# 0.47” Single Spring Tip (SST) DMD Optical Reference Designs

**Rev. A**

# Important Notice

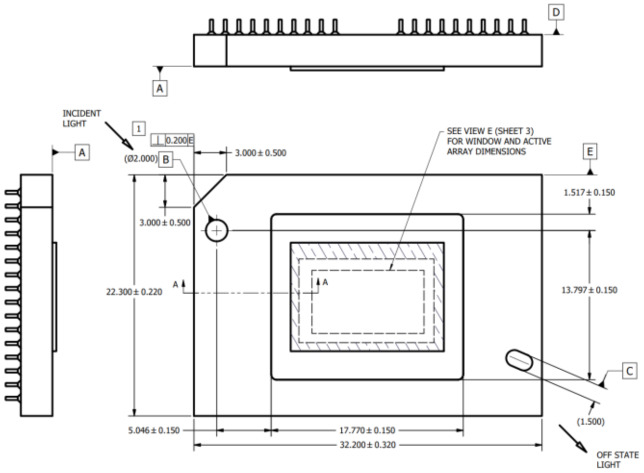
- All optical files were created with Zemax Opticstudio version 23.1
  - Please use the .zar archive file which includes all glass catalogs, user-defined surfaces/apertures, analysis IMA files, etc. necessary to open the file as designed

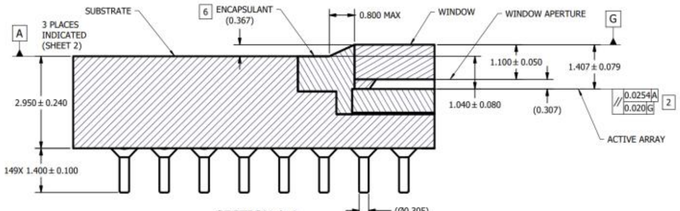
- For older versions of Zemax, please open the .zmx file
  - Some functionality will be limited
  - Custom surfaces and glass materials among other items may be lost
  - We encourage you to download the latest Zemax version and open the .zar archive file

- The following designs are to provide customers example references of several optical configurations for the 0.47” DMD. Variations of these configurations may be possible but it is up to the customer to make tradeoffs to achieve their own target specs.
  - *Note: designs may include illuminator but mostly demonstrate the illumination relay optics only. Projection lens not included*.

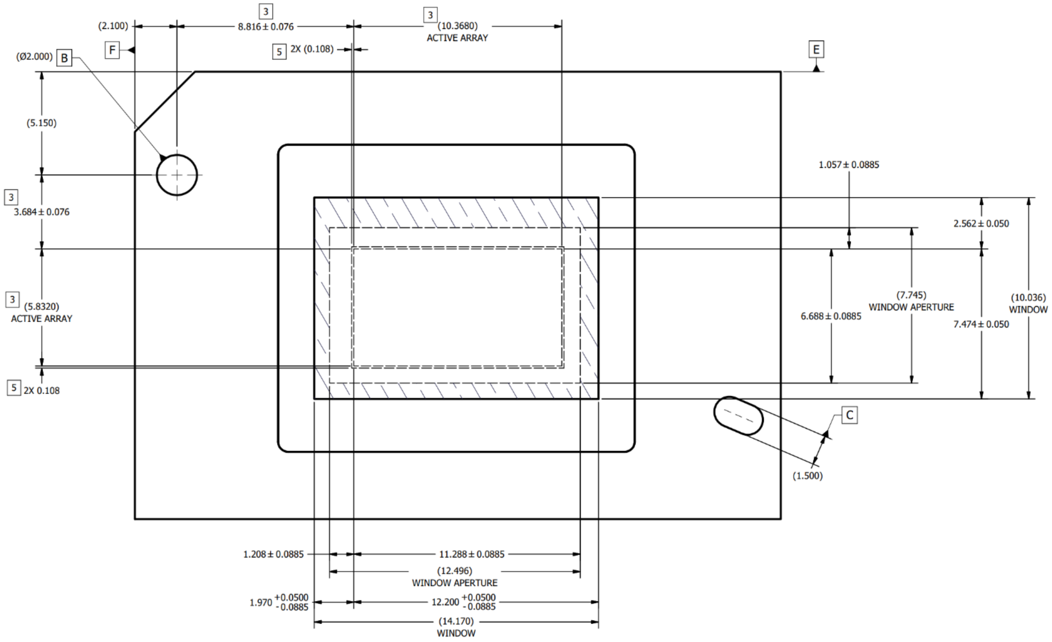
# 0.47" HSSI SST s453

## refer to mechanical ICD/datasheet for complete drawing




SECTION A-A
SCALE 20 : 1




Active Array: 10.368mm x 5.832mm
Window Thickness: 1.100mm
Window to Array: 0.307mm

# TIR prism–based Optical Reference Design

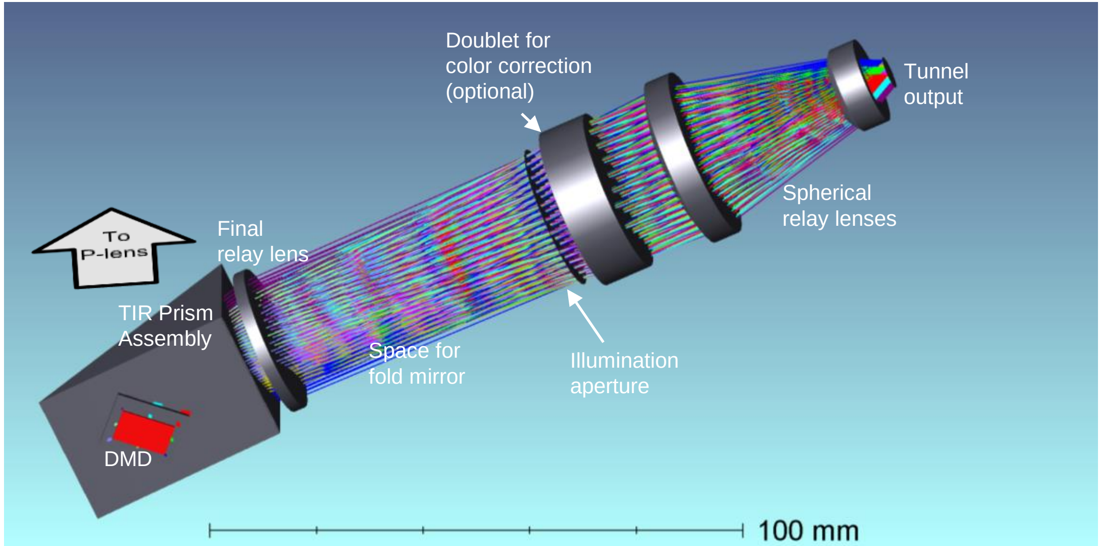
**Relay Optics: Tunnel to DMD**

**Illuminator & Projection Lens not included**

# Discussion

- The following reference design shown is for 0.47” SST DMD using an s453 package
  - 14.5° mirror tilt, corner illumination
  - 10.368mm x 5.184mm array size
- The following design shows an example of an illumination optical design using a light tunnel as the homogenizer and a TIR (total internal reflection) prism
  - Tunnel output modeled only, must determine length when incorporating the illuminator for best homogenization
  - TIR prism typically has higher contrast than RTIR (right angle prism) architectures
  - TIR prism requires a tight airgap (~5-10µm) in the projection path between the two prisms to minimize affect on projection lens MTF image quality
    - This requires precise assembly and may impact cost
- Design example is for F/2.0 illumination @ 30° angle of incidence compared to typical 29° (2x mirror tilt)
  - This extra 1° helps maximize the contrast at expense of very minimal light loss by creating more pupil separation as well as accounting for mirror tilt tolerance
  - Customer can make their own tradeoff on efficiency and contrast
- TIR prism angle is critical in 14.5° mirror tilt DMDs due to a back reflection in the TIR airgap that can enter the pupil after reflection from off-state mirrors and degrade image contrast
- Further optimizations and trade-offs of the design may be possible

# TIR Prism Illumination Design Layout

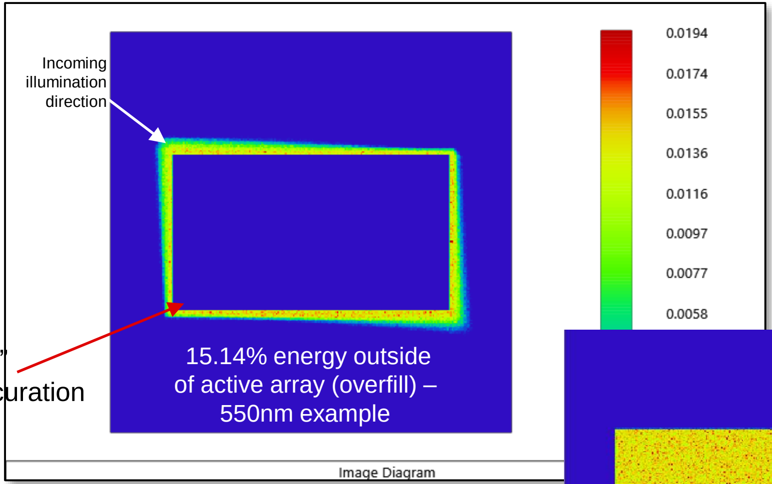



Refer to Zemax file: *p47SST_TIR relay.zar / .zmx*

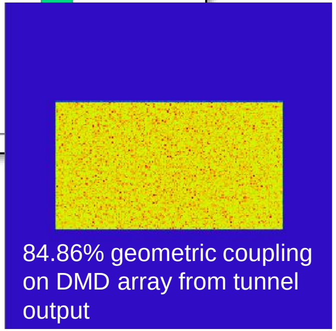
- Light tunnel parameters:
  - ±28° light cone output
  - Output aperture: 5.40mm x 3.18mm
- Telecentricity:
  - Chief rays ≤±0.5°
  - Larger variation in chief ray angles may result in reduced efficiency as well as flat state contributed contrast degradation
- Additional comments:
  - Spherical lenses can be replaced with aspheres to reduce lens count
  - Doublet is optional for color correction and equal overlap across all wavelengths (more efficient)
  - Final relay lens sometimes can be glued onto input of TIR prism
  - TIR prism material is N-BK7 for lowest cost
  - TIR prism angle selection is critical (see slides 8-9)

# Performance

## Illumination on 0.47" DMD active array

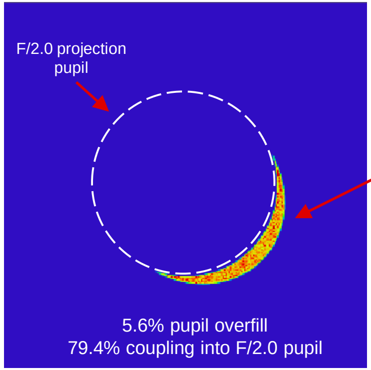



0.47" obscuration




*Note: Tunnel output can be shaped like a parallelogram to inversely correct the distorted illumination edges to be rectilinear*

## Far-field F/2.0 pupil

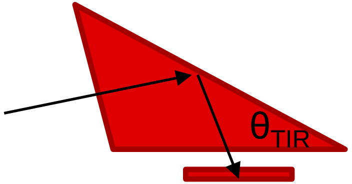



Pupil overfill / stretching due to anamorphism

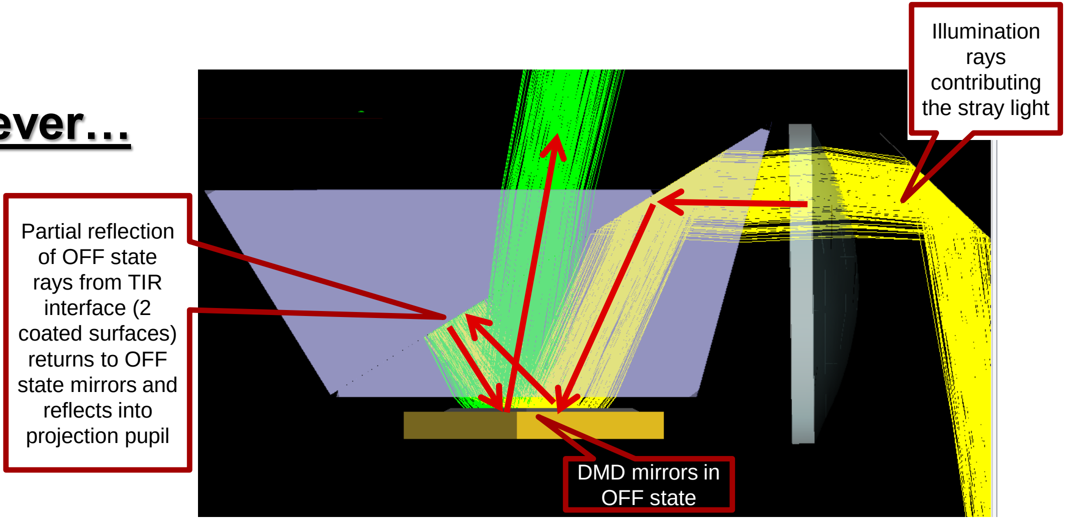
No illumination aperture

*Recommend to use illumination aperture (elliptical or 'cat's eye') to remove this excess light to avoid any potential stray light artifacts. (Refer to surface 9 in Zemax file for aperture design example)*

# Prism angle selection critical for 14.5° mirror tilt DMD




**However…**



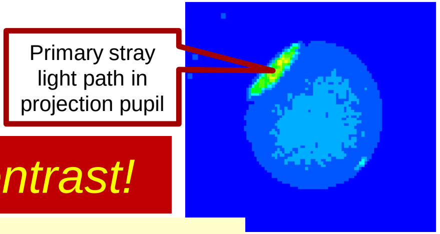

## TIR prism angle calculation for F/2.0 light cone in N-BK7

$$Prism\ material \rightarrow n_C = 1.51432$$

$$\boldsymbol{\theta_{critical}} = \sin^{-1}\left(\frac{n_1}{n_2}\right) = \sin^{-1}\left(\frac{1}{1.51432}\right) = 41.33°$$

$$\boldsymbol{\theta_{half\ cone\ in\ glass}} = \sin^{-1}\left(\frac{n_1}{n_2}\sin(\theta_{half\ cone})\right) = \sin^{-1}\left(\frac{1}{1.51432}\sin(14.5°)\right) = 9.52°$$

$$\boldsymbol{\theta_{TIR}} = \theta_{critical} - \theta_{half\ cone\ in\ glass} = 41.33° - 9.52° = 31.8°$$



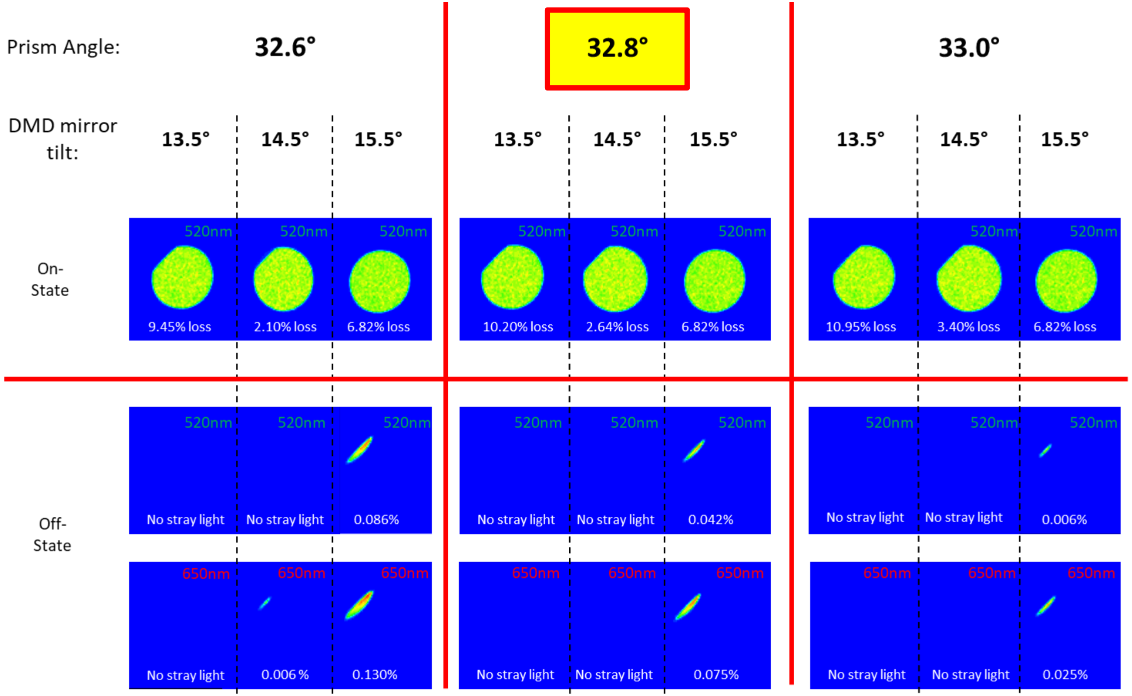

*This will affect image contrast!*

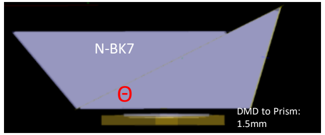
Solution: Slight efficiency or Etendue (F/#) tradeoff for contrast (next slide)

# Prism angle selection critical for 14.5° mirror tilt DMD

*Analyzed for F/2.0 at 29° uniform illumination*

*Note: no loss occurs for incoming illumination bundle- 100% TIR*




Analyzed using 2% reflectance coating on prism airgap surfaces. All other surfaces 100% transmission. – Worst case offstate energy w/in projection pupil indicated above.

**Best compromise to Cost (due to size) and Performance is adjustment to TIR angle of ~1°**

# Non-Telecentric Optical Reference Design

**Relay Optics: Tunnel to DMD**

**Illuminator & Projection Lens not included**

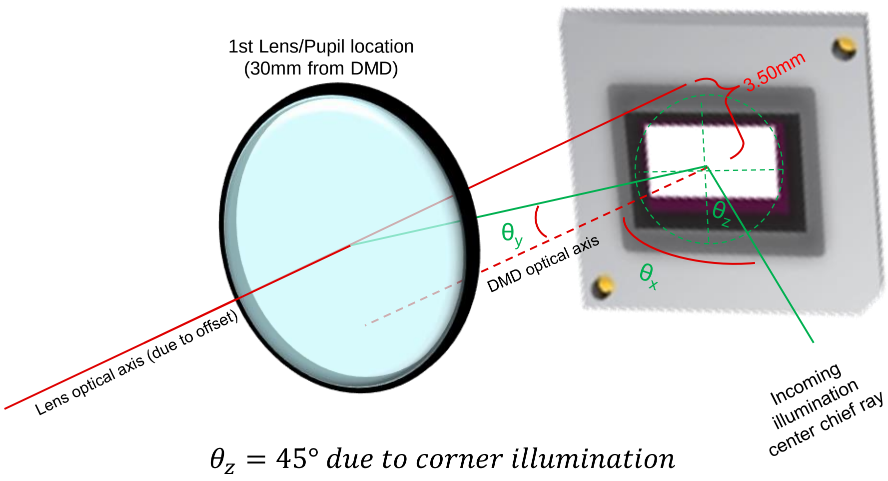
# Discussion

- The following reference design shown is for 0.47” SST DMD using an s453 package
  - 14.5° mirror tilt, corner illumination
  - 10.368mm x 5.184mm array size
- The following design shows an example of an illumination optical design using a light tunnel as the homogenizer and non-telecentric optics (prism-less)
  - Tunnel output modeled only, must determine length when incorporating the illuminator for best homogenization
  - Non-telecentric requires the exit pupil size and location of the illumination to match the entrance pupil size and location of the projection lens
  - Illumination angle onto the DMD must incorporate the pupil location as well as any projection image offset
  - Incoming illumination light bundle onto DMD may interfere with reflected light bundle on its way to the projection lens
    - It is common to have a cut-out in the illumination lens which sacrifices some efficiency but allows for a compact, prism-less lens
  - Non-telecentric is commonly a low-cost architecture and thus fewest number of lenses were used. Aberrations are more prevalent in the DMD illumination profile as well as the pupil illumination profile and thus efficiency coupling and uniformity performance is somewhat reduced. This can be further optimized with additional lenses if desired.
- Design example is for F/2.0 illumination
  - Higher F/# (i.e. F/2.4) is possible and may improve illumination design performance
- Further optimizations and trade-offs of the design may be possible

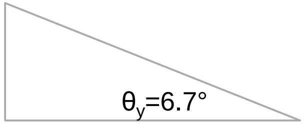
# Non-Telecentric Illumination Angles

- Center chief ray illumination angle on DMD is a function of:
  - DMD active array
  - DMD illumination direction
  - DMD mirror tilt angle
  - Projection image offset
  - Projection pupil position

- Calculation at right represents the reference design and assumes the following:
  - 0.47” 1080p s453 (10.368mm x 5.832mm)
  - Corner illumination – 45° rotation w.r.t. DMD array
  - 14.5° mirror tilt
  - 120% vertical image offset only
  - 30mm pupil location




$$\theta_z = 45° \; due\ to\ corner\ illumination$$

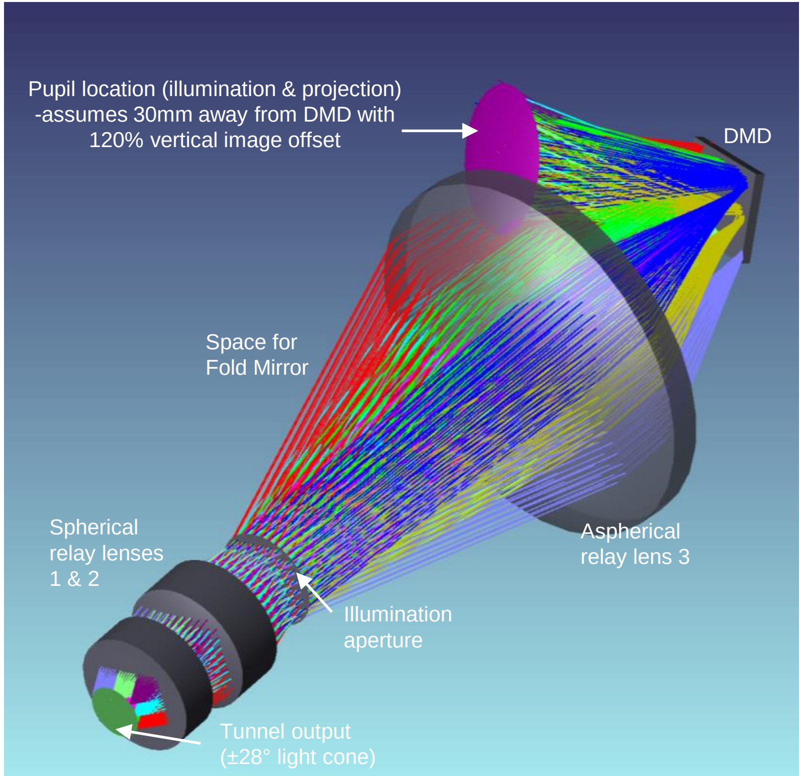



$$\boldsymbol{Illumination\ angle \approx 2 \times mirror\ tilt + \theta_y \approx 2 \times 14.5° + 6.7° \approx 35.7°}$$

Note: This may cause a decenter of the pupil along the horizontal x-axis. Can add an x-component ($\theta_x$) to the incoming illumination angle if horizontal centration is desired.

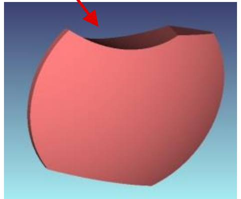
Recommend to add chief ray solves to the pupil decenter in Zemax to optimize more accurately.

# Non-Telecentric Illumination Design Layout




- Light tunnel parameters:
  - ±28° light cone output
  - Output aperture: 5.40mm x 3.18mm

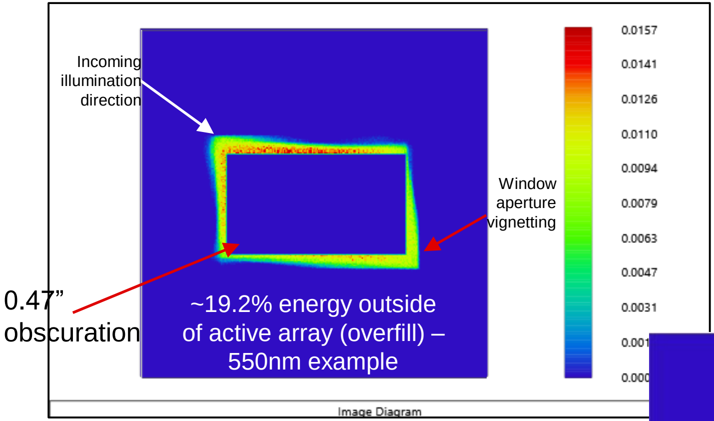
- Important notes about non-telecentric design:
  - Architecture is designed for low cost as most non-telecentric architectures are and thus distortion and chromatic aberration correction is at a minimum.
  - Relay lens 3 commonly interferes with pupil location and thus during molding of such part, a notch/cut-out is common which minimizes interference with projection lens at a minimal impact to efficiency due to the pupil's location.
    - Efficiency on next slide do not take this into account



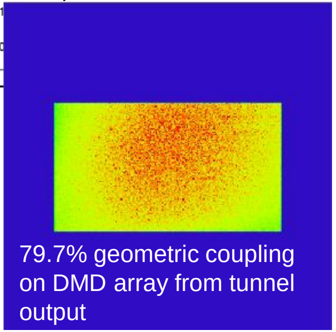
Refer to Zemax file: *p47tunnel2DMDrelay_f2nontele.zar /.zmx*

# Performance

## Illumination on 0.47” DMD active array

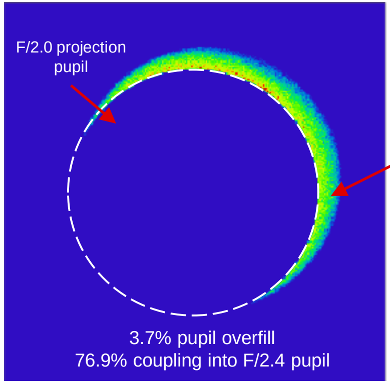



*Note: illumination overfill in non-telecentric is commonly not sharp distorted, and typically higher than telecentric illumination. The ‘tails’ at top-left and bottom-right (along the direction of illumination) can be compensated for with a non-rectangular, parallelogram-shaped tunnel. This can be important when considering incident heat on the DMD window aperture.*




Uniformity is commonly compromised in non-telecentric architectures

F/2.0 pupil at 30mm distance from DMD




Pupil overfill

Can use illumination aperture to eliminate the pupil overfill which can potentially cause scattering within the projection lens and lower contrast. Must be careful not to cut into efficiency.

# TIR prism-based illumination using F/# overdrive optical reference design

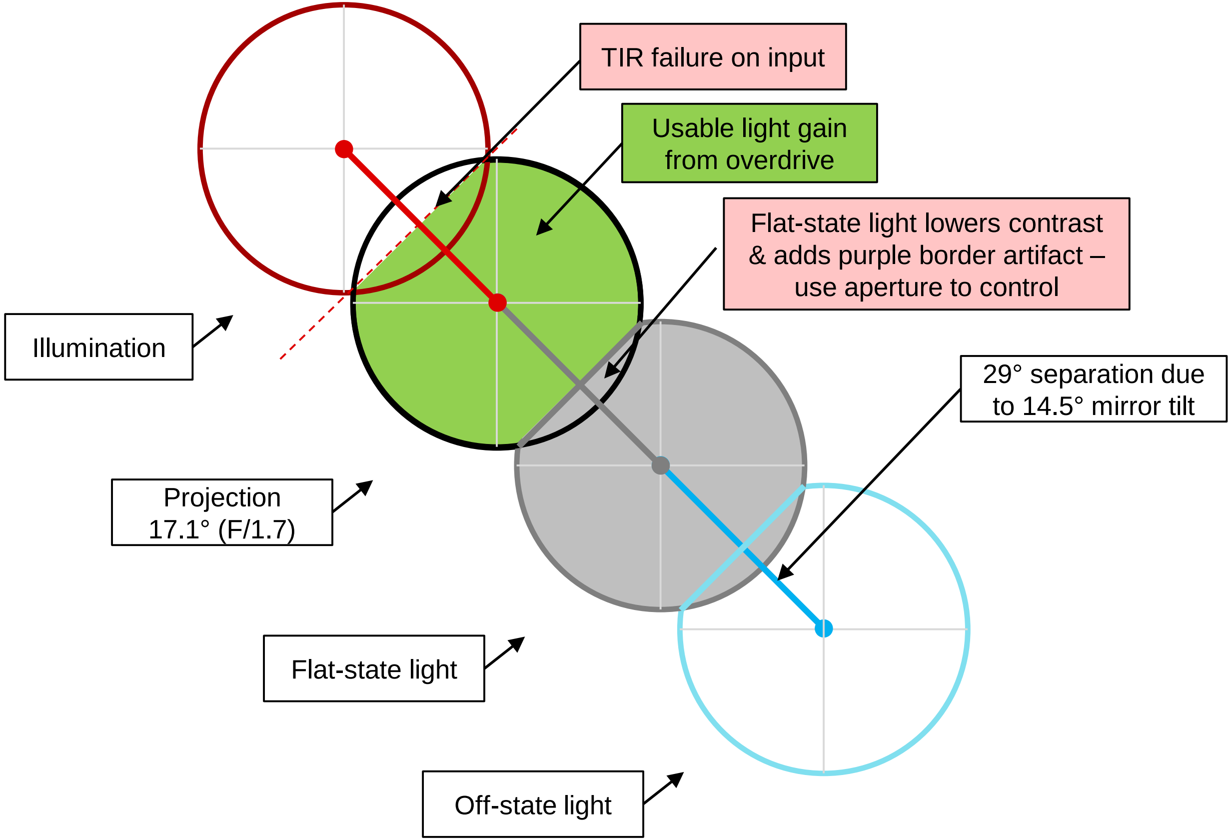
**Relay Optics: Fly's eye array (FEA) to DMD**

**LED illuminator included**

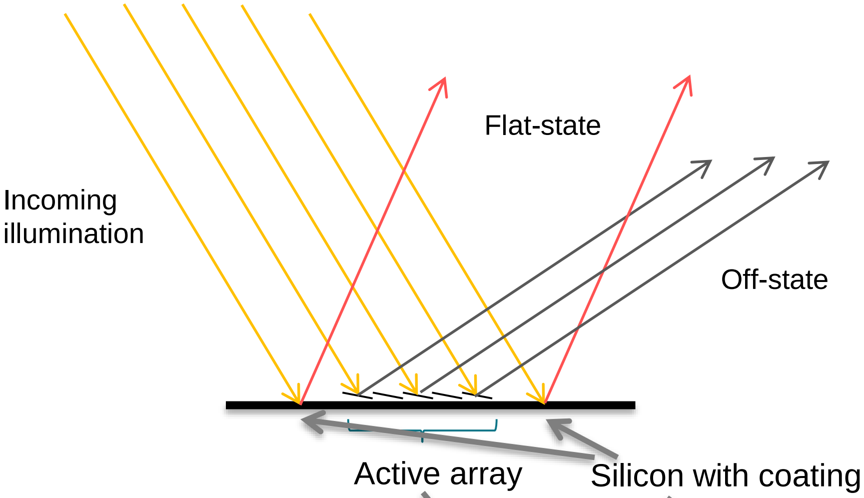
# Discussion

- The following reference design shown is for 0.47” SST DMD using an s453 package
  - 14.5° mirror tilt, corner illumination
  - 10.368mm x 5.184mm array size
- Illumination F/# overdrive concept (see slide 17 for pupil diagrams)
  - Light collection angle (faster F/#) is increased beyond 2x the DMD tilt angle in order to increase the brightness of the projector
  - This causes flat-state light pupil overlap with the projection pupil and results in degradation of image contrast and potential for flat state light artifacts unless properly mitigated
- The following reference design has these illumination architecture attributes:
  - 4-channel LED configuration
    - 3-channel configuration is also possible, in-line dichroic or x-plate configuration
    - Design can be modified for different LED sizes than reference example
      - Designer must be mindful of any possible Etendue mismatches
  - Fly’s eye array homogenizer
    - Common in LED systems for compactness
    - Designed can be modified to accommodate a light tunnel if retrofitting to an existing optical engine
  - TIR prism: commonly used due to lower cost optical material (i.e. N-BK7)
    - Best for contrast and pupil vignetting in illumination F/# overdrive architectures
- Further optimizations and trade-offs on size, cost, performance may be possible

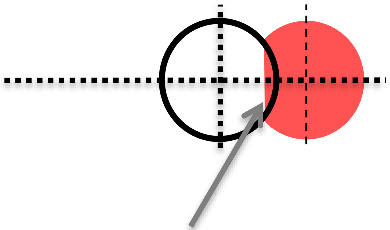
# Illumination F/# Overdrive: Pupil Light Gain/Loss



# Illumination Overdrive Potential Flat-State Artifacts



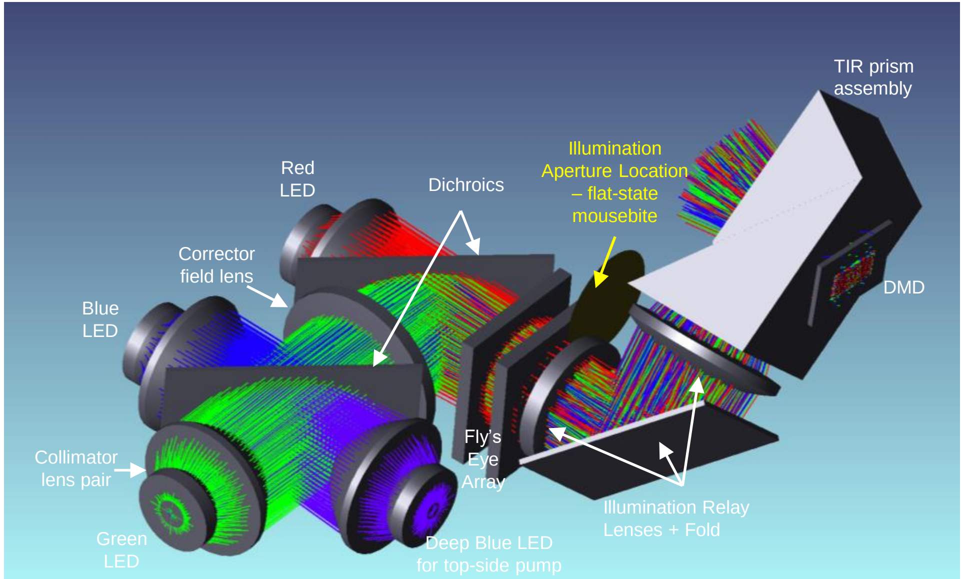

◆**When using large cone angle to increase the projector brightness, the flat-state light overlaps with on-state light in angular space, allowing flat-state light to go through the lens pupil and form a border.**



This is the area flat-state light can go through the projection lens and form color border.

Recommend to mask out area to prevent this flat-state light and artifacts. Trade-off between brightness gain from overdrive and contrast.

# Optical Design Layout




Refer to Zemax file:
*p47SST_using_4chLED_seq.zar / .zmx*

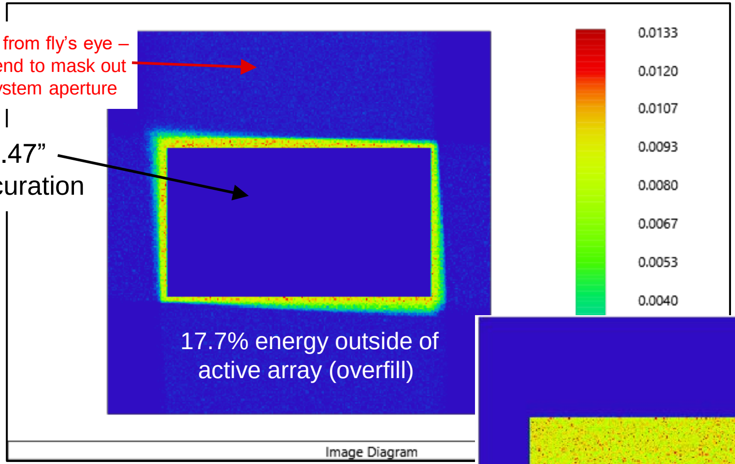
For file with non-sequential prism, refer to Zemax file:
*p47SST_using_4chLED_NSCprism.zar / .zmx*

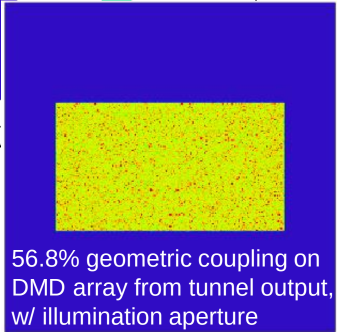
- Designed for P1 LED size: 3.35mm x 1.55mm
  - 4-channel illuminator example
- F/1.7 overdrive on a native F/2.0 (14.5° tilt) DMD
- Telecentricity of illumination at DMD:
  - Chief rays ≤±0.5°
  - Larger variation in chief ray angles may result in reduced efficiency as well as flat state contributed contrast degradation
- Additional comments:
  - Illuminator corrector field lens typically used to improve efficiency for green/blue channels
  - Fly's eye array can be separate glass plates or single double-sided part
  - Mousebite aperture recommended to reduce flat-state light in overdrive condition
  - Relay lenses are spherical for low cost with minimal color correction (different overfill per color) – can change lens material if needed
  - TIR prism material is N-BK7 for lowest cost
  - TIR prism angle set to 32.8° to avoid stray light affecting contrast (see slides 8-9)
  - File 2

# Performance

## *Green channel*

### Illumination on 0.47” array

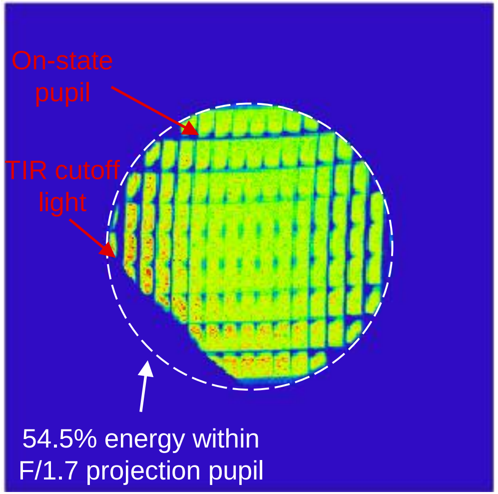



*<u>Red Channel</u>*
- *Energy overfill: 19.5%*
- *Geometric efficiency @ DMD: 59.8%*

*<u>Blue Channel</u>*
- *Energy overfill: 16.6%*
- *Geometric efficiency @ DMD: 58.4%*

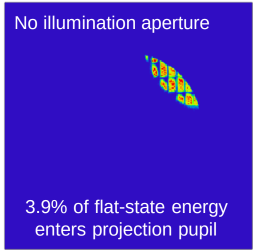
### Far-field pupil

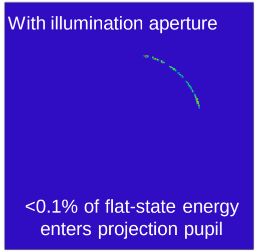



*<u>Red Channel</u>*
- *Energy within F/1.7 pupil: 58.9%*

*<u>Blue Channel</u>*
- *Energy within F/1.7 pupil: 56.4%*

*Illumination aperture is elliptical w/ mouse-bite to prevent flat-state from entering projection pupil. Minimize flat-state light artifacts from slide 18*

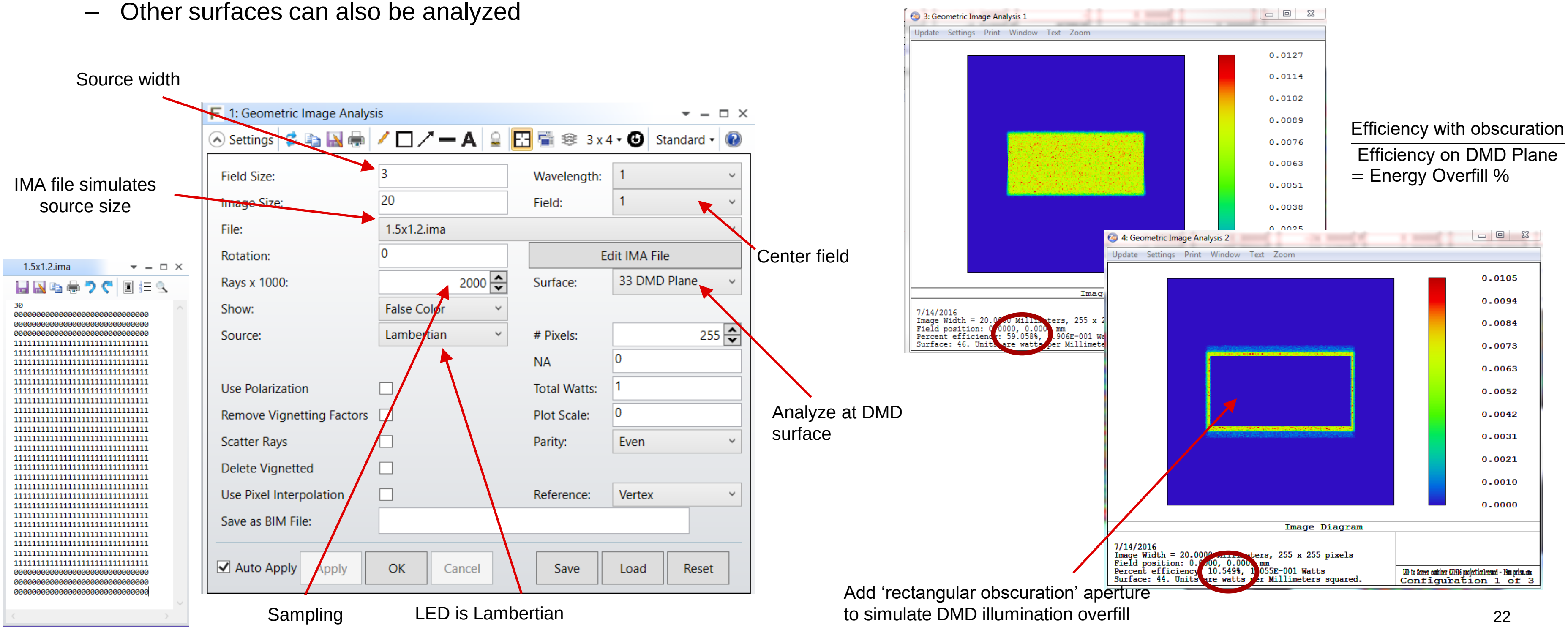


# Backup

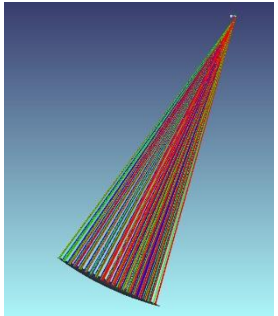
# Zemax Modeling Tip : Irradiance Analysis

- To model the illumination profile including overfill on DMD, use “Geometric Image Analysis”.
  - Other surfaces can also be analyzed



# Zemax Modeling Tip: Far Field Analysis

- Used to analyze F/# and pupil in telecentric systems



Lens Data Editor: Config 2/3

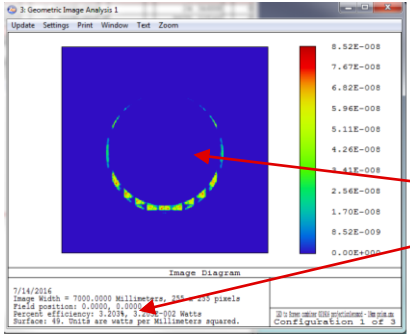
Edit Solves View Help

| Surf : Type | Comment | Radius | Thickness | Glass | Semi-Diameter | Conic | Par 0.. | Decenter X | Decenter Y | Tilt About X |
|---|---|---|---|---|---|---|---|---|---|---|
| 36 Coordinat.. | Center and AOI | | 0.00000 | – | 0.00000 | | | 0.0000 | -3.608 | -7.84786 |
| 37* Tilted | upper prism | | 5.00000 | S-BSL7 | 44.48146 | | | 0.0000 | 0.3840 | |
| 38* Tilted | | | 0.30000 | | 28.53285 | | | 0.0000 | 1.0000 | |
| 39* Tilted | Rt Angle Prism | | 7.00000 | S-BSM4 | 27.90523 | | | 0.0000 | 1.0000 | |
| 40* Standard | | Infinity | 1.00000 | | 27.83941 | 0.00 | | | | |
| 41* Standard | DMD Coverglass | Infinity | 1.10000 | EAGLEXG | 25.81214 | 0.00 | | | | |
| 42* Standard | | Infinity | 0.00000 | | 25.00227 | 0.00 | | | | |
| 43* Standard | window aperture | Infinity | 0.51000 | | 25.00227 | 0.00 | | | | |
| 44* Standard | DMD Obscuration | Infinity | 0.00000 | | 10.00000 U | 0.00 | | | | |
| 45* Standard | DMD apeture | Infinity | 0.00000 | | 10.00000 U | 0.00 | | | | |
| 46* Standard | DMD Plane | Infinity | 0.00000 | | 0.00000 | 0.00 | | | | |
| 47 Coordinat.. | | | 0.00000 | – | 0.00000 | | | 0.0000 | 0.0000 | 24.00000 |
| 48 Standard | | Infinity | 1.0000E+004 | | 24.36808 | 0.00 | | | | |
| 49* Standard | ffp | -1.000E+004 | -1.000E+004 P | | 9075.32540 | 0.00 | | | | |
| 50 Coordinat.. | | | 0.00000 | – | 0.00000 | | | 0.0000 | 0.0000 | -24.00000 P |

Add radius for solid angle (depending on distance set)

Set far-field distance

Illumination AOI (if analyzing DMD far-field)




Circular obscuration to match F/# to determine how much light is lost

*Note: Circular obscuration radius= distance*sin(θ) where θ =half-angle*

*Can similarly analyze non-telecentric architecture by adjusting pupil distance to the designed value and matching the radius appropriately.*