HORIZON EUROPE
Digital and emerging technologies for competitiveness and fit for the Green Deal

HYPERIMAGE

A universal spectral imaging sensor platform for industry, agriculture, and autonomous driving.

Starting date of the project: 01/12/2023
Duration: 42 months

= Deliverable D2.3 =

Prototype of a SWIR pixel shifter

Due date of deliverable: 30/06/2025
Actual submission date: 30/06/2025

Responsible WP: Michael Büeler, Optotune Switzerland AG (OPTO)
Responsible TL: Michael Büeler, Optotune Switzerland AG (OPTO)
Version: V1.2

Dissemination level		
PU	Public	x
SE	SENSITIVE – limited under the conditions of the Grant Agreement	

This project has received funding from the European Union's Horizon Program under grant agreement No.101135827

AUTHOR

Author	Institution	Contact (e-mail, phone)
Michael Büeler	OPTO	michael.bueeler@optotune.com

DOCUMENT CONTROL

Document version	Date	Change
V1.0	27.06.2025	First version
V1.1	27.06.2025	Layout improved
V1.2	30.06.2025	Final review

VALIDATION

Reviewers		Validation date
Work Package Leader	Michael Büeler	27.06.2025
Project Manager	Marina de Souza Faria	27.06.2025
Project Coordinator	Alexander Kabardiadi-Virkovski	30.06.2025

DOCUMENT DATA

Keywords	Pixel shifter, Super-resolution, Steering mirror, Image stabilization, Aerial drone, Vertical farming, WUR, SILIOS, NEIOO, OPTO
Point of Contact	Name: Michael Büeler Partner: Optotune Switzerland AG (OPTO) Address: Bernstrasse 388, 8953 Dietikon Phone: +41 58 856 30 16 E-mail: michael.bueeler@optotune.com
Delivery date	30.06.2025

Executive Summary

As part of WP 2.3 one steering mirror and two pixel shifters have to be provided for three different applications.

Application 1: Fast steering mirror (MR) for image satabilization for NEO
A steering mirror MR-15-30-PS-25x25D was identified as a potential solution to meet all target specifications. A mirror was modified and shipped to NEO for testing.

Application 2: Pixel shifter (XPR) for increasing spatial resolution for NEO
A pixel shifter XPR-33 was identified as a potential solution to meet all target specifications. Three pixel shifters were customized, tested and shipped to NEO for testing.

Application 3: Pixel shifter (XPR) for increasing spatial resolution in vertical farming for WUR and SILIOS
A pixel shifter XPR-20 was identified as a potential solution to meet all target specifications. The shifter most probably even has the potential to meet the nice-to-have scanning spec of 4x4 pixels, which would be very interesting for the application. Final clarifications regarding transmittance, timing and mechanical integration are currenly being made before a sample will be shipped to SILIOS for testing.

For each of the three applications we could identify a product that has the potential to meet the specifications of our partners. In two cases OPTO has already customized and tested the optical elements and shipped them to the partners for testing. In one case we believe to have found a suitable solution that is even able to meet the nice-to-have specification which would be very interesting for the application.

Table of Contents

1. INTRODUCTION

Application 1: Fast steering mirror (MR) for image satabilization for NEO
A fast steering mirror is needed by NEO for demonstrator 2.2. The mirror will be used for image stabilization in hyperspectral imaging on an aerial drone.

Application 2: Pixel shifter (XPR) for increasing spatial resolution for NEO
A pixel shifter (XPR) is needed by NEO for demonstrator 2.3. The shifter will be used for increasing the spatial resolution in a hyperspectral camera.

Application 3: Pixel shifter (XPR) for increasing spatial resolution in vertical farming for WUR and SILIOS
A pixel shifter (XPR) is needed by WUR and SILIOS for increasing spatial resolution in a hyperspectral camera for vertical farming.

2. RESULTS AND DISCUSSION

Application 1: Fast steering mirror (MR) for image satabilization for NEO

A tunable mirror is needed by NEO for demonstrator 2.2. The mirror will be used for image stabilization in hyperspectral imaging on an aerial drone.

Rough specifications include an aperture size of 15-30mm, a bandwidth of 50-100Hz, a resolution of 25urad in the VNIR range and 50um in the SWIR range. Mechanical tilting needs to be in the order of +/-10° (min +/-2-3°).

To meet the target specifications the MR-15-30-PS-25x25D was identified as a potential solution.

Fig. 2.1: Tunable mirror MR-15-30-PS-25x25D to be used for image stablization in an aerial drone

A protected silver coating was chosen to guarantee reflectance in the necessary wavelength range.

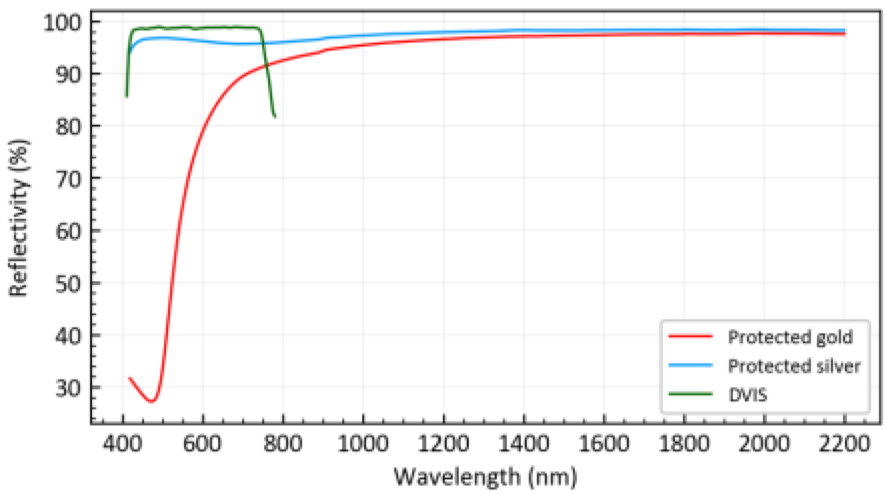

Fig. 2.2: Reflectance of the chosen protected silver coating on the tunable mirror

Various performance data were measured to ensure that the tunable mirror can meet all specs.

The mechanical tilting angle depends on the oscillation frequency. The maximum recommended RMS current per coil on the MR-15-30 when actuating one axis is 0.37 A (corresponding to 0.52 A peak current for a sine wave). Higher currents can be used, but only for short durations before overheating the mirror.

The maximum achievable oscillation frequency of the MR-15-30 as a function of deflection angle is shown in the folowing figure. Note that data for actuation of a single axis is shown. When operating both axes simultaneously, the RMS limit is 0.26 A (0.37 peak for a sine wave). The maximum mean actuation power should not exceed 1.5 W.

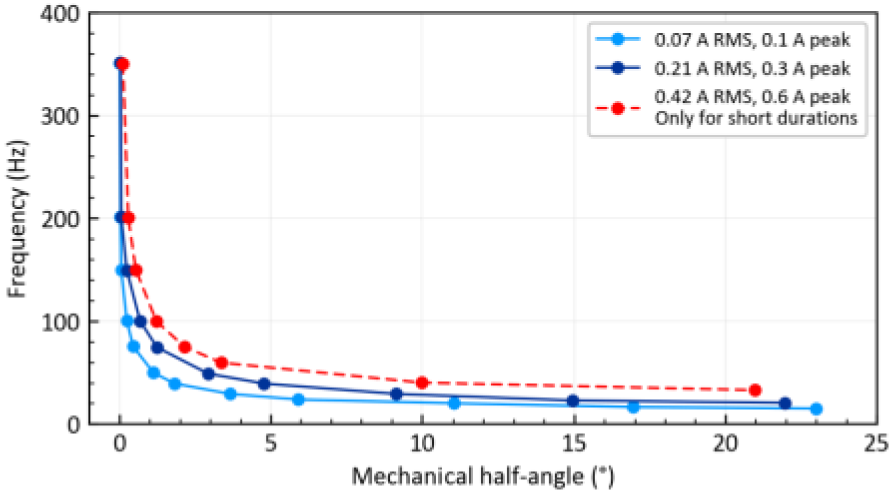

Fig. 2.3: Maximum oscillation speed (sinusoidal) of the X axis as a function of the mechanical half-angle and driving current. RMS currents above 0.37 A can only be used for short durations

The relationship between the applied current and the resulting mechanical tilt angle was assessed. The static deflection of the MR-15-30 as a function of applied current and power is shown in the following figure. Note that because of hysteresis arising due to friction and magnetic remanence, the deflection of the mirror will depend on its previous positions. In closed-loop operation, the hysteresis is compensated for via the mirror calibration.

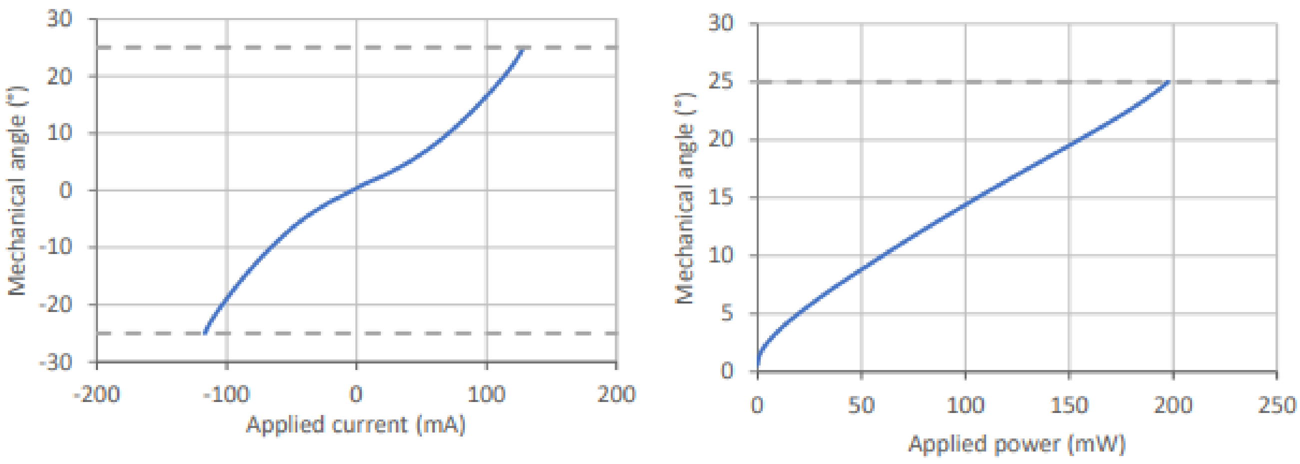

Fig. 2.4: (Left) Mechanical angle versus applied current for a single axis. (Right) Mechanical angle versus applied power. The slope corresponds to ~8.6 mW/°

This tunable mirror MR-15-30-PS-25x25D was sent to NEO for testing. No test results are available yet.

Application 2: Pixel shifter (XPR) for increasing spatial resolution for NEO

A pixel shifter (XPR) is needed by NEO for demonstrator 2.3. The shifter will be used for increasing the spatial resolution in a hyperspectral camera.

Specifications include a speed to meet a framerate of 50-100Hz, single-axis tilting, a spectral range of 960 to 2500nm, reflectivity of <2% at 8 degrees angle-of-incidence and a surface flatness of P-V lambda/2 at 532nm.

A pixel shifter XPR-33 was identified as the basis to meet the specifications. 3 pcs of XPR-33 were modified with a special glass made from material CaF2 to guarantee transmittance in the needed spectral range. Calculations of the optical tilt angle have suggested a thickness of 2.56mm for the glass window.

The following figure shows the excellent transmittance of the CaF2 glass over a wide range of wavelengths from UV to IR.

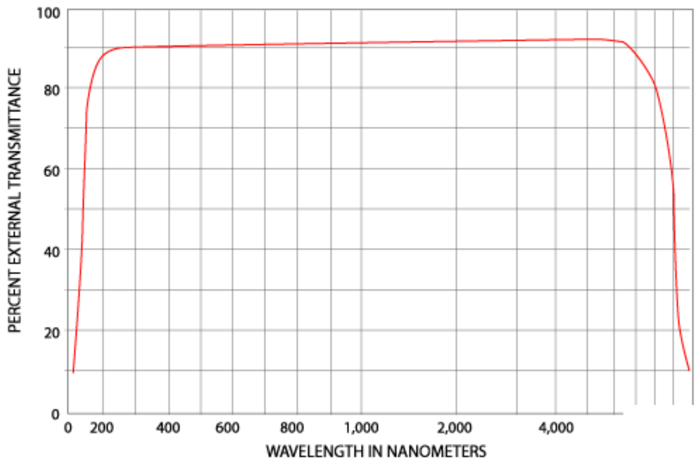

Fig. 2.5: Transmittance data of the glass material CaF2

3 pcs of XPR-33 were modified with this special glass by Optotune. Various performance measurements were performed on the samples.

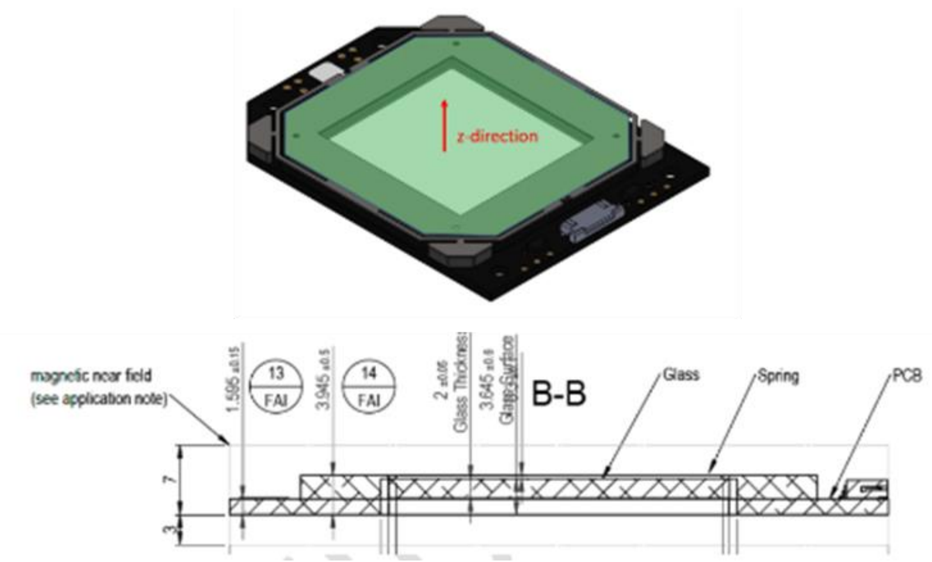

Fig.2.6: Pixel shifter XPR-33 for beam shifting

The figure below shows the optical performance of the XPR-33 working with a 60Hz waveform optimized for 1.4ms transition time. Blue line shows the angular position on the horizontal X-axis and orange line shows the position on the vertical Y-axis.

The main criteria are the accuracy of the angular position and the speed of the transition between the different positions. The angular position during a steady state should never exceed the tolerance rectangle defined as a percentage of nominal angular distance (±0.16°). The typical accuracy for angular position is better than 7% of the nominal angular distance (depicted as the thick black lines) and it should never exceed 12.5% (depicted as a thinner grey lines). The transition time is defined as the time it takes to switch from one ±12.5% "tolerance line" to the next.

With different input waveforms, the behavior can be tuned for different movement patterns. It can be optimized for short transition times, stable flat top profiles, or low acoustical noise operation.

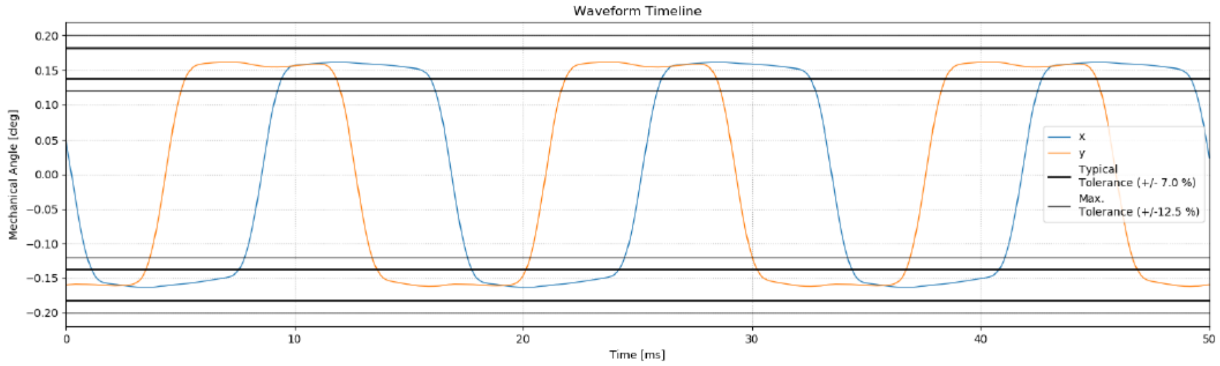

Fig 2.7: Typical time response at 60Hz; transition time 1.4ms. The black lines illustrate typically achieved angular tolerance, while the thinner grey lines illustrate worst case angular tolerance.

The 3 samples were sent to NEO along with a controller and accessories and are currently being tested.

Application 3: Pixel shifter (XPR) for increasing spatial resolution in vertical farming for WUR and SILIOS

A pixel shifter (XPR) is needed by WUR and SILIOS for increasing spatial resolution in a hyperspectral camera for vertical farming.

Specifications include good transmittance over a spectral range from 420 to 870nm, a pixel size to be scanned of 3.45um, a 4x4 pixel/filter arrangement.

The minimum specification for the pixel scanning is 2x2 pixels. The nice-to-have specification would be 3x3 or even 4x4 pixels.

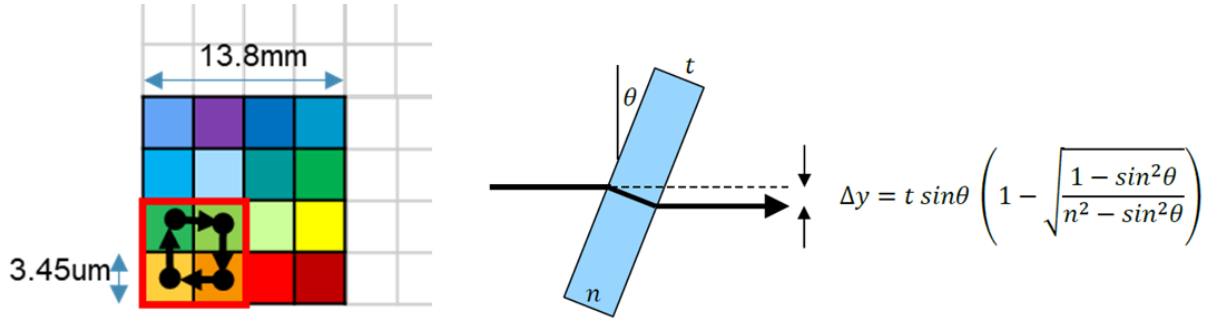

Fig. 2.8: Illustration of the 4x4 filter pattern on the pixels. With a XPR, pixels can be exposed multiple times sequentially with a slightly shifted portion of the object space to multiply the resolution of single images.

A pixel shifter XPR-20 was identified as the basis to meet the specifications. Transmittance might need to be optimized for best performance. Testing of the current standard glass type and coating is recommended.

In order to analyze the dynamics of the pixel shifter for a certain application, a timing diagram was required. We had received the following diagram from WUR

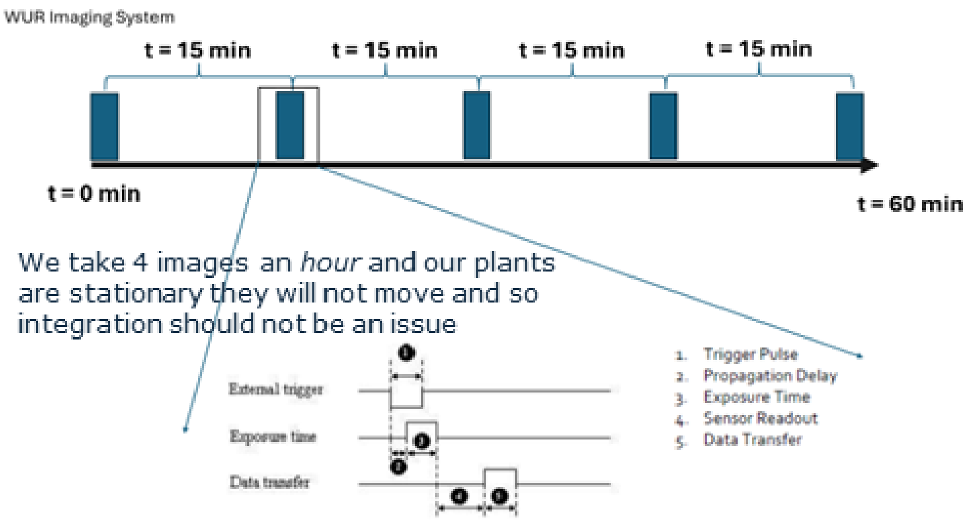

Fig. 2.9: Timing diamgram from WUR for the vertical farming application.

The temporal situation was found to be rather generous for the XPR-20 in terms of dynamics and power. If acquisition is fast enough (much faster than thermal time constant of XPR-20) and if subsequent waiting time is long enough, the XPR can achieve 2-3 times its nominal stroke (subsequent cooling is important). This would mean that scanning of entire 4x4 color filter pattern might be possible. The only limit is mechanical space for the stroke.

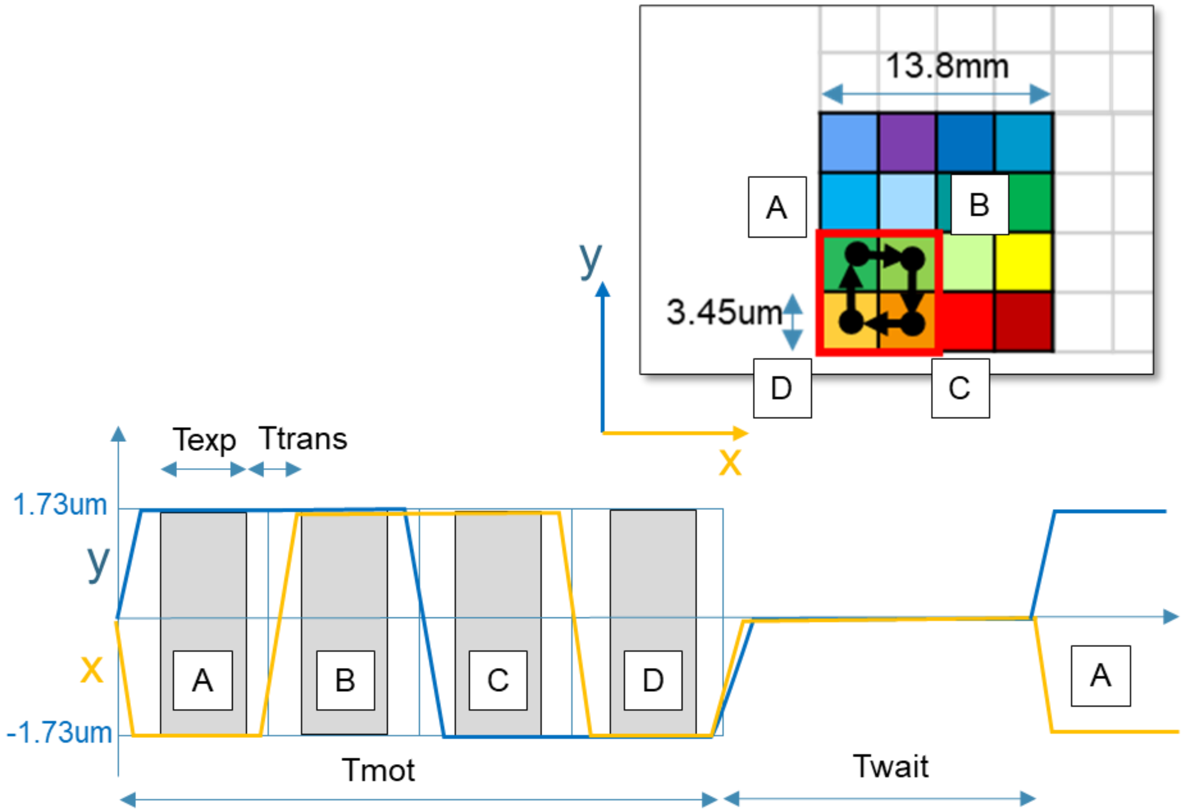

Fig. 2.10: Analysis of the XPR timing for the present application in vertical farming

The following timing was assumed: exposure time Texp = 100ms, transtion time Ttrans >3ms, motion time Tmot ca 0.5s, waiting time Twait = 10s.

This would result in the following power consumption and potential stroke: ~130mA expected for 3.45um shift, 10.35um possible with ~400mA shortterm (sufficient cooling guaranteed), duty cycle dc = Tmot/Twait = 0.05, possible power overstroke factor = sqrt(1/dc) = 4.4.

We consider it realistic that with some power overdriving and some corresponding rest time for cooldown, that the entire 4x4 color filter pattern can be scanned with the XPR-20.

After having clarifed final questions, some XPR-20 samples will be built and shipped to SILIOS for testing.

The mechanical mounting of the XPR between a lens objective and the image sensor needs to be developed.

3. CONCLUSIONS

Application 1: Fast steering mirror (MR) for image satabilization for NEO
A steering mirror MR-15-30-PS-25x25D was identified as a potential solution to meet all target specifications. A mirror was modified and shipped to NEO for testing.

Application 2: Pixel shifter (XPR) for increasing spatial resolution for NEO
A pixel shifter XPR-33 was identified as a potential solution to meet all target specifications. Three pixel shifters were customized, tested and shipped to NEO for testing.

Application 3: Pixel shifter (XPR) for increasing spatial resolution in vertical farming for WUR and SILIOS
A pixel shifter XPR-20 was identified as a potential solution to meet all target specifications. The shifter most probably even has the potential to meet the nice-to-have scanning spec of 4x4 pixels, which would be very interesting for the application. Final clarifications regarding transmittance, timing and mechanical integration are currenly being made before a sample will be shipped to SILIOS for testing.

4. DEGREE OF PROGRESS

As part of WP 2.3 one steering mirror and two pixel shifters have to be provided for three different applications.

For each of the three applications we could identify a product that has the potential to meet the specifications of our partner. In two cases OPTO has already customized and tested the optical elements and shipped them to the partners for testing. In one case we believe to have found a suitable solution that is even able to meet the nice-to-have specification which would be very interesting for the application.

Based on the work presented and the resolution of the identified technological issues, we consider this deliverable to be fully completed (100%).

5. DISSEMINATION LEVEL

Public