30*6.9 mm, SF11	52
P-lens-5	67-996	D20*3.5 mm, SF11	39.5
P-lens-6	67-999	D25*3.5 mm, SF11	40.5

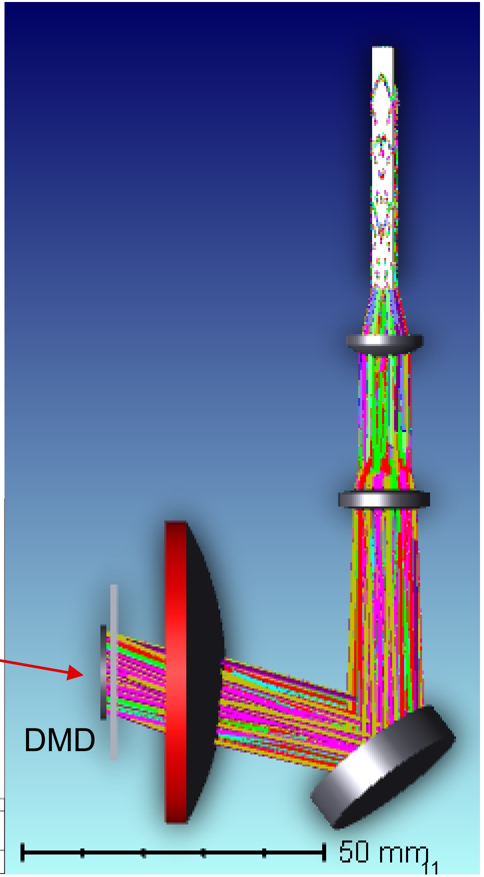
Search stock# at www.edmundoptics.com for details including ZMX and CAD files

Design Details

Illumination Design

- Custom integrator rod dimension:
  - 2.3*3.6*40 mm
  - For smaller footprint on DMD (0 overfill with tolerance), shrink the size of 2.3*3.6 mm
  - For better homogenization/uniformity, increase the length of the rod
- Incident angle to DMD: 24°, corner illumination
- Illumination footprint on DMD:
  - 0 overfill as designed.
  - Consider smaller rod exit size for tolerance margin
- Edmund optics stock #:
  - See slide #9





TEXAS INSTRUMENTS

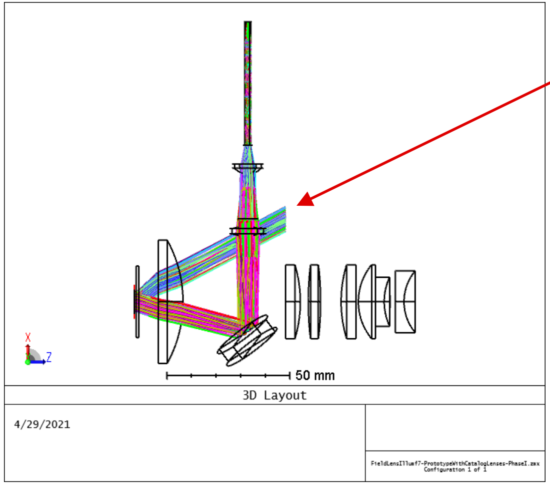
Design Architecture Selection and Notes

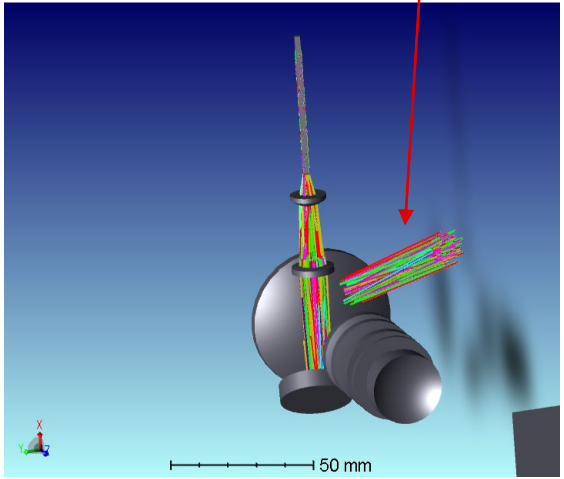
- TI chose a field lens architecture for prototype
  - Primarily due to low cost off-the-shelf prototype requirement. It also has compact size benefit
  - Other architectures can be used, see options in slides 19~29
  - Some architecture, e.g., TIR prism architecture, has better stray light performance, with higher cost and larger optical size
- f/# selection for illumination and projection lens
  - Small laser Etendue allows slow illumination f/# with simpler, lower cost illumination optics;
  - Projection f/# is recommended to be faster than illumination f/# to accommodate DMD mirror tilt variation, to capture more DMD diffraction orders resulting in higher efficiency
- DMD illumination overfill: ~0 percent
  - At high optical power, overfilling the DMD active mirror array with illumination light will create additional heat and impact the DMD lifetime
  - Underfilled illumination will reduce the number of usable DMD pixels, but helps alignment tolerance.
  - Consider careful trade-offs when underfilling the mirror array with illumination light

Design Architecture Selection and Notes (Continued)

- Off state light dump capture
  - Off state can have very high power and needs to be captured by beam dump
  - For field lens design, off-state path see slide 14
  - Best practice to determine where the off state light goes and capture that light in a controlled way
  - Recommend a heat sink or other thermal mitigation accommodation on the beam dump depending on optical power level used in the application
- AR Coating waveband recommendation and red pilot laser alignment comments
  - V-coating for 1064 nm can achieve best transmission at low cost
  - If red pilot laser alignment is needed, consider covering the visible red wavelength in the AR coating specification for the optics
  - If using a field lens design, analyze and minimize illumination reflections from the curved surface of the field lens (source of possible ghost reflection)
- High optical power handling
  - Optical element heating – integrator rod is having the higher power density.
  - Coatings and Opto-mechanics must withstand high flux load
  - DMD must be kept to temperature according to DMD specification

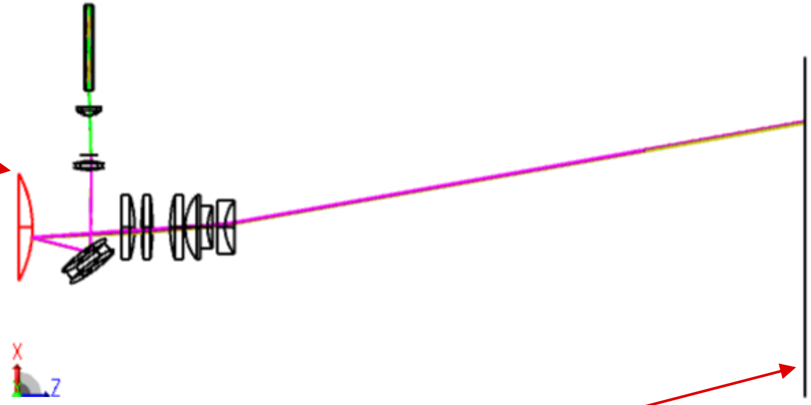
Off-state Needs to be Absorbed by a Cooled Beam Dump

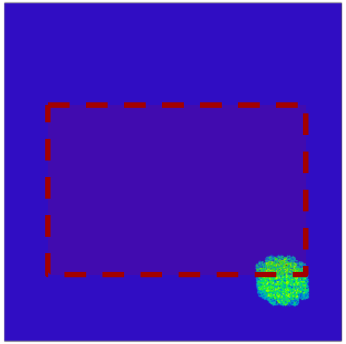




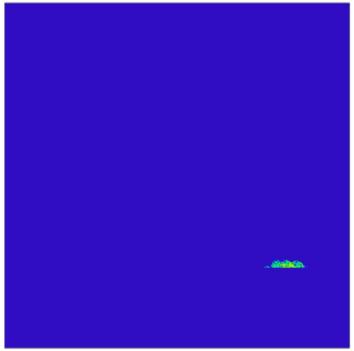
Field Lens Ghost Reflection

- Ghost reflection source:
  - Non-perfect AR coating of the curved surface of the field lens
- Impact:
  - Lower contrast at a corner of the effective pixel area
  - Ghost intensity depends on AR coating reflectivity, e.g., 0.4% reflectivity gives ~250:1 contrast
- Ghost mitigation:
  - Minimize reflectivity of the surface: v-coating can have good performance
  - Shift the surface position to push the ghost out of the effective area, e.g., by lens offset





Full ghost reflection on screen plane

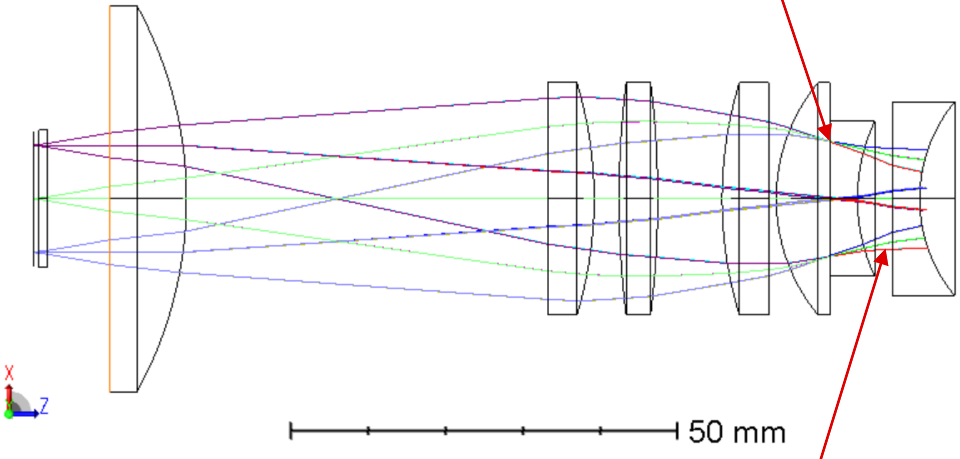


Ghost within effective pixel area

Projection Lens Design

- f/3-f/7
  - Designed at f/3, can be stopped down to f/7
- Element count: 7
  - All lenses are from Edmund optics
  - Lens stock # from left to right:
    - #67-583; #48-786; #67-664; #67-572; #67-567; #67-996; #67-999
- Throw Ratio: 2.1
  - Image size: 128 mm x 80 mm @ 270 mm throw distance
- Distortion: 5.6%
- MTF>50% all fields @Nyquist frequency

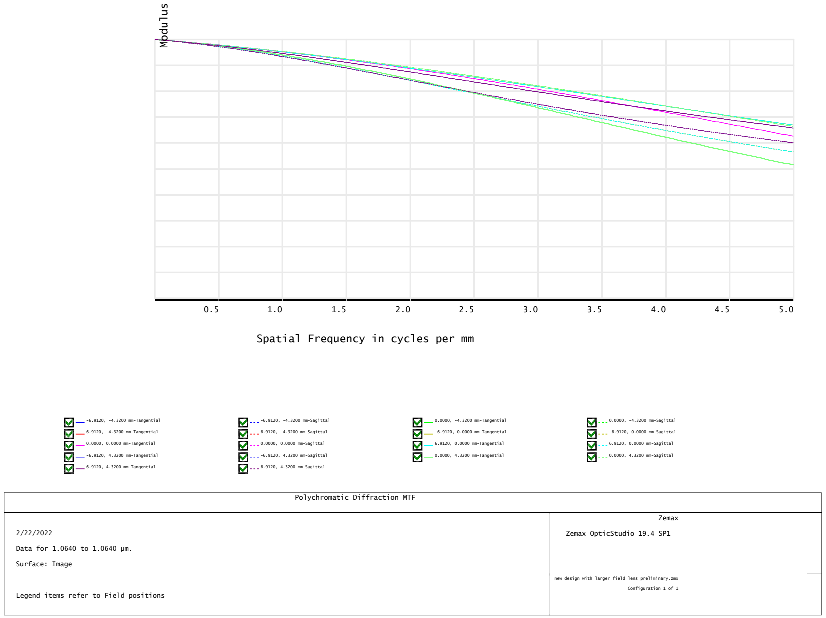
Aperture stop location in Zemax Design



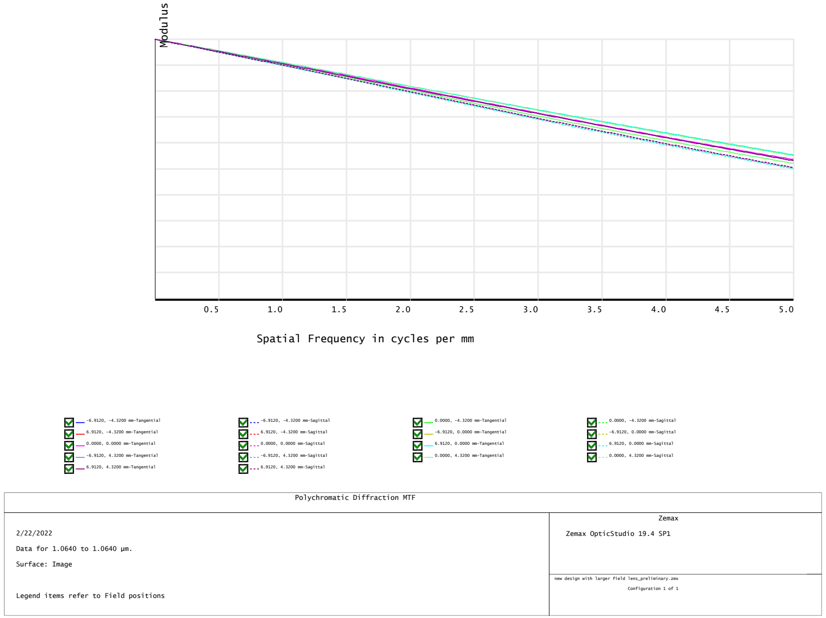
Note: Due to mechanical constraints, the physical stop aperture was placed here

Projection Lens: MTF Plot

MTF@f/3

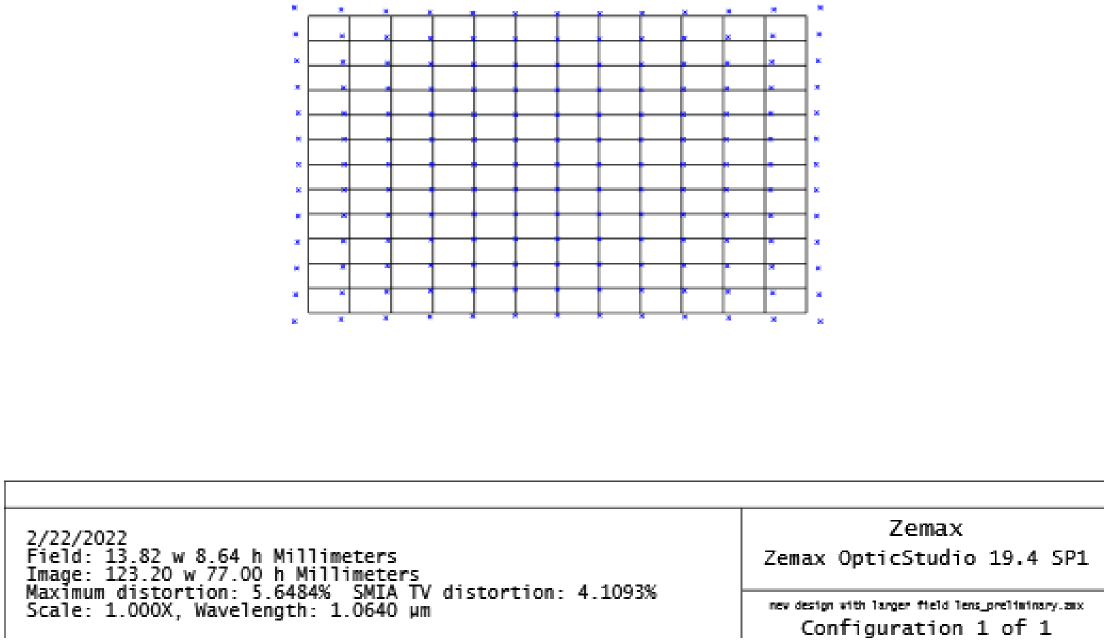


MTF@f/7



Projection Lens: Distortion Plot

Distortion: 5.6%

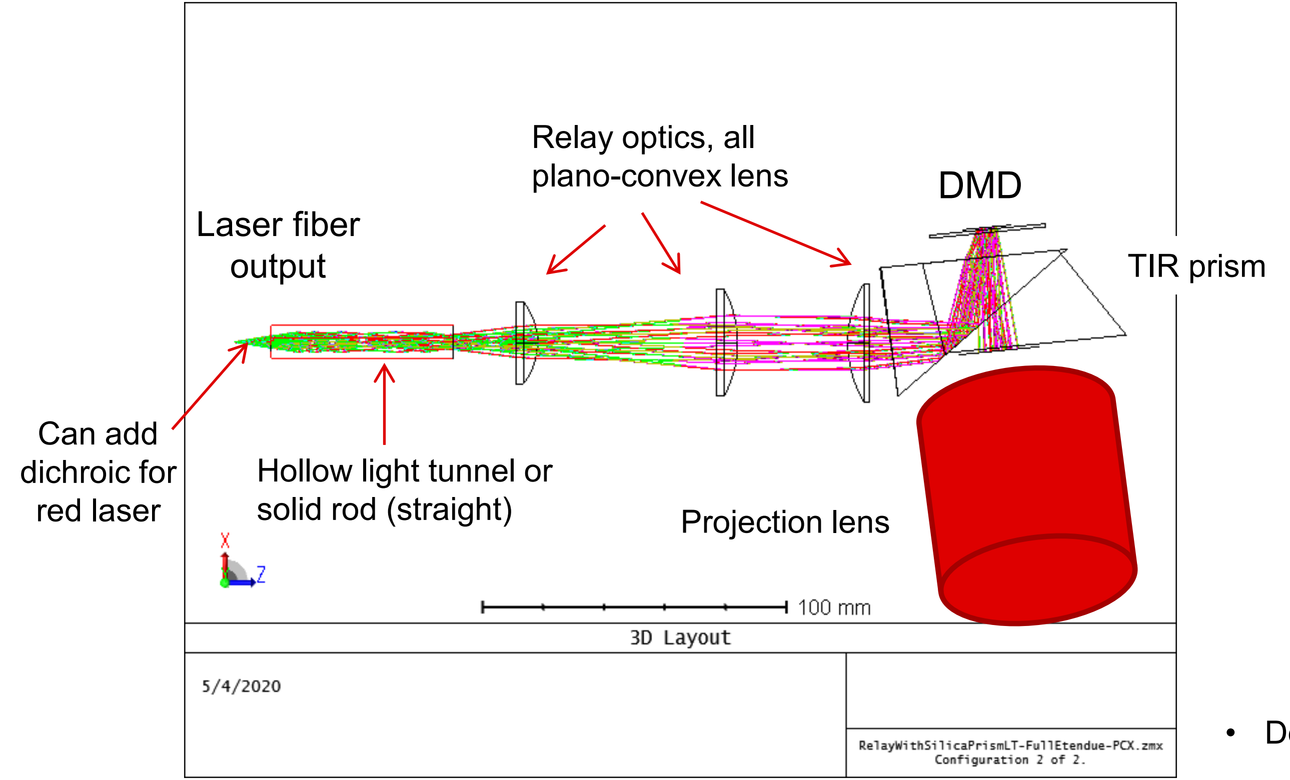


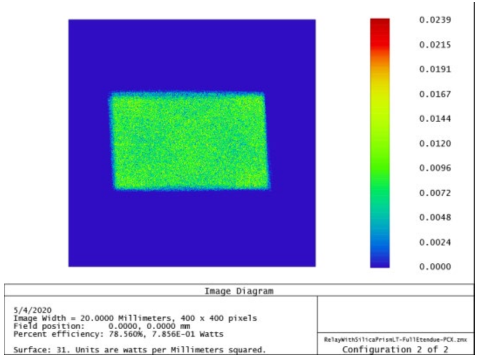
Projector Design Architecture Options for NIR

Option 1: TIR Prism Architecture

Allows f/2.4 system f/#, widely used in projection

TIR Prism Illumination Optics (f/2.4)

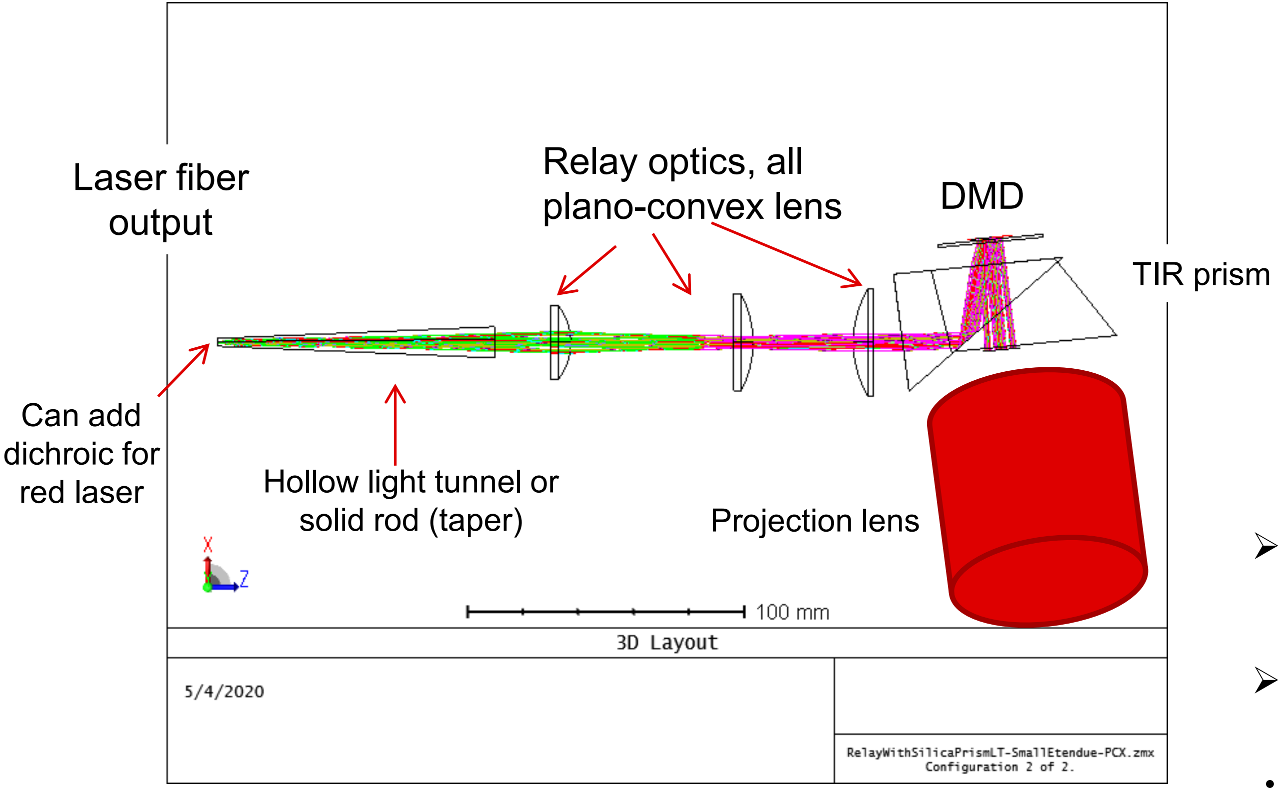


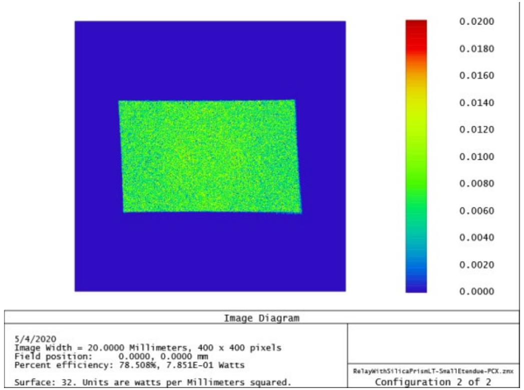


Illumination on DMD active mirror array. 0% overfill.

- Design file: d65NIR-TIRf2d4.zar

TIR Prism Illumination Optics (f/7)



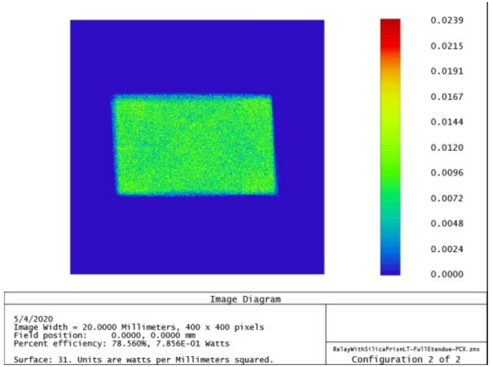


Illumination on active array
0% overfill

- Reused relay optics and TIR prism, likely also projection lens, with simple mechanical change.
- Light tunnel needs to change (relatively easy)

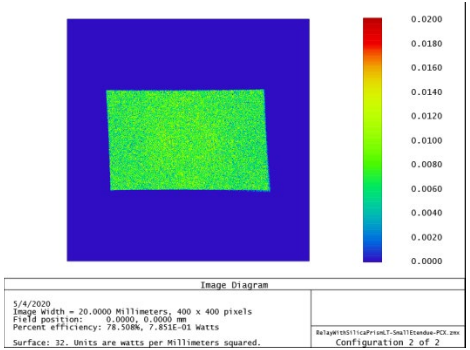
- Design file: d65NIR-TIRf7.zar

Comparison: f/2.4 vs. f/7 Illumination optics



f/2.4

f/7

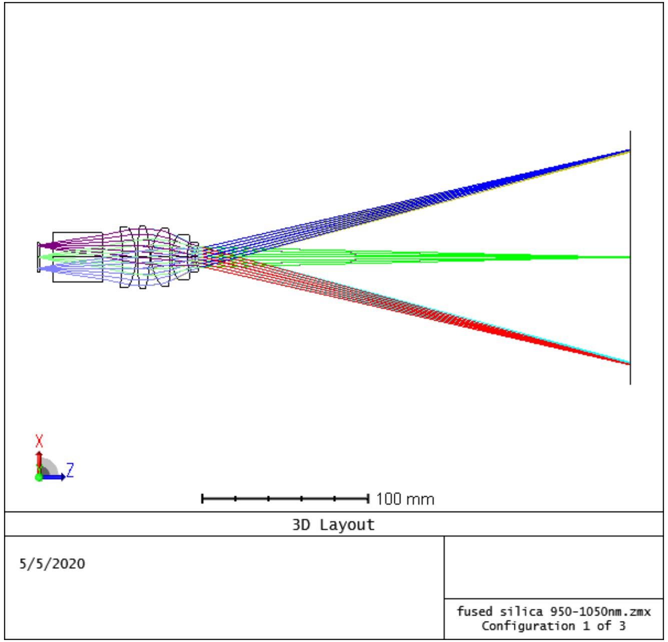


- Shorter tunnel length needed to create uniform light output at tunnel exit
- Some cases may need the large Etendue (e.g., with diffuser for speckle reduction)
- Larger optics, higher cost to manufacture

- Much sharper image – low power loss.
- Projection optics cost reduction – can be significant
- Requires longer tunnel length to create uniform light output at tunnel exit

- Note: Possible to use a non-rectangular tunnel (parallelogram) to reduce slanted illumination image on the DMD

Example f/2.4 Telecentric Projection Lens



DMD	.65 WXGA
Projection distance	263 mm@ 975 nm
Image size	128*80 mm
f/#	2.4
Wavelength	Nominal: 975 nm; 950~1150 nm with refocus
MTF	>60% @ 975 nm; >58% @950 nm; >63% @1050 nm >50% @1150 nm
Distortion	6.2%
Back working distance	DMD - 0.703 air - 1.05 cover glass - 8 air - 30 Fused Silica - plens

- Prism and Lens material all Fused Silica

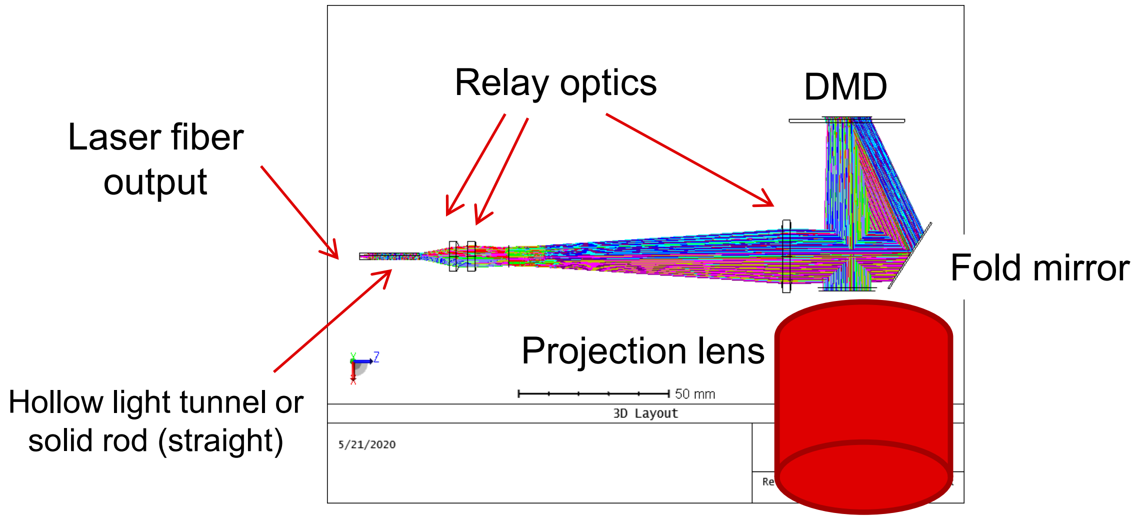
Option 2: Prism Free Architecture

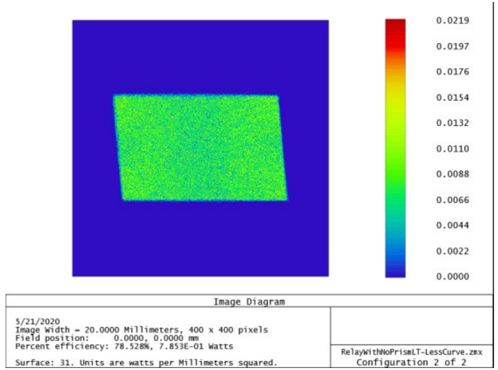
Simple and low cost optics

High system f/# required to avoid interference between illumination and projection beams

Illumination at f/14, projection can be f/8~f/5.

Prism Free Illumination Optics (f/14)





Illumination on active array.
0% overfill

- ➢ No TIR prism in design
- ➢ Illumination smaller due to high f/#
- ➢ Beam homogenizer (light tunnel or solid rod) is small

- Design file: d65NIR-NoPrismf14.zar

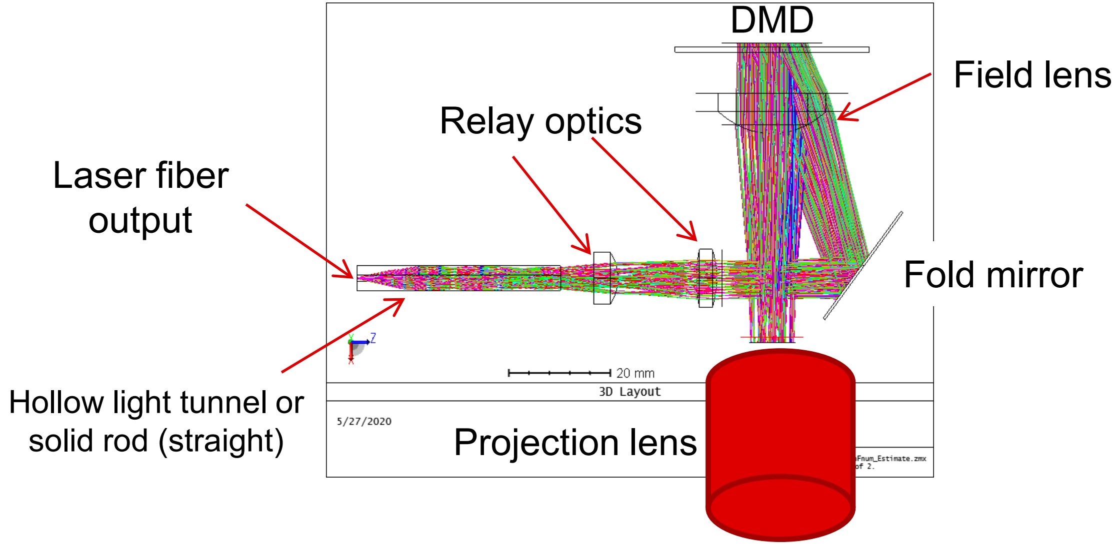
Option 3: Field Lens Architecture

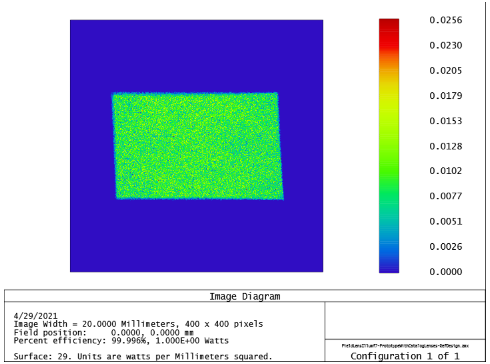
Smallest form factor, simple optics

Illumination and projection can allow faster f/# (e.g., f/3).

Ghost reflection from field lens may show in off state of projected image

Example field lens Illumination Optics (f/7)





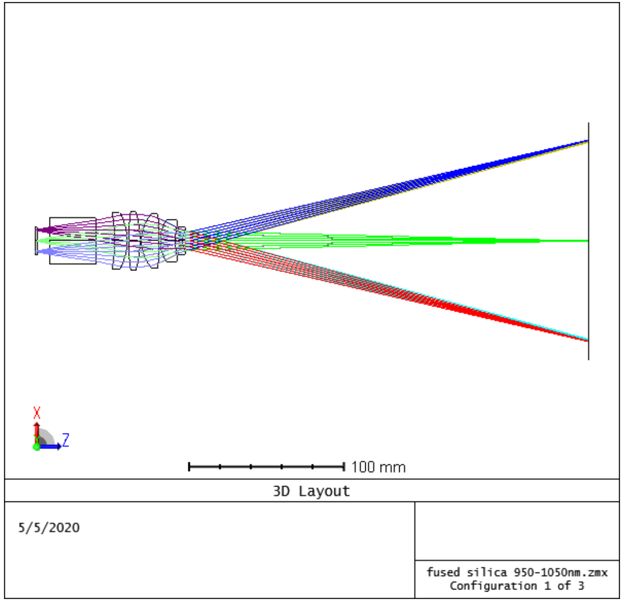
Illumination on active array.
0% overfill

- No TIR prism in design
- Field lens in both illumination and projection optical paths
- Illumination is smaller

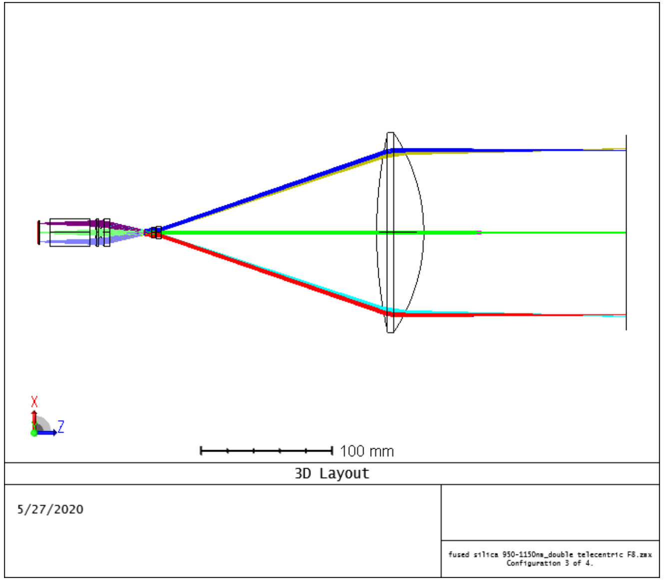
- Note: Ghost reflection from curved surface of field lens may show in off state of projected image. This ghost image will either need to be mitigated in the design or analyzed for acceptability for use case
- Design file: d65NIR-FieldLensf7.zar

Texas Instruments

Projection Lens: Telecentric vs. Double Telecentric



- Traditional f/2.4
- Image size changes with focus



- Double telecentric f/8
- Last lens before image is larger than the projected image
- Image size does not change with focus