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OPTICAL WAVEGUIDE TESTING SYSTEM WITH STANDOFF

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OPTICAL WAVEGUIDE TESTING SYSTEM WITH STANDOFF

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FIELD OF THE INVENTION

[0001] This disclosure relates generally to optical testing of waveguides, and more specifically to an optical waveguide testing system with standoff.

BACKGROUND

[0002] Optical waveguides may be used in various display systems. In order to ensure an optical waveguide is performing according to specification, it is subject to various optical tests.

DETAILED DESCRIPTION

[0003] An optical waveguide testing system is described herein and in the Appendix. The optical waveguide may be used as part of a waveguide display. The waveguide display may be part of, e.g., a headset for artificial reality applications. The optical waveguide testing system may be used to test various optical parameters of an optical waveguide. The optical parameters related to image quality (IQ) may include, e.g., efficiency, uniformity, contrast, modulation transfer function (MTF), one or more types of distortion and/or aberration, or some combination thereof.

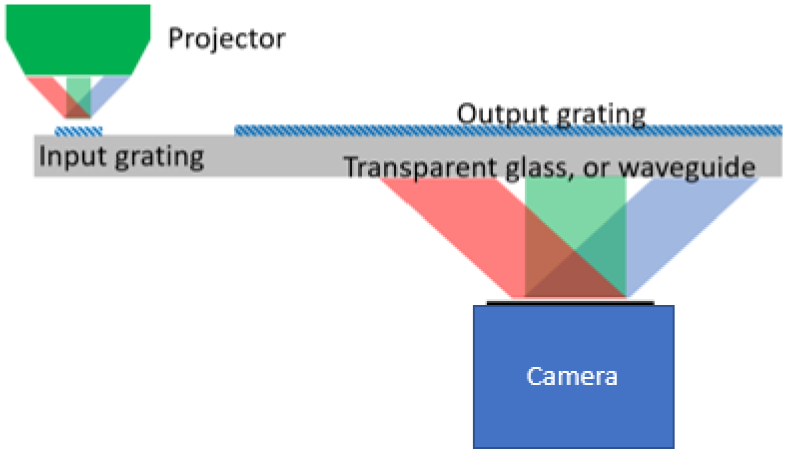

Figure 1

[0004] Figure 1 illustrates an example optical waveguide testing system for testing an optical waveguide under test. The optical waveguide testing system includes a mounting assembly, one or more projectors, a camera, and a controller. In other embodiments, the optical waveguide testing system may include other components.

[0005] The optical waveguide under test is referred to as a device under test (DUT). The DUT includes an input area (e.g., optical grating) and an output area (e.g., optical grating). Note as shown the DUT includes an input grating and an output grating that are a single side of a body of a waveguide. But more generally, the input area may include gratings on a top and/or bottom side of the body, the output area may include gratings on the top and/or bottom side of the body. In some embodiments, the gratings are etched into the body of the waveguide.

[0006] The mounting assembly is configured to hold the DUT in a particular position relative to the one or more projectors and the camera. For simplicity, the mounting assembly is not shown in Figure 1. In some embodiments, the mounting assembly is configured to hold the DUT in a fixed position, while the one or more projectors and/or the camera are configured to move relative to the DUT. In other embodiments, the mounting assembly may be configured to position the DUT with one or more (e.g., 6) degrees of freedom. An example mounting assembly is depicted as part of the system show in slide 15 of the Appendix.

[0007] Slide 15 of the Appendix shows an example structure of waveguide MTF tester with multiple projectors below and DUT and multiple cameras or detectors above the DUT. Even though waveguide MTF-tester has multiple projectors and cameras, the field-of-view(FOV) of projectors and cameras are much smaller than the optics used on waveguide IQ tester. In slide 15 the a DUT may be carried by the 6-axis stage and can move relative to projector and camera. As illustrated, the cameras are mounted on a 3-axis stage and can move in X/Y/Z direction.

[0008] The one or more projectors are configured to project light into the input area of the DUT. Note in Figure 1, there is a single projector illustrated – but in other embodiments, there may be multiple projectors (e.g., for measuring MTF). The one or more projectors may emit various test patterns (e.g., checkerboard pattern) towards the input areas. Each of the one or more projectors has a virtual exit pupil that is positioned at a pupil standoff distance from the corresponding projector. The virtual exit pupils may be generated using relay lens groups as described below with regard to Figure 4. The pupil standoff distance is such that the DUT and/or a projector may be moved relative to each other without colliding. For example, a pupil standoff distance may be, e.g., 8 cm or more. The position of the virtual exit pupil relative to the DUT varies based on optical parameter is being tested. For example, for IQ the virtual exit pupil is positioned at ~ a walkoff distance (~0.2 mm – 0.5 mm), whereas for MTF testing the virtual exit pupils are configured to be placed at the location of the input area. This is further described in later figures and the Appendix. One or more of the projectors may be mounted on, e.g., one or more stages to adjust their position relative to the DUT in one or more degrees of freedom.

[0009] Light input via the input area is transmitted to the output area via a body of the DUT. The output area out-couples the light toward the camera.

[0010] The camera captures images of light out-coupled from the output area of the DUT. Note that while a single camera is shown, in other embodiments, there may be multiple cameras (e.g., positioned at various angles relative to the output area of the DUT). The camera may be mounted on, e.g., one or more stages to adjust its position relative to the DUT in one or more degrees of freedom.

[0011] A controller (not shown) is configured to process the captured images to determine one or more optical parameters of the DUT. For example, the controller may compare the test pattern to the test pattern in the captured images to determine one or more optical parameters.

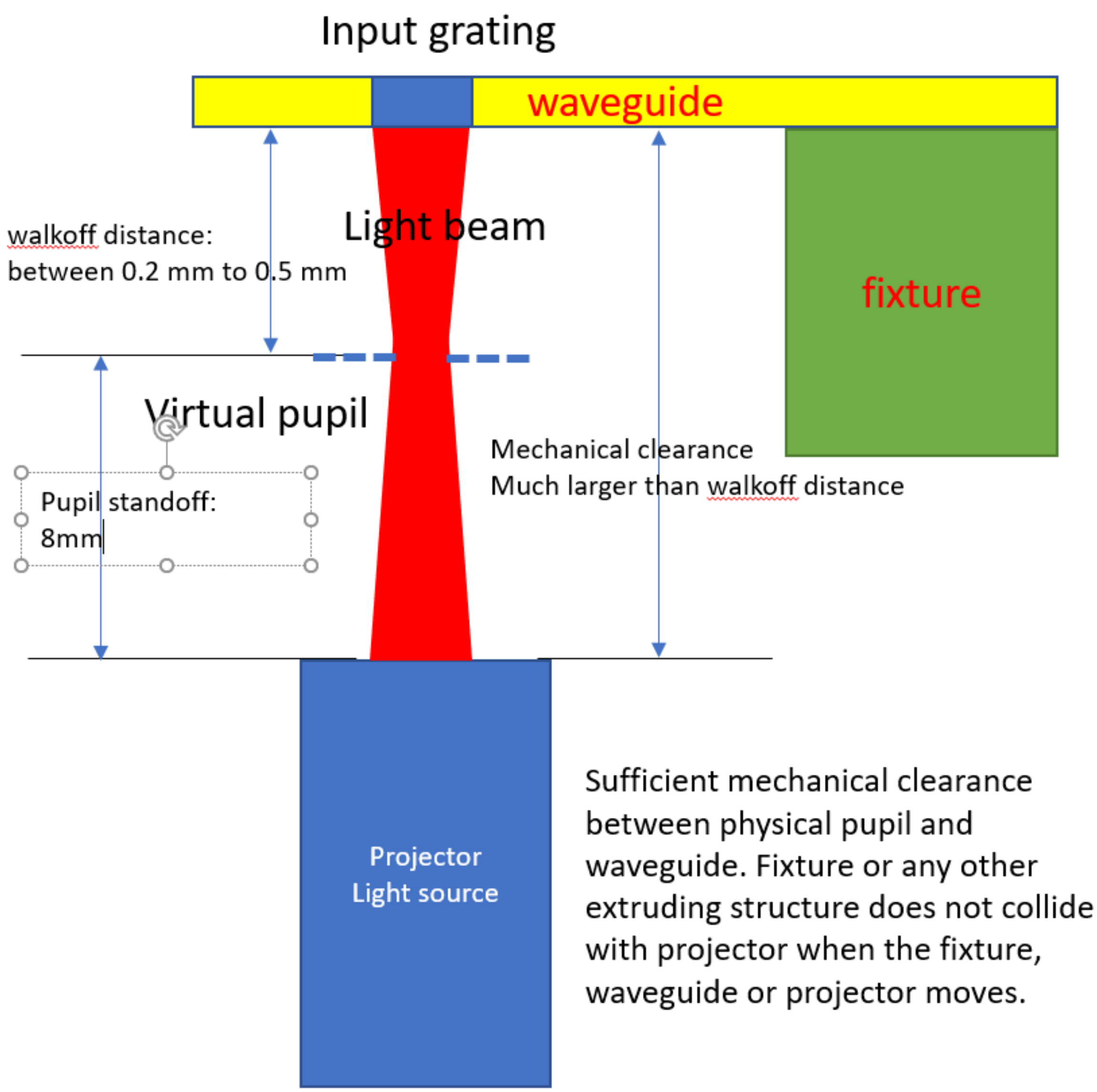

Figure 2

[0012] Figure 2 illustrates a portion of the optical waveguide testing system configured to measure IQ. Note that a total distance between the DUT and the projector is the walkoff distance plus the pupil standoff distance. And that this places the projector far enough away so that the DUT and/or the projector may be re-positioned without colliding. In contrast, conventional testing systems use a physical exit pupil (see slide 6 of the Appendix) that results in the projector being positioned very close to the DUT. Figure 2 is discussed in detail in the Appendix at slide 7.

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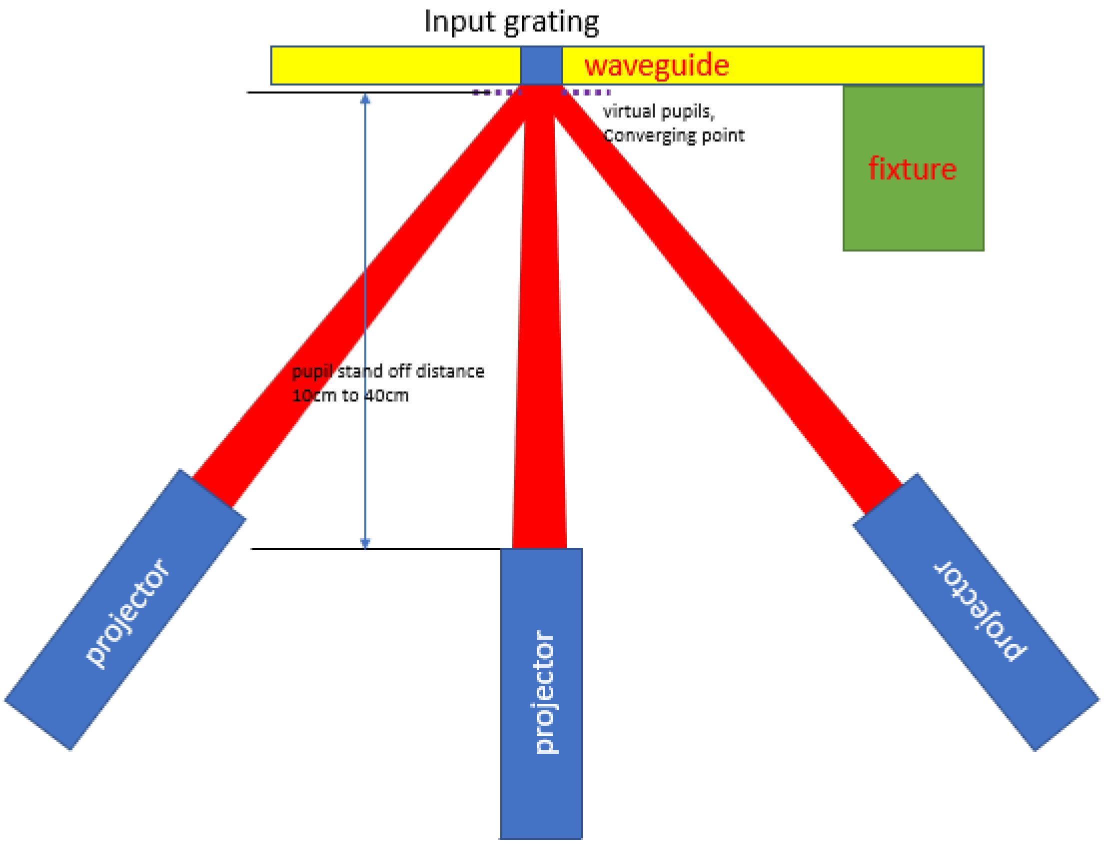


Figure 3

[0013] Figure 3 illustrates a portion of the optical waveguide testing system configured to measure MTF. Note that a distance between the DUT and each projector is the pupil standoff distance for that projector. And that this places the projectors far enough away so that the DUT and/or the projectors may be re-positioned without colliding. Moreover, a size of the virtual exit pupil is matched to a size of the entrance area. In contrast, conventional solutions that use a physical pupil, an external aperture, etc., are non-ideal for the reasons discussed in the Appendix at slides 10-12. Figure 3 is discussed in detail in the Appendix at slide 14.

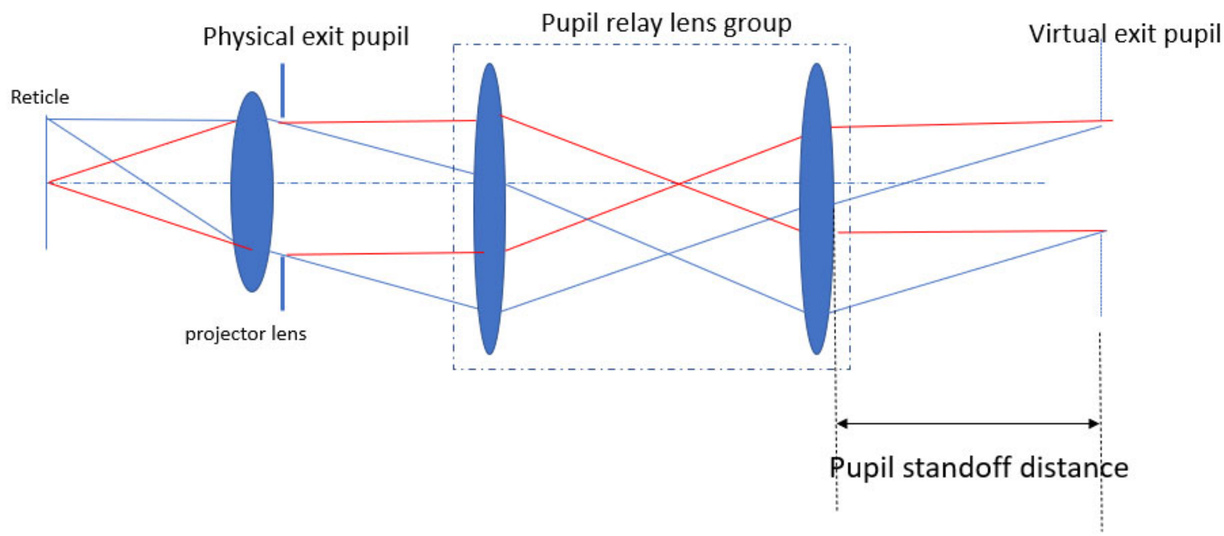


Figure 4

[0014] Figure 4 is an example of a relay system used in a projector to generate a virtual exit pupil. The relay lens group acts to generate a virtual exit pupil of the physical exit pupil of the projector at a pupil standoff distance. Note the focal lengths of the lenses in the relay lens group and/or the positioning can be adjusted to control a size of the virtual exit pupil as well as the pupil standoff distance.

[0015] Embodiments of the invention may include or be implemented in conjunction with an artificial reality system. Artificial reality is a form of reality that has been adjusted in some manner before presentation to a user, which may include, e.g., a virtual reality (VR), an augmented reality (AR), a mixed reality (MR), a hybrid reality, or some combination and/or derivatives thereof. Artificial reality content may include completely generated content or generated content combined with captured (e.g., real-world) content. The artificial reality content may include video, audio, haptic feedback, or some combination thereof, any of which may be presented in a single channel or in multiple channels (such as stereo video that produces a three-dimensional effect to the viewer). Additionally, in some embodiments, artificial reality may also be associated with applications, products, accessories, services, or some combination thereof, that are used to create content in an artificial reality and/or are otherwise used in an artificial reality. The artificial reality system that provides the artificial reality content may be implemented on various platforms, including a wearable device (e.g., headset) connected to a host computer system, a standalone wearable device (e.g., headset), a mobile device or computing system, or any other hardware platform capable of providing artificial reality content to one or more viewers.

Additional Configuration Information

[0016] The foregoing description of the embodiments has been presented for illustration; it is not intended to be exhaustive or to limit the patent rights to the precise forms disclosed. Persons skilled in the relevant art can appreciate that many modifications and variations are possible considering the above disclosure.

[0017] Some portions of this description describe the embodiments in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are commonly used by those skilled in the data processing arts to convey the substance of their work effectively to others skilled in the art. These operations, while described functionally, computationally, or logically, are understood to be implemented by computer programs or equivalent electrical circuits, microcode, or the like. Furthermore, it has also proven convenient at times, to refer to these arrangements of operations as modules, without loss of generality. The described operations and their associated modules may be embodied in software, firmware, hardware, or any combinations thereof.

[0018] Any of the steps, operations, or processes described herein may be performed or implemented with one or more hardware or software modules, alone or in combination with other devices. In one embodiment, a software module is implemented with a computer program product comprising a computer-readable medium containing computer program code, which can be executed by a computer processor for performing any or all the steps, operations, or processes described.

[0019] Embodiments may also relate to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, and/or it may comprise a general-purpose computing device selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a non-transitory, tangible computer readable storage medium, or any type of media suitable for storing electronic instructions, which may be coupled to a computer system bus. Furthermore, any computing systems referred to in the specification may include a single processor or may be architectures employing multiple processor designs for increased computing capability.

[0020] Embodiments may also relate to a product that is produced by a computing process described herein. Such a product may comprise information resulting from a computing process, where the information is stored on a non-transitory, tangible computer readable storage medium and may include any embodiment of a computer program product or other data combination described herein.

[0021] Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the patent rights. It is therefore intended that the scope of the patent rights be limited not by this detailed description, but rather by any claims that issue on an application based hereon. Accordingly, the disclosure of the embodiments is intended to be illustrative, but not limiting, of the scope of the patent rights, which is set forth in the following claims.

What is claimed is:

1. An optical testing system comprising:

a mounting system configured to hold a device under test (DUT), wherein the DUT is an optical waveguide that includes an input area and an output area;

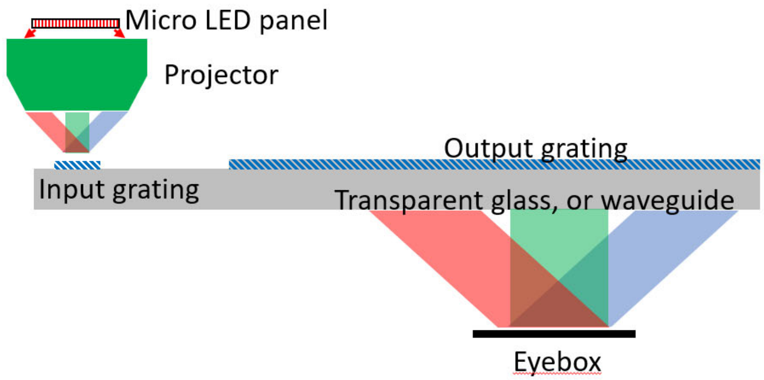
a projector configured to illuminate the input area with a test pattern, and a virtual exit pupil of the projector is positioned at a pupil standoff distance from the projector such that a position of at least one of the DUT or of the projector may be adjusted without colliding with each other; and

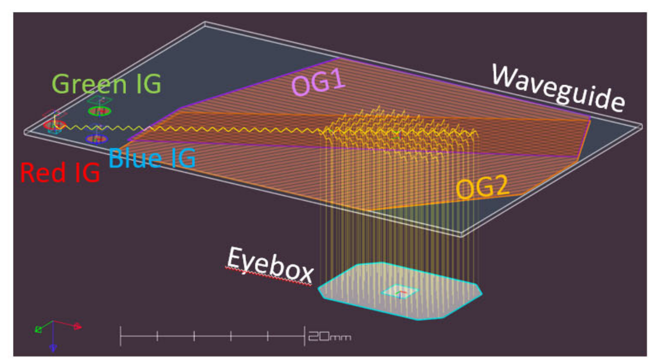
a camera assembly configured to detect the test pattern output from the output area.

Appendix

Introduction to AR waveguide used for augmented-reality(AR) display and metrology tools to test AR waveguide.

- AR waveguide is an optical device that transmit projected image into human eye while allow human eye to see through the waveguide at the outside world in the meantime. In this way, the human eye can see both the virtual image and real world in the meantime, which is the foundation for augmented reality(AR) or mixed reality(MR).
- To test the imaging quality(IQ) of AR waveguide, one needs to develop optical metrology tools to measure metrics of imaging performance like efficiency, uniformity, contrast and modulation-transfer-function(MTF) of each AR waveguide. The metrology tool consists of two major parts: projection light source and imaging camera. Shown as below, the projector(projection light source) projects the target pattern to the input grating of AR waveguide, the target pattern is transmitted from input grating to the output grating by the AR waveguide, then the imaging camera take the output image at the output grating. The target images taken at output grating are used for getting the IQ metrics of AR waveguide with some image analysis.



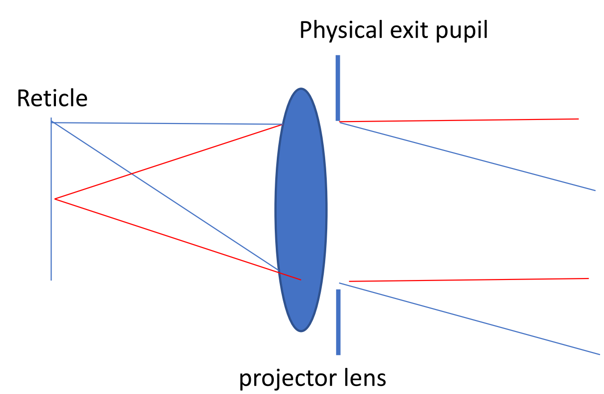


Virtual pupil on projection light source

- In this IP, a new concept is described about design of light source for AR waveguide metrology tool.
  - Instead of using physical pupil at the front of projector, a virtual pupil is used instead at a certain distance in front of projector lens. This design will benefit both waveguide IQTester(one pair projector and camera with large field-of-view(FOV)) and waveguide MTFtester(with multiple pairs of projectors and cameras with small FOV), but in different ways.
  - Next issues with physical pupil for both waveguide IQTester and waveguide MTFtester are doscissed.

Implementation of virtual pupil on projector light source from optical design perspective

Definition of pupil standoff distance: the on-axis distance between first mechanical surface of lens and the exit pupil.

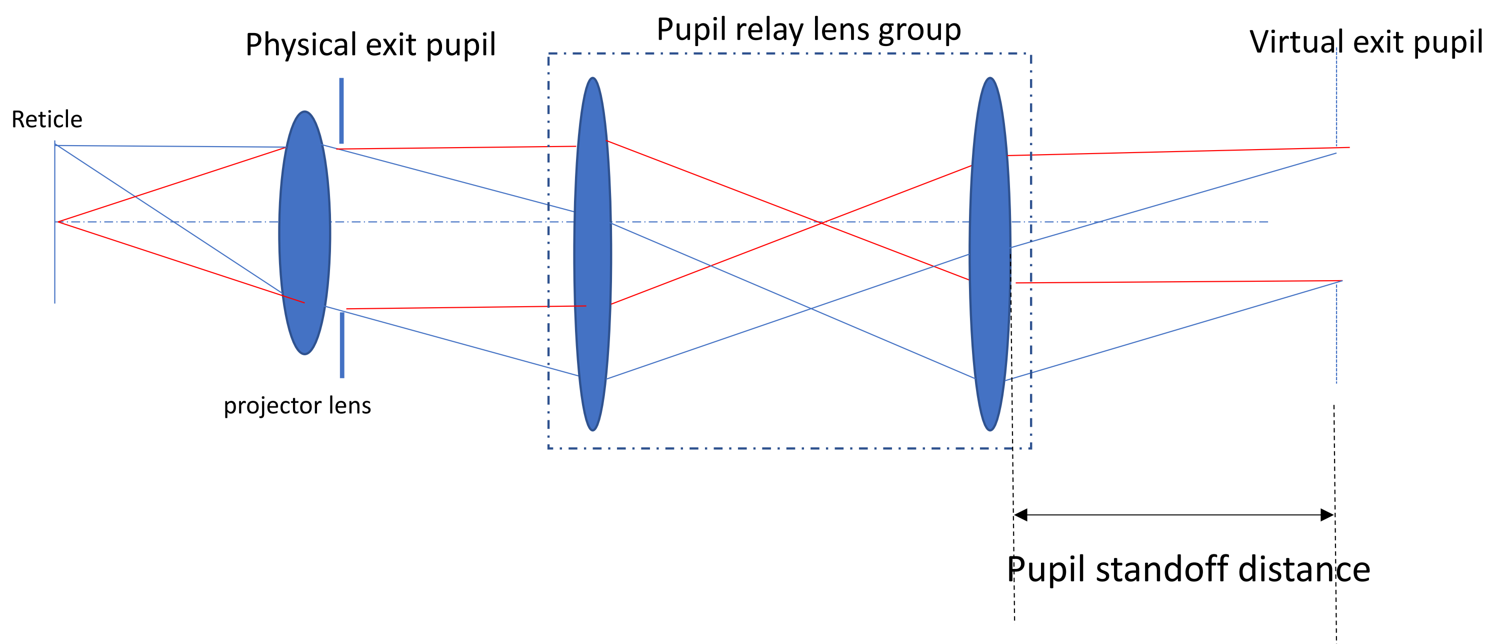


Ordinary projector lens with physical pupil.

For ordinary projector lens, since the 1st mechanical surface is the physical exit pupil itself, the pupil standoff distance is zero.

See next page on how one modifies this projector lens to implement virtual exit pupil

Implementation of virtual pupil on projector light source from optical design perspective: adding pupil relay lens group



A pupil relay lens group is behind projector lens to implement the virtual exit pupil:

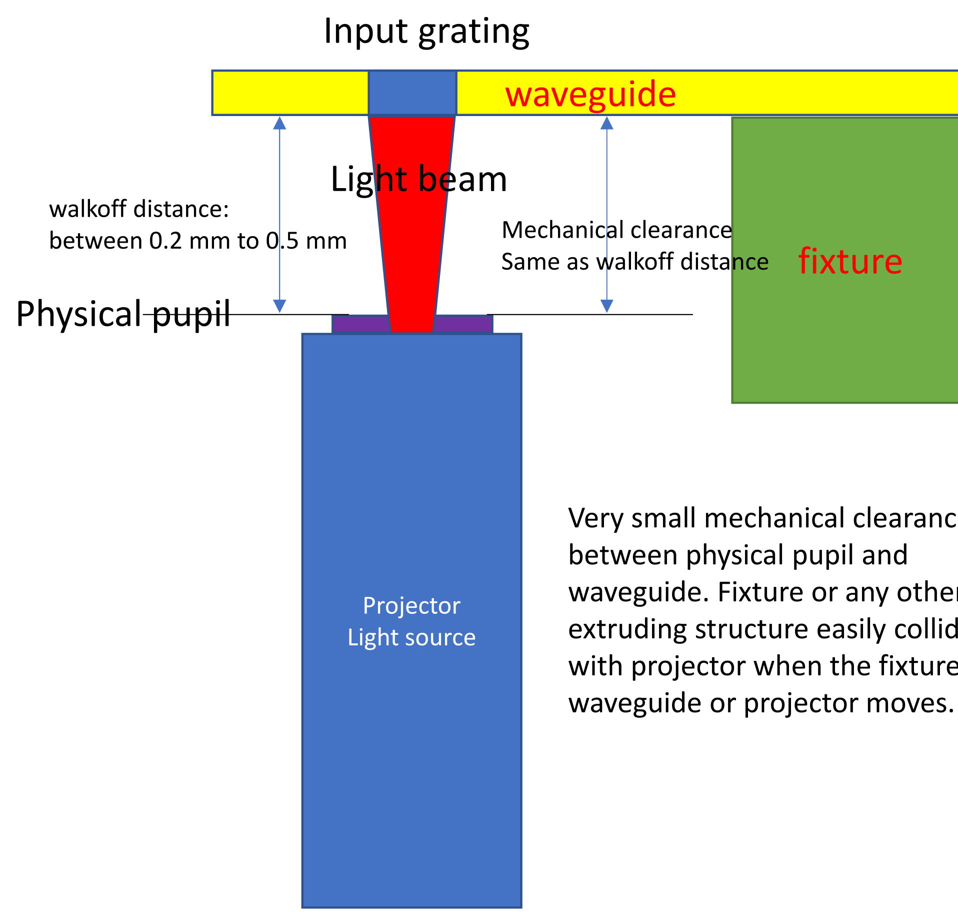
Virtual exit pupil is the image of physical exit pupil by pupil relay lens group

Pupil standoff distance: distance between first surface of pupil relay lens group to virtual exit pupil

Using virtual pupil on IQTester light source

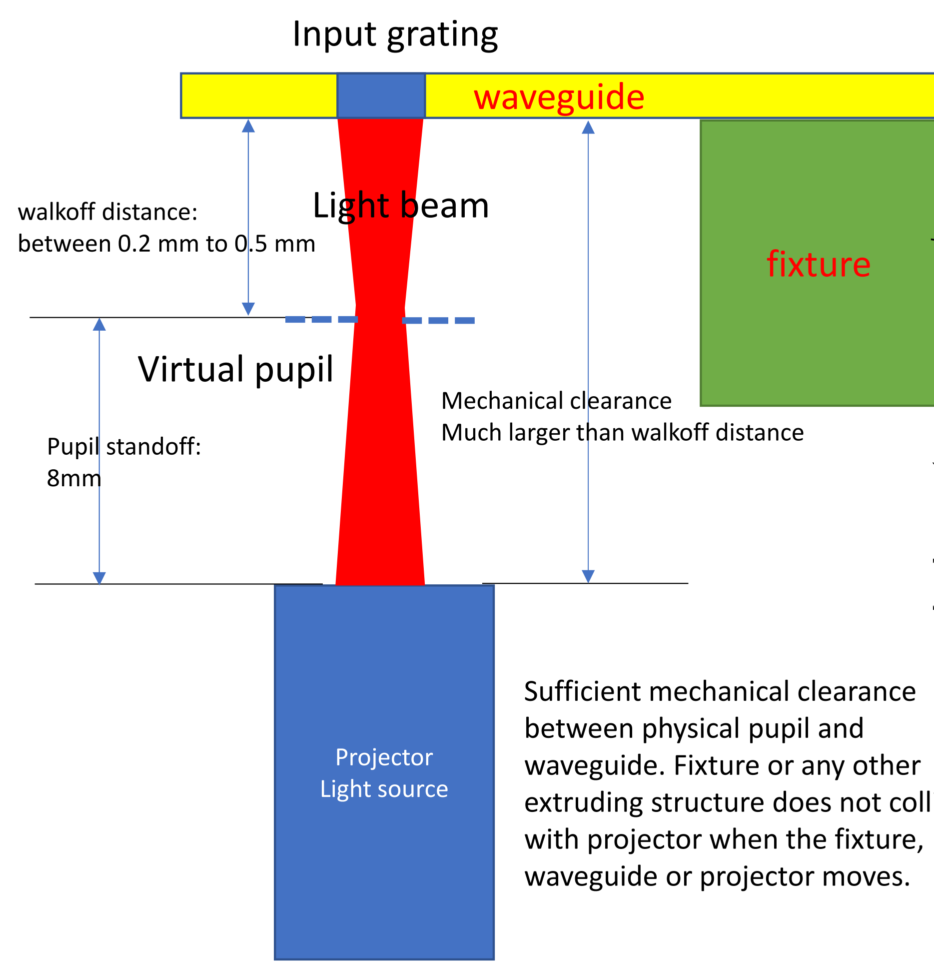
Problem with physical pupil on IQTester light source (large FOV, for metrics like efficiency, uniformity and contrast)

- Large FOV IQTester, briefly IQT, use one pair of projector and imaging with large FOV > 70 deg.
- Definition of walkoff distance: the distance between exit pupil of projector and waveguide surface
- The walkoff distance is very small between 200 um to 500 um. Mechanical clearance is same as walkoff distance so it is also small.
- For projector with physical pupil, the pupil is almost touching the waveguide with tiny mechanical clearance(walkoff distance). This gives very little mechanical clearance if one wants to move the waveguide relative to the projector. Any fixture holding the waveguide or structure extruding from waveguide will easily collide with projector pupil.



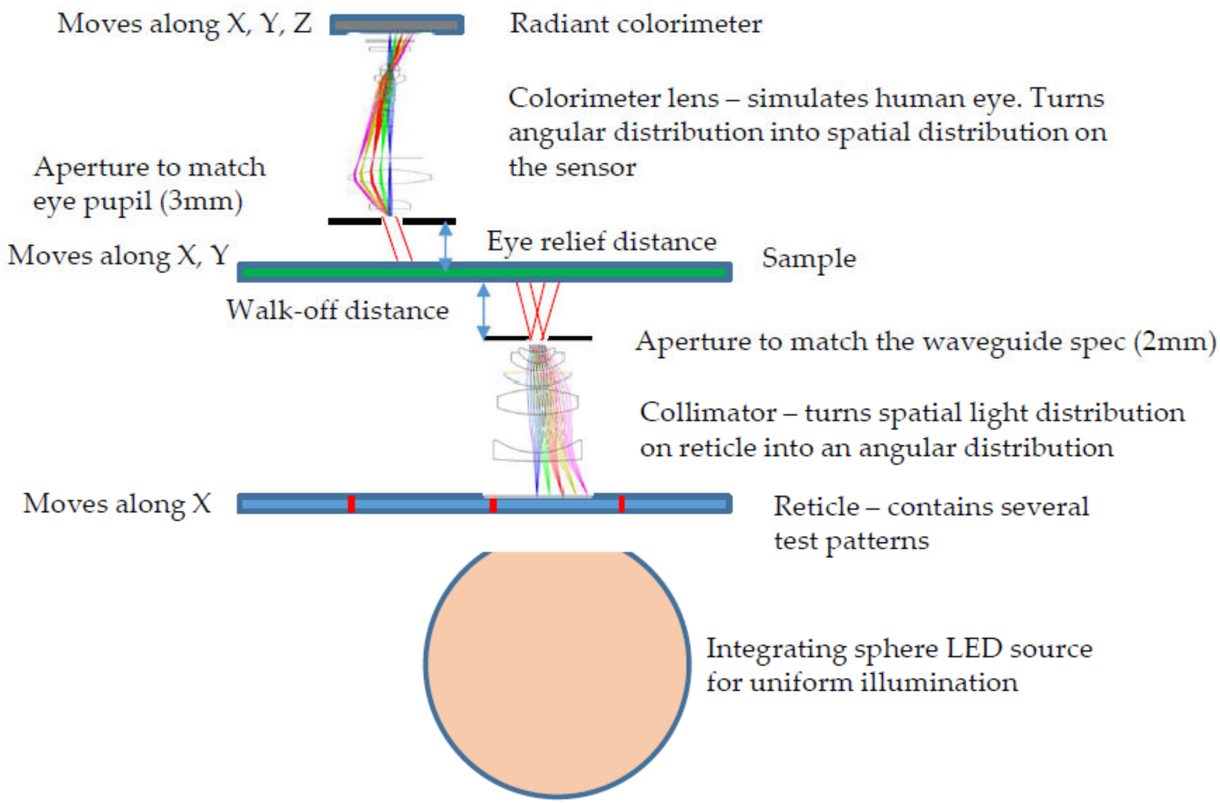
Our approach by using virtual pupil on IQTester light source

- Mechanical clearance between waveguide and projector is much larger than walkoff distance(distance between waveguide and virtual pupil).
- Mechanical clearance = walkoff distance + pupil standoff distance
- The light beam converge before virtual pupil while diverge after virtual pupil. At the virtual pupil the beam is at its narrowest width of pupil diameter.
- Our current design has pupil standoff of 8mm, which gives us more than enough mechanical clearance to move DUT, fixture and projector without collision.



Sufficient mechanical clearance between physical pupil and waveguide. Fixture or any other extruding structure does not collide with projector when the fixture, waveguide or projector moves.

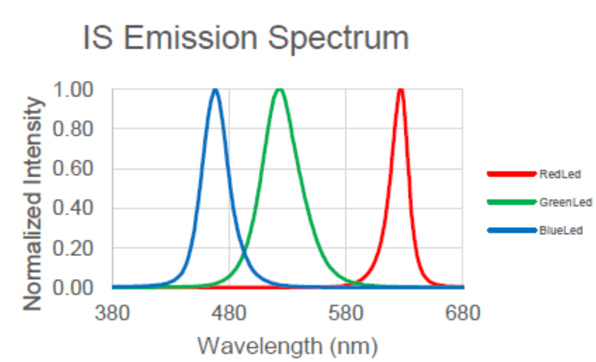
Principle of waveguide IQT



IQT Working principal

Key requirements

- FOV
- Pupil size (entrance/exit pupils)
- Eye relief
- Eye box
- Walk off distance

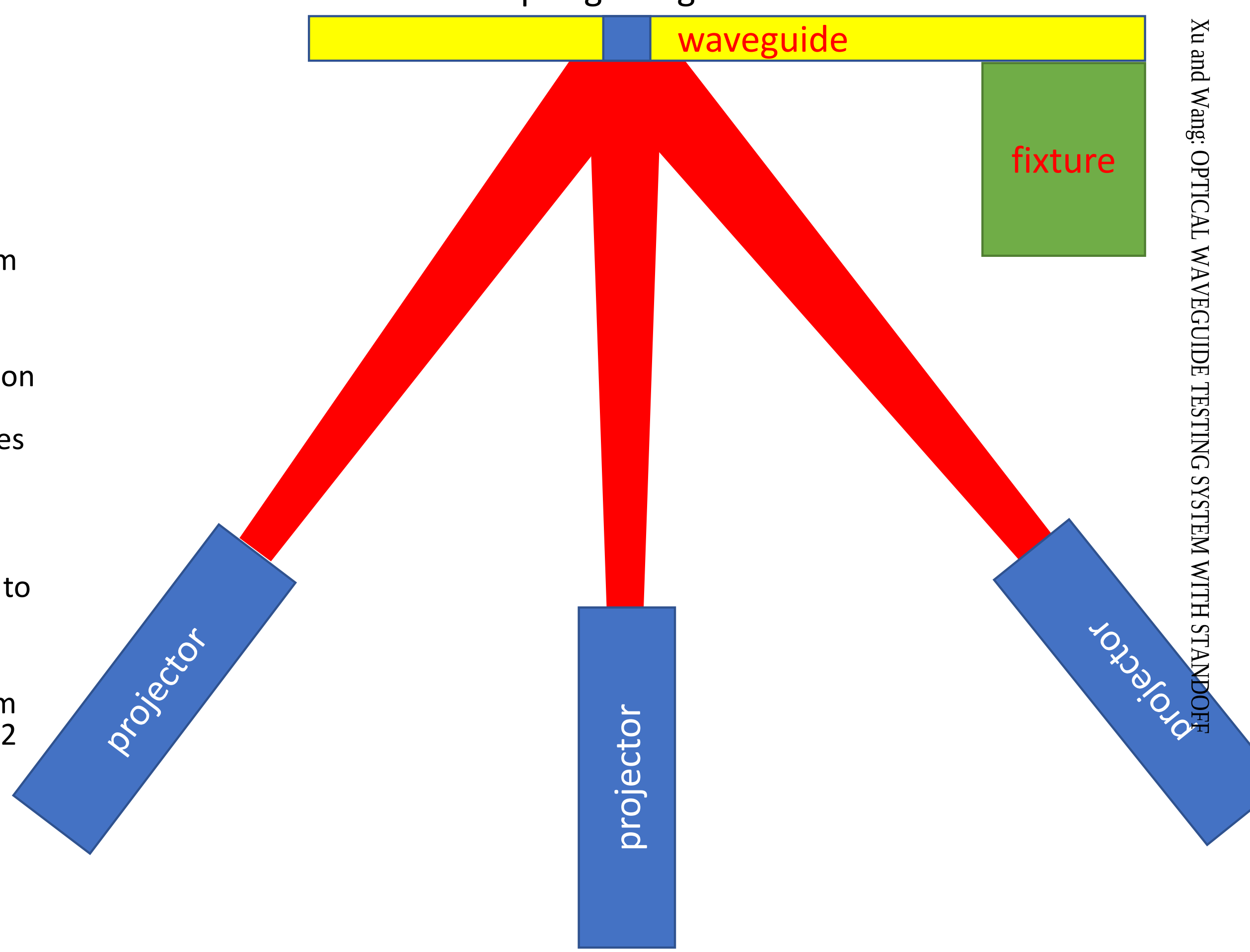


Peak wavelength: 468nm, 522 nm, 626 nm

Using virtual pupil on MTFtester light source

Beam expansion problem with physical pupil on MTF tester(small FOV, for metrics like MTF and CRA)

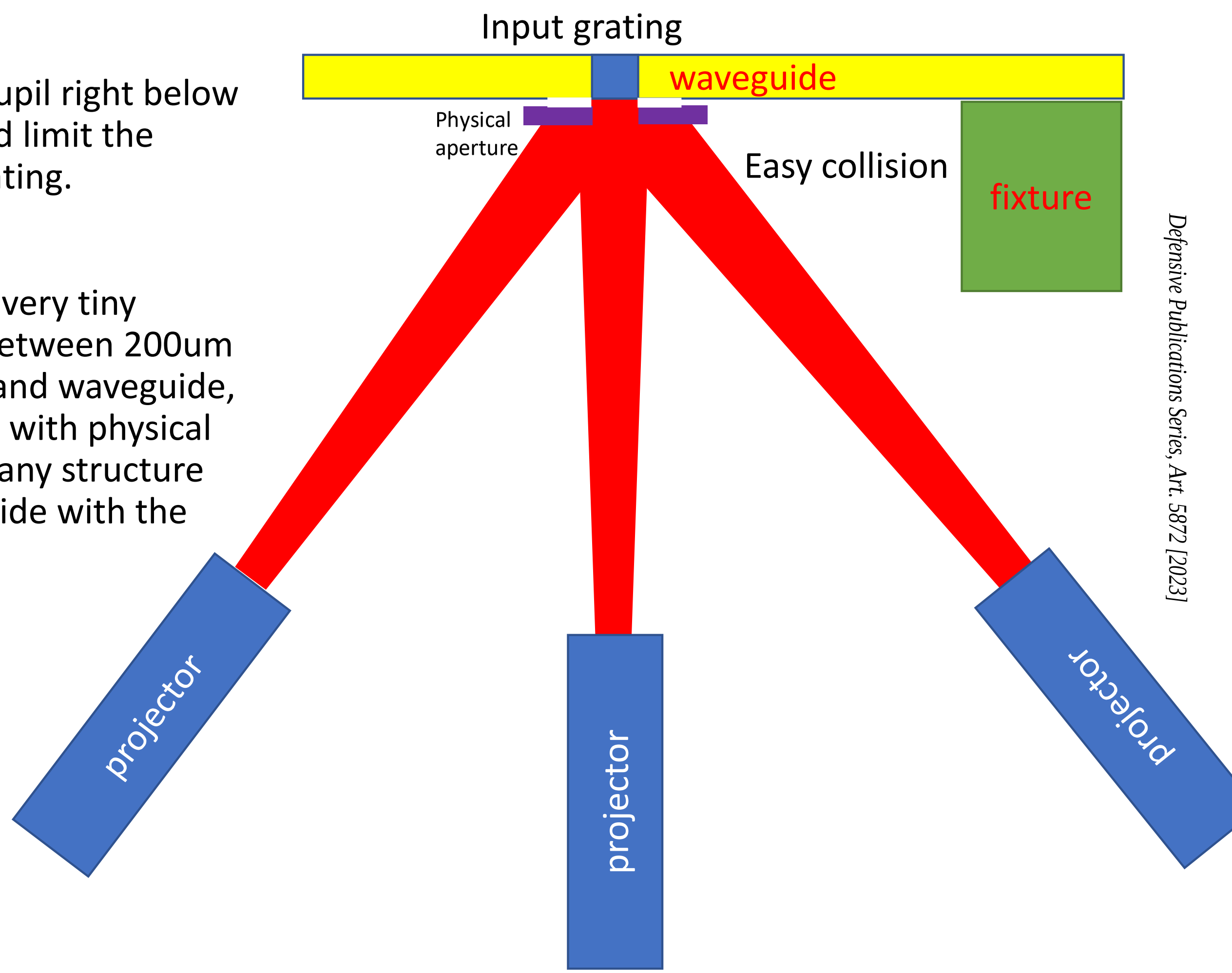
- MTFtester has multiple pairs of projector/camera with small FOV, oriented at different angles.
- The light beams from multiple projectors converge at input grating of waveguide.
- Due to mechanical clearance between multiple projectors, the projectors need be placed far away from waveguide at about 20cm.
- For projector with physical pupil, the light beam will diverge after projector. The divergence angle depends on the FOV of projector. When light beam reach the waveguide input grating, the beam size usually becomes twice as big as the pupil size.
- With the light beam become larger than the pupil, and the waveguide input grating. With area outside input grating illuminated, much straylight will be introduced to the waveguide imaging path and severely affects the imaging quality and metrology quality.
- There are 2 previous approaches to deal with this beam expansion problem. Next 2 slides will talk about these 2 approaches.



Previous approach 1 to deal with beam expansion problem: additional physical aperture below the input grating

- Previous approach 1: add one physical pupil right below the input grating of waveguide to cut and limit the beam profile within the area of input grating.

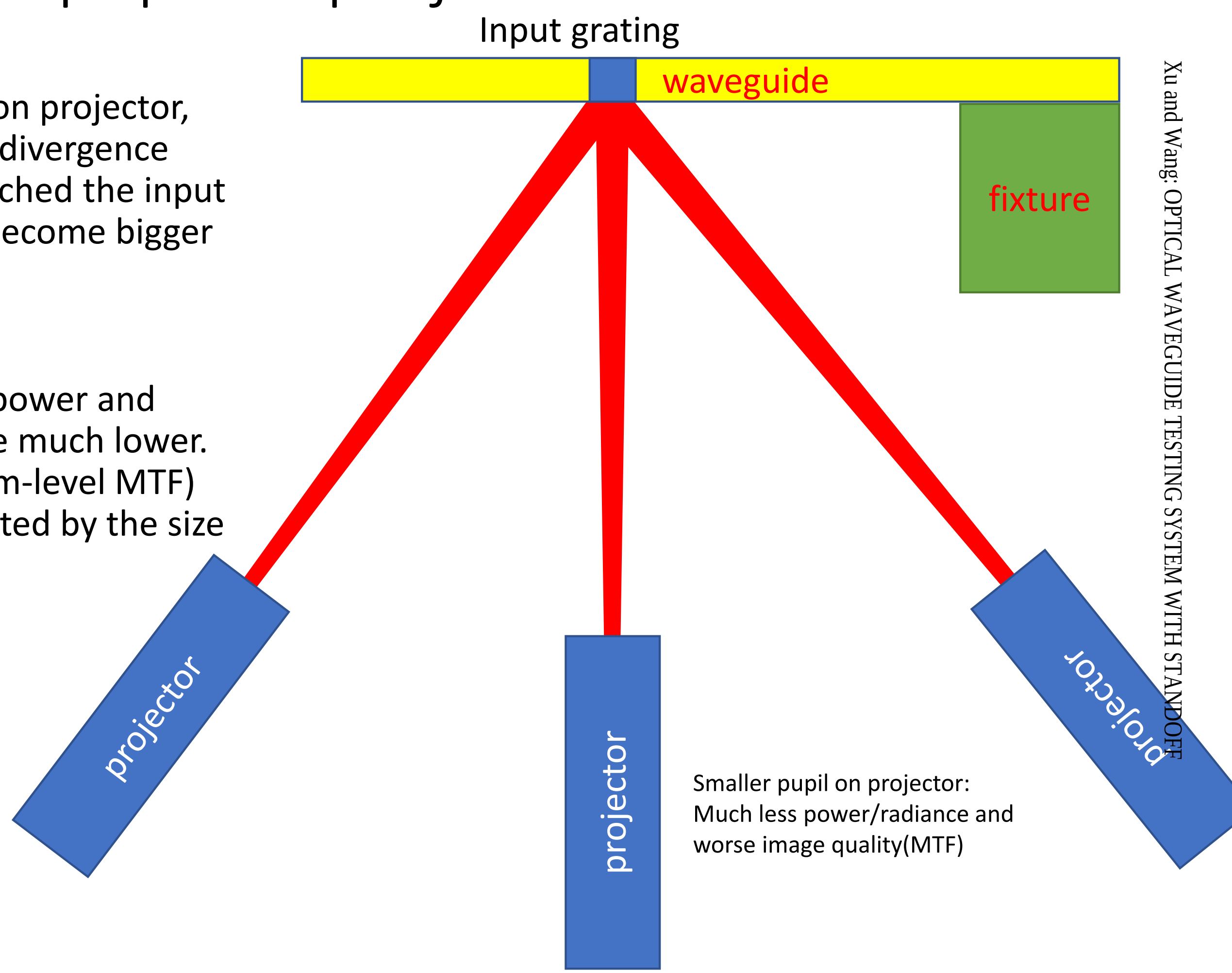
- Problem with previous approach 1: with very tiny mechanical clearance(walkoff distance between 200um and 500um) between physical aperture and waveguide, it has same issue as IQTester light source with physical pupil: Fixture holding the waveguide or any structure extruding from waveguide will easily collide with the additional aperture for any movement.



Previous approach 2 to deal with beam expansion problem: using smaller pupil on projector

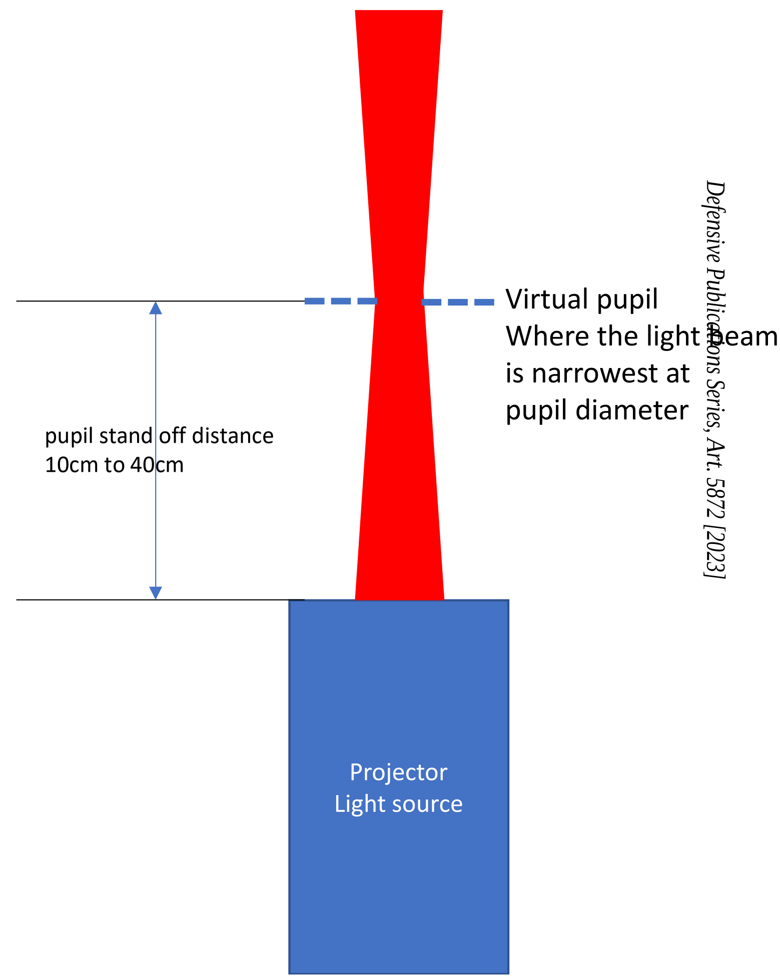
- Previous approach 2: use smaller pupil on projector, the beam size will be smaller but beam divergence angle stay the same. So when beam reached the input grating it expands a little but does not become bigger than the area of input grating.

- Problem with previous approach2: the power and radiance of projector light source will be much lower. And the image quality(specifically system-level MTF) become worse since it is diffraction-limited by the size of projector pupil.



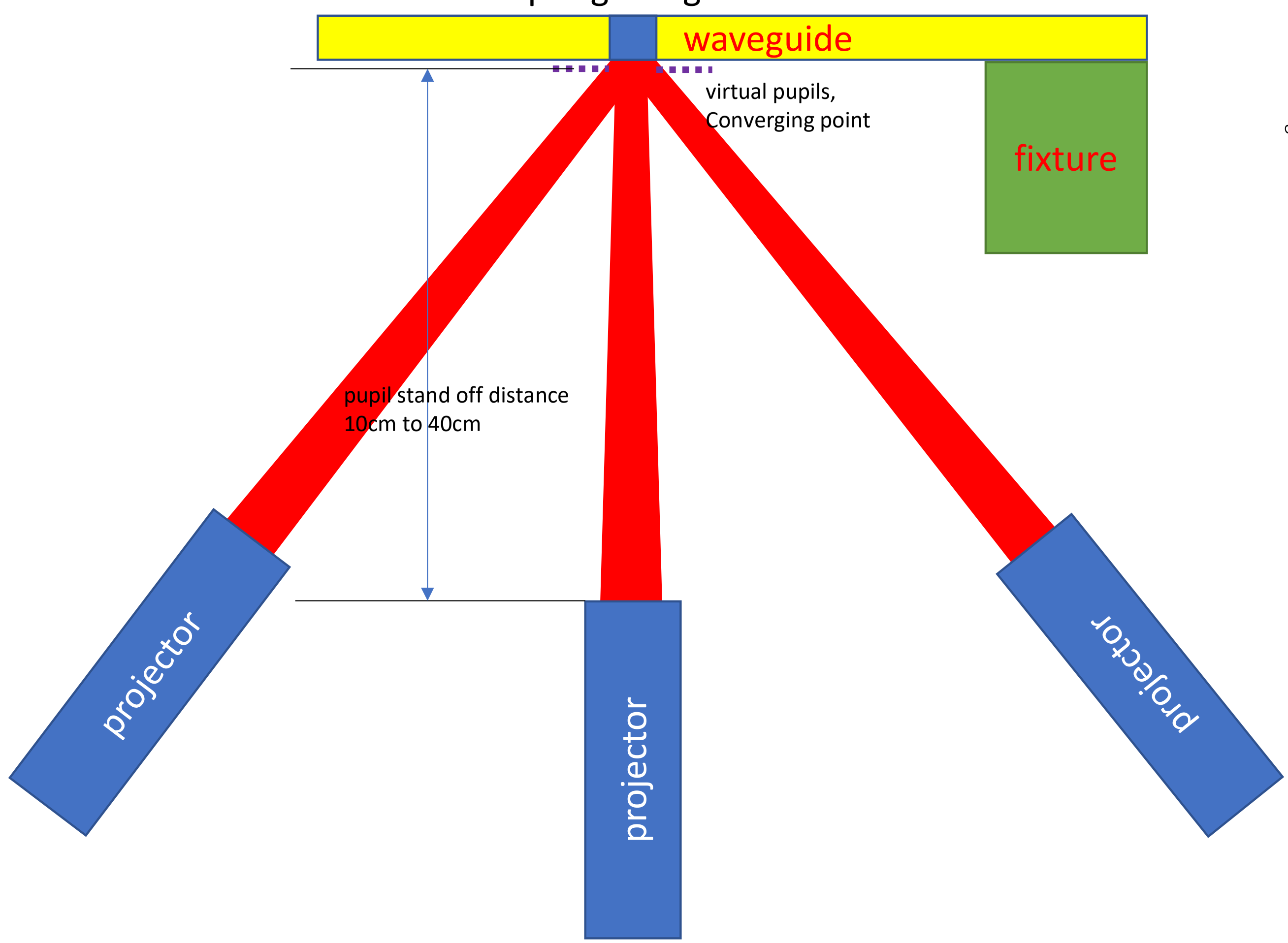
Our approach by using virtual pupil on MTFtester lightsource

- With virtual pupil standing off in front of projector lens, the light beam converge before virtual pupil while diverge after virtual pupil. At the location of virtual pupil, the light beam is at its narrowest width of pupil diameter.
- Since the FOV of MTFtester projector is very small between 3 deg to 8 deg, the pupil stand off distance(distance between virtual pupil and front surface of projector lens) can be designed quite long between 10cm and 40 cm.

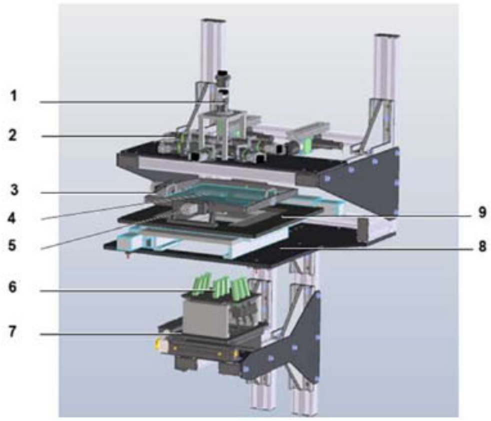


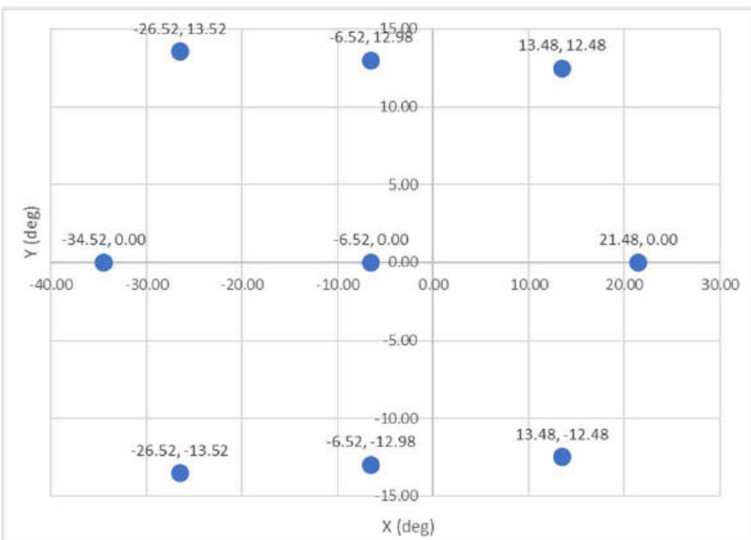
Our approach by using virtual pupil on MTFtester lightsource

- With virtual pupil far in front of projector lens at long pupil standoff distance between virtual pupil and projector lens, one places all projectors at their respective angles so that their virtual pupils all overlap with each other. This point is called a "converging point" where the center of all virtual pupils overlap.
- Because the light beam converge at the virtual pupil at its narrowest beam width at its pupil diameter, as long as the pupil diameter is not bigger than the area of input grating, the beam size at converge point will not be bigger than the area input grating. In this case, straylight caused by illumination outside area of input grating is avoided.
- This approach doesn't have the problem of mechanical clearance or collision as previous approach 1, as no physical aperture is used right below the waveguide input grating at walk-off distance, and there is a very long mechanical clearance with very long pupil standoff distance between 10 cm to 40 cm.
- This approach doesn't have the problem of power loss or image quality(MTF) loss as previous approach 2, as the pupil size on projector is not lowered.



Structure of waveguide MTF#2 TriOptics Pro@AR





9 Field angles