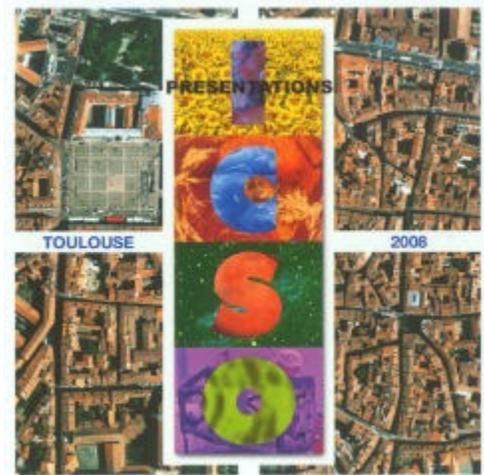


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## *Technological development of spectral filters for Sentinel-2*

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**ABSTRACT**

In the frame of the initiative for Global Monitoring for Environment and Security (GMES), jointly undertaken by the European Commission and the European Space Agency a technological development of two filter assemblies was performed for the Multi-Spectral Instrument (MSI) for Sentinel-2. The multi-spectral pushbroom imaging of the Earth will be performed in 10 VNIR bands (from 443 nm to 945nm) and 3 SWIR bands (from 1375 nm to 2190 nm).

Possible filter coating techniques and masking concepts were considered in the frame of trade-off studies. The selected deposition concept is based on self-blocked all-dielectric multilayer band pass filter. Band pass and blocking characteristic is deposited on the space side of a single filter substrate whereas the detector side of the substrate has an antireflective coating.

The space- and detector side masking design is realized by blades integrated in the mechanical parts including the mechanical interface to the filter assembly support on the MSI focal plane.

The feasibility and required performance of the VNIR Filter Assembly and SWIR Filter Assembly were successfully demonstrated by breadboarding.

Extensive performance tests of spectral and optical parameters and environmental tests (radiation, vibration, shock, thermal vacuum cycling, humidity) were performed on filter stripe- and filter assembly level.

The presentation will contain a detailed description of the filter assembly design and the results of the performance and environmental tests.

**1. INTRODUCTION**

Within the scope of the preparatory activities for the Sentinel-2 - a multi-spectral optical imaging mission for high resolution observation with a large swath width – the feasibility and performance of two multi-spectral filter assemblies for the Multi-Spectral Instrument were investigated and demonstrated by breadboarding .

The so-called VNIR Filter Assembly contains 10 VNIR bands (from 443nm to 945nm) and the so-called SWIR Filter Assembly includes 3 SWIR bands (from 1375nm to 2190nm).

The sophisticated development of the filter assemblies is caused by the specified spectral performance parameters and the high stray light requirements due to the topology of the spectral bands.

**2. DESIGN DESCRIPTION**

**2.1 Coating Design**

The selected deposition concept is based on self-blocked all-dielectric multilayer band pass filter. Each of the coatings for the different filters is deposited on a separate BK7 substrate and each coating realizes both the pass band and the blocking function of the filter directly on the first surface of the substrate. The second surface of the substrate gets an AR coating for minimum reflection within the wavelength range of some of the bands. There are at least three AR coatings, one common coating for all SWIR filters and two different coatings for the VNIR filters. The residual reflectance is < 0.5 % in any spectral range where the VNIR or SWIR filters are located.

Fig. 1 and Fig. 2 show the theoretical performance values as a transmittance versus wavelength plot. Fig. 2 also includes the blocking characteristics of the dichroic. For the rejection requirement of the SWIR band pass filters the blocking of the dichroic was considered. The reason for this approach was the spectral position of the B10 band placed within a minimum of transmission of the atmosphere and the extreme worst case of the SNR in comparison with the other bands.

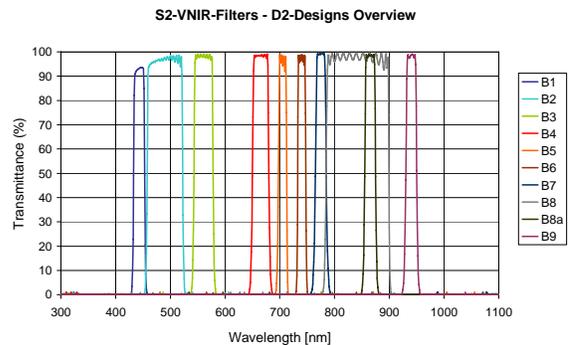


Fig. 1: Designed performance of the VNIR filters

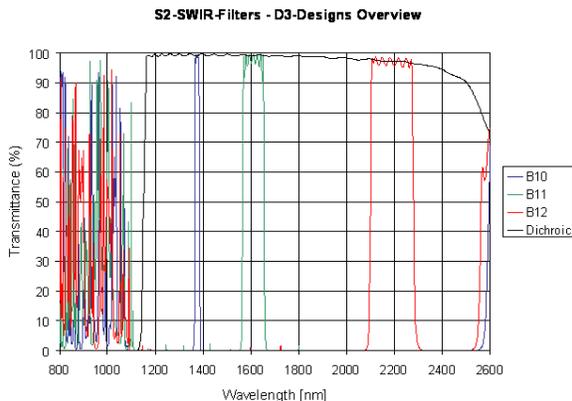


Fig. 2: Designed Performance of the SWIR filters

## 2.2 Mechanical Design

### 2.2.1 Filter Design

The solution preferred and finally selected in the technological development is based on single filter stripes.

The feasibility of the filter substrate manufacturing is strongly related to the requirements to the single filter elements of the VNIR and SWIR spectral range.

The realized length of the breadboard filter stripes is 25 mm (useful length 20.3 mm VNIR / 20.9 mm SWIR) with a width of 1.1 mm for the VNIR filter and 2.9 mm for the SWIR filters. The filter thickness of the VNIR filters varies between 1.943 mm and 2mm and is for the SWIR range 1.975 mm.

### 2.2.2 Filter Assembly Design

The VNIR- and SWIR Filter Assembly concept is the assembly of single filter stripes to a mechanical mount realized by breadboarding. The single filter stripes are put into the mount and are aligned to each other. After aligning the filter stripes they are fixed to the mount by mechanical clamping done by a front face frame. This clamping is supported by gluing with an elastic adhesive. The VNIR Filter Assembly and the SWIR Filter Assembly are shown in Fig. 3 and Fig. 4.



Fig. 3: VNIR Filter Assembly



Fig. 4: SWIR Filter Assembly

The dimensions of the whole VNIR Filter Assembly accounts 30.3 mm x 18.3 mm x 5.7 mm.

The SWIR Filter Assembly has an overall envelope of 30.3 mm x 15.3 mm x 5 mm.

## 3. MANUFACTURING AND TEST RESULTS

### 3.1 General

For every Filter Assembly (VNIR and SWIR resp.) one breadboard was produced. Additionally samples for environmental durability tests and radiation tests were manufactured in the same coating run as the breadboard filter stripes.

Performance and environmental tests were performed on sample-, filter stripe-, and filter assembly level.

### 3.2 Tests on Sample Level

#### 3.2.1 Environmental Durability Tests

Four witness samples per spectral band were manufactured for the environmental durability tests including adhesion and abrasion tests. The samples were subjected 5 cycles in the temperature range from -65°C to +70°C. After that the samples were subjected to humidity of 95% at +55°C. Spectral measurements were performed at the beginning and the end of the environmental test campaign. No remarkable changes of the transmittance were visible.

#### 3.2.2 Radiation Tests

Radiation tests were performed on two sets of 14 filter samples. One set was subjected to proton irradiation at the cyclotron with an energy of 40 MeV at a flux of 1.5 to 1.8 x 10<sup>8</sup> p<sub>+</sub>/cm<sup>2</sup>/s.

The other set of filter samples was subjected to gamma ray irradiation up to an irradiation dose of 60 krad at a mean dose rate of 1.05 rad/s.

The transmittance of each sample was measured before and after each irradiation campaign and was also checked between the irradiation steps. No difference in the spectral performance before and after the proton irradiation and gamma ray irradiation campaign was visible.

### 3.3 Tests on Filter Stripe Level

Spectral measurements on the VNIR filters under operating conditions were performed at vacuum and at 300K on filter stripe level. The maximum observable shift was -0.4nm and the average shift was -0.1%. Both values are within the knowledge for the spectral measurement, i.e. there is not any spectral difference of the transmittance between vacuum and ambient conditions.

Spectral measurements on the SWIR filters under operating conditions were performed at vacuum and at 210 K on filter stripe level. The center wavelength, spectral width and transmittance were measured on three positions of the filter stripe. All the spectral parameters show the required values under operating conditions.

### 3.4 Tests on Filter Assembly Level

#### 3.4.1 Performance Measurements

The required spectral parameters of the center wavelength, spectral width, rejection (< 1%), response values (< 1) and the measured average transmittance with (> 70%) were met for all spectral bands.

The planarity and the wave front error (WFE) of each filter of the VNIR Filter Assembly and SWIR Filter Assembly were determined by using an interferometer.

The planarity value measured for each VNIR band was better than 2 μm (required < 3 μm) and better than 4.3 μm for each SWIR band (required < 6 μm). The measured WFE of each spectral band was significant lower than the required value. The values account between 3.1 to 15.4 rms in nm.

The measured value of the polarization sensitivity for each VNIR- and SWIR filter was lower than 0.03 (required < 0.01).

For all spectral channels, the channel-to-channel crosstalk was specified less than 0.05% of the specified reference radiance for any input radiance illuminating one filter only. This sophisticated requirement could not met for each spectral band.

#### 3.4.2 Environmental Tests

Besides the conducted performance tests the VNIR Filter Assembly and SWIR Filter Assembly were subjected environmental load tests as sine and random vibration, shock test and a thermal vacuum cycling test (-80°C to +50°C).

Before and after each environmental test the planarity, the tilting and spectral parameter were measured to check the stability of the filter assembly design.

Fig. 5 shows the planarity for each band measured during the environmental test campaign. No significant changes were visible.

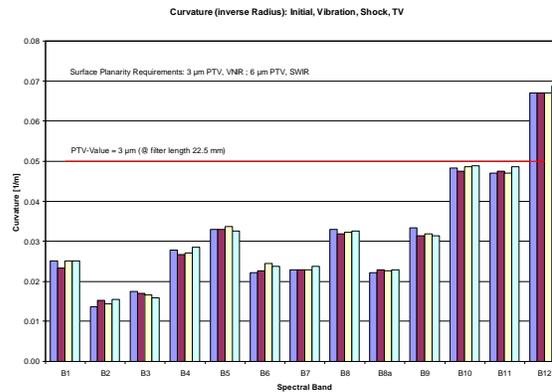


Fig. 5: Radii of curvature measured on both breadboards during the environmental test campaign

Fig. 6 demonstrates the changes of the tilting difference of adjacent filter measured before and after the vibration, shock and thermal vacuum cycling test. No significant changes are visible (maximum values for VNIR 0.2 μm; for SWIR 0.6 μm).

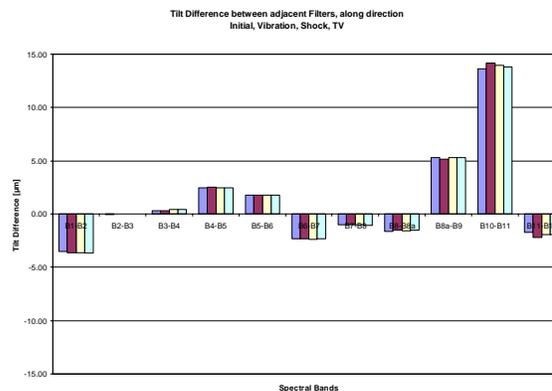


Fig. 6: Change of tilting difference of adjacent filters before and after environmental conditions

Fig. 7 and Fig. 8 show the results of the transmittance versus the wavelength for each filter measured initially and after all environmental tests.

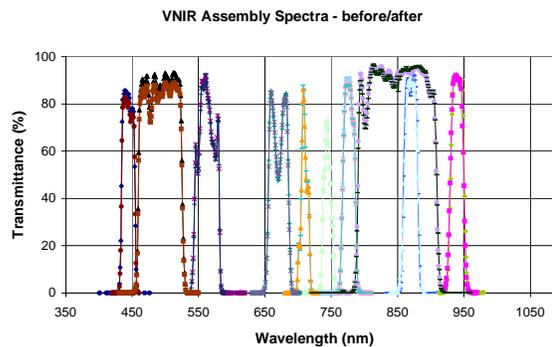


Fig. 7: Initial and final test results of transmittance vs wavelength for the VNIR filter

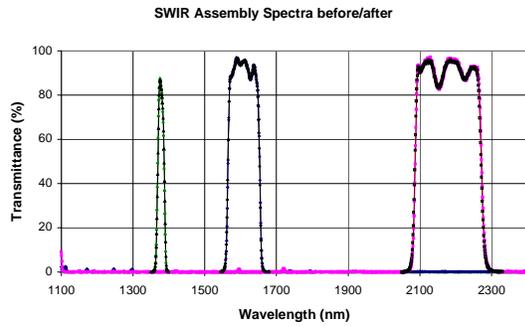


Fig. 8: Initial and final test results of transmittance vs wavelength for the SWIR filter

#### 4. CONCLUSION

The excellent qualification results demonstrated on the both breadboards of the filter assemblies and filter samples confirm that the selected design and the realized manufacturing and assembly process were correct and successful.

The specified spectral, optical, thermal and geometrical performance as well as the stability of these parameters over the whole environmental test campaign were demonstrated by the manufactured breadboards of the VNIR- and SWIR Filter Assemblies.

The successful pre-development phase is basis to start the manufacturing and qualification of the flight hardware of the filter assemblies.

A revision of the existing mechanical filter assembly design with respect to the improvement of the absorption behaviour of the black coating, the reduction of the dimensions of the upper and lower mask apertures and slanted edges of the mask apertures shall lead to a minimization of the cross talk between the spectral bands.

#### 5. ACKNOWLEDGMENTS

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