Influence of Optical Components on the Imaging Performance

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Introduction

The Imaging Path

• The imaging path consists of several optical components. Some of them are very obvious like the lens or an optical filter in front of it. Others are less visible like the sensor cover glass or the micro lens elements in front of each sensor pixel.

• Each optical component has its own influence on the performance of the whole imaging system.

• Following we present the individual components and show the individual requirements and the interaction within the total imaging path.
Optical System Components

Scheme

- Lens
- Camera filter glass
- Sensor cover glass
- Sensor micro lenses
- Front filter glass
- Active Sensor Surface
Front Filter Glass

Scheme

Front filter glass
Front Filter Glass

Surface Quality of the Front Filter Glass

The surface quality of the front filter can have a major influence on the imaging performance of the whole system. The following graphs show the performance of a diffraction limited lens with filters of different quality.

Perfect filter
(no wavefront deformation)
Practically no loss of performance

High quality industrial filter
(λ/4 wavefront deformation)
Visible but acceptable loss of performance

Standard photo filter
(λ/2 wavefront deformation)
Extreme loss of performance
Front Filter Glass

Blueshift of Interference Filters (e.g. Bandpass, IR-Cut, …)

The characteristics of an interference filter depends on the angle of incidence of the incoming light. The steeper the angle the more the filter characteristics moves to shorter wavelengths.

Cinegon 1.8/4.8 with IR-Cut in front of lens
- max. angle of incidence: 47.8°
- max. blueshift: 93mm

Cinegon 1.8/4.8 with IR-Cut behind the lens
- max. angle of incidence: 8.6°
- max. blueshift: 1nm
Blue Shift with Interference Filters

Blueshift of Interference Filters (e.g. Bandpass, IR-Cut, …)

Example: Blue Shift with BP 540-300 HT 486)
Camera Filter Glass

Scheme

Camera filter glass
Camera Filter Glass

Position

The position of the camera filter glass has a major influence on the quality and cleanliness requirements. Optically the position does not matter.

**Close to the sensor**
- Dirt and other imperfections are easily visible on sensor
- Very high optical quality required due to small ray bundles

**Close to the lens**
- Dirt and other imperfections are much less visible
- No higher optical quality required compared to front filter
Sensor Cover Glass

Scheme

Sensor cover glass
Sensor Cover Glass

Quality and Tolerances

Usually the sensor comes with a mounted cover glass. Some sensor manufacturers give detailed information about the cover glass in their sensor specification. This includes:

- Thickness, incl. Tolerance
- Glass type
- Surface Quality
- Transmission

Usually the quality of the cover glass is on such a level that the influence on the system performance is negligible.

Nevertheless the sensor cover glass needs to be considered in the optical design. Since cover glasses are different, an average cover glass is used during the lens design process.
Sensor Micro Lenses

Scheme
Sensor Micro Lenses

 Angular Sensitivity

Most modern sensors are equipped with micro lenses on each pixel in order to increase energy quantum efficiency. But these micro lenses may cause that light under a certain angle is not projected onto the active pixel area.

- Pixel at sensor edge
- Large CRA (chief ray angle)
- Light misses active area (grey)

- Pixel at sensor center
- CRA = 0°
- Light hits active area (grey)

Standard Lens
Sensor Micro Lenses

Angular Sensitivity

In order to minimize the shading effect special lenses are required which are optimized for the sensor characteristics (Anti Shading Lenses).

- Pixel at sensor edge
- Very low CRA
- Light hits active area (grey)

- Pixel at sensor center
- CRA = 0°
- light hits active area (grey)
Sensor Micro Lenses

Angular Sensitivity of Sensors in the Datasheet

Nowadays the angular sensitivity of sensors is very often specified in the sensor data sheet – usually by a curve showing the angular response in relation to the angle of the incoming light.

This is an example of a sensor with different sensitivities in horizontal and vertical direction resulting in shaded sides (as shown before). There are also sensors available with equal sensitivities in both directions showing a concentric shading.

Relative Angular Response
Beamsplitter Cubes

Influence of Beamsplitter Cubes on Lens Design

Beamsplitter cubes are often used for coaxial illumination. They can be positioned in front of the lens, between lens and camera and also integrated into the lens.

Every additional piece of glass has a negative influence on the lens performance a long as it is not considered in the lens design.

The influence of thin filters is often negligible so that they can be used with standard lenses.

But for the use of a beamsplitter cube a special lens design is required. Standard lenses are not recommended for use with a beam splitter.

Xenon Diamond 2.6x with BS
Beamsplitter Cubes

Influence of Beamsplitter Cubes on Lens Design

Example: MTF of the Xenon-Diamond 2.6x without and with beamsplitter cube.

XN-D 2.6x without BS

XN-D 2.6x with BS

XN-D 2.6x (BS optimized) with BS
Summary

- The optical quality of filters is very important. The wavefront deformation should not exceed $\lambda/4$.

- Large angles of incoming light, very typical for wide angle lenses, cause blueshift with interference filters in front of the lens. The filter may be positioned between the camera and the sensor.

- A filter between camera and sensor should be located as close as possible to the lens.

- Sensors with micro lenses on the pixel require special attention regarding the lens choice. Anti-Shading lenses with a low chief ray angle (CRA) may be required.

- A beamsplitter within the system require special lens designs.
Thank You
for your attention