Characterization of UV-visible filters for the Wide field camera 3 of Hubble Space Telescope

[4842-10]

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ABSTRACT

A set of 48 UV-Visible (UVIS) filters in the Wide Field Camera 3 (WFC3) will be deployed in the Hubble Space Telescope (HST) in 2004. We summarize the specifications for the UVIS filters derived through interaction with the Science Oversight Committee (SOC). A detailed characterization of the 48 UVIS filters will be presented.

Keywords: WFC3, HST, UVIS filters, filter characterization

1. Introduction

In 2004, the WFC3 a fourth-generation facility instrument will be deployed to extend the operational life of HST through the next decade. A set of 48 UVIS filters were designed, fabricated and characterized for the WFC3 instrument. The UVIS filter specifications were derived closely through interaction between WFC3 Scientific Oversight Committee (SOC), which is chartered to provide scientific advice to the WFC3 project.

In this paper we summarize the specifications for the UVIS filters and the characterization approach and instrumentation used for testing the UVIS filters. A total of 98 UVIS filters (two filters from each type) were characterization. With a close consultation with the SOC members one UVIS filter from each type was selected as a flight filter.

The heritage of (WF/PC-2) and (WF/PC-1) is found in many aspects of WFC3 UVIS filters. This heritage is found in the use of three flight spare filters from WF/PC-2 among the 48 flight UVIS filters. These filters are UVIS-7 (F555W), UVIS-13 (F850LP) and UVIS-47 (G280) (UVIS-47 was fabricated for the WF/PC-2 however never installed). The UVIS filters will be installed in the refurbished WF/PC-1 SOFA filter wheel.

UVIS filters are divided into four major categories according to spectral bandwidth. These are:

The first UVIS filter category "very wideband" consist of 4 filters, UVIS-14 through 17. The substrate materials and the fabrication technology are the limiting factor to the filter spectral bandwidth in this category.

The second UVIS filter category is the "wideband". This category consists of 13 filters, UVIS-1 through 13. The FWHM in this category ranges between 300nm through 2555nm.

The third UVIS filter category is the "mediumband". This category consists of 9 filters, UVIS-18 to 25 and UVIS-49 (UVIS-49 F890LP was fabricated as a UVIS spare filter). The FW90M in this category ranges between 190nm to 870nm.

The fourth UVIS filter category is the "narrowband". This category consists of 17 filters, UVIS-26 though 41. The FW90M in this category ranges between 14nm to 228nm.

A separate 5 narrowband Quad UVIS are added to the narrowband filter category. The Quad filters are UVIS-42 through 46. The FW90M in the Quad narrowband ranges between 12nm to 112nm.

In addition to the above four UVIS filter categories, a single grism filter UVIS-47 G280 is categorized as a special filter. This grism filter was fabricated for the WF/PC-2 instrument however was never installed. The grism is a prism wedged single substrate fused silica with a transmitting diffraction gating and will be used a UV spectrometer.

The WFC3 UVIS filter specification document is available at `http://wfc3.gsfc.nasa.gov`

After the delivery of each filter a series of visual inspection and mechanical dimension measurements were performed.

The testing environment was performed in class 100,000-laboratory and flow bench arrangement. When filters were not under test, they were kept in a controlled environment (purged dry N_2, 20 °C temperature, and 30% RH storage facility).

UVIS filters characterizations approach is discussed in the following sections. These are: spectral transmission, out of band transmission, focus shift, transmitted wavefront and filter wedge.

1. Spectral Characterizations

The filters specification identifies each UVIS filter by its descriptive **filter name** (e.g. F555W) and its sequential **filter number** (e.g. UVIS 7).

The following is a summary of the UVIS filter spectral performance definitions:

λ_{-90} and λ_{+90}: The wavelengths between which the transmittance is everywhere greater than 90% of peak.

λ_{-50} and λ_{+50}: The wavelengths on either side of the passband where the transmittance equals 50% of peak and remains less than 50% of the peak for all wavelengths shortward of λ_{-50} and longward of λ_{+50} respectively.

λ_{-01} and λ_{+01}: The wavelengths on either side of the central wavelength at which the transmittance is less than 1% absolute and remains below 1% for all wavelengths shortward of λ_{-01} and longward of λ_{+01}, respectively.

FWHM: The full width at half-maximum transmittance $FWHM = [\lambda_{+50} - \lambda_{-50}]$.

FW90M: For narrowband filters, $FW90M = [\lambda_{+90} - \lambda_{-90}]$. is defined as the width over which the transmittance exceeds 90% of the peak transmittance.

λ_0: The central wavelength of the passband $\lambda_0 = [\lambda_{-50} \times \lambda_{+50}]^{1/2}$.

$T(\lambda_{-90}:\lambda_{+90})$: Acceptable minimum average value for the absolute transmittance averaged over the wavelength range from λ_{-90} to λ_{+90}.

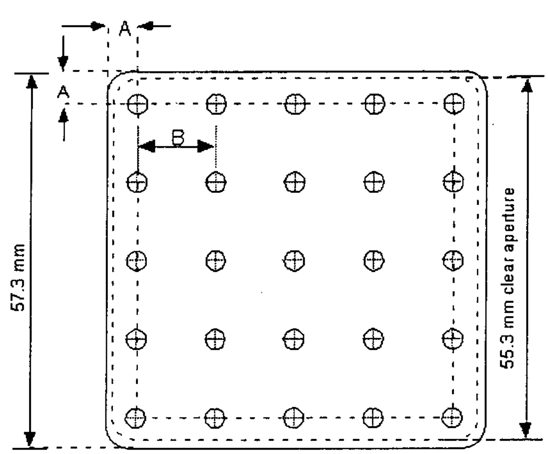
Out of Band, Max T @ λ: Out-of-band transmittance shall be less than the tabulated absolute upper limit at all wavelengths longward of the tabulated wavelength. In some cases, the out-of-band transmittance is specified stepwise at two or three wavelengths. The blocking shall extend longward of the tabulated wavelength at least to the silicon detector cutoff at 1100 nm.

OUT-OF-BAND REJECTION SHORTWARD OF THE PASSBAND

Out-of-band transmittance at wavelengths shortward of λ_{-01} is to be minimized. For all but the but the narrowband filters, the absolute transmittance at wavelengths shortward of the filter passband shall be less than 10^{-6} at all wavelengths shortward of λ_{-01} by a wavelength shift equal to the FWHM, i.e. at wavelengths $\lambda < [\lambda_{-01} - \lambda_{+50} + \lambda_{-50}]$. For the narrowband filters (for which λ_{-50} and λ_{+50}, are unspecified in Appendix A), the absolute transmittance at wavelengths shortward of the filter passband shall be less than 10^{-6} at all wavelengths $\lambda < [2\times\lambda_{-01} - \lambda_{+01}]$.

Each filters is loaded into a specially designed filter holder and loaded into the 2-axis sample stage of a modified CARY 5E spectrophotometer. Modifications to the CARY 5E spectrophotometer made at JPL were necessary to allow repeatable spectral uniformity measurements across the filter clear aperture. Using a computer controlled 2-axis driven positioning sample stage (± 0,0005mm and ± 0.001mm horizontal and vertical accuracy respectively), a uniform spaced 5x5 grid for each UVIS filter was established. The spectrophotometer controls the sample stage (x y steps) to acquire 25 individual spectral measurements across the clear aperture of each filter (Figure-1). The communication between the spectrophotometer and the sample stage is accomplished using the Application Development Language (APL) control routines developed at JPL for the WFC3 effort. To show the transmission uniformity of the individual filter, the data set is processed and 25 curves are plotted as a function of wavelength (in the desired spectral range).

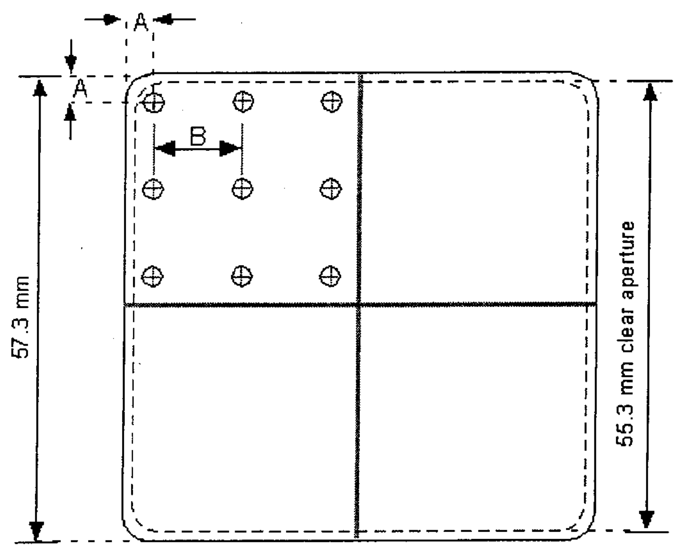
Controlling the stray-light in the sample chamber and balancing the sample light beam with that of the reference beam in the spectrophotometer were further modified made on the Cary 5E to enable out of band spectral transmission measurements below 10^{-4}. Less than 10^{-6} out of band transmission and 4nm spectral sampling was achieved.



Filter 5X5 measurements grid

Figure-1, A 5X5 grid map for the UVIS filter. Parameter "A" is 8.65 mm and 14.41mm for transmission and out of band transmission measurements respectively. Parameter B is TBD1mm and TBD2 for the transmission and out of band transmission measurements respectively

Using a different 3x3 grid size, a similar approach was used to record the transmission and out of band transmission for Quad UVIS filters Figure-2.



QUAD 3X3 measurements grid

Figure-2, A 3X3 grid map for the QUAD filters. Parameter "A" is 4.33 mm and 5.33mm for transmission and out of band transmission measurements respectively. Parameter B is TBD1mm and TBD2 for the transmission and out of band transmission measurements respectively

3. Filter Focal Shift Measurements

The filter focus shift measurements is done using an instrument developed at JPL for the WF/PC-2 filters focus shift measurements (Figure-1). A defused white light is brought to illuminate an optical target plate. The image of the target bounces through a 45 mirror and then reflected off an F/25 converging mirror. The image is then focused through an objective. The image of the target is recorded and viewed using a CCD camera that is attached to the objective assembly. A filter is first placed in position A and the target focus is established by moving the objective/CCD camera assembly. The filter is then moved to position B and another re-focus measurement is taken. This step is necessary to compensate for the chromatic aberration in the refractive elements of the objective optics. The measurements are repeated several times and an average focus shift is recoded for this filter.

The compliance of the focus shift measurements for the UVIS filters were driven by a very accurate measurements of the index of refraction of each substrate material used to fabricate the UVIS filters. Using the Facility Index of Refraction Measurement (FIRM) at GSFC, a set of specially fabricated substrate materials prisms (made from the same glass melts for the UVIS filters) were used to measure the index of refraction of each material within ± 0.0002 accuracy [1] (Required accuracy of ±0.005).

To meet the parfocal requirements of the UVIS filters the vendors used the following equation to achieve the filter substrate thickness:

$$Focus\ shift = \frac{(n_1 - 1)}{n_1} t_1 + \frac{(n_2 - 1)}{n_2} t_2 + \ldots + \frac{(n_{fs} - 1)}{n_{fs}} \times 10.922mm = 5.151mm.$$

This equation adds together the focus shifts of each plano/plano element of the optical filter ($k=1,2,\ldots$ as appropriate, where t_k is the thickness and n_k the refractive index of element k at the filter's central wavelength λ_0) plus the additional focus shifts of two optical windows in the UVIS CCD optical path. For this purpose, the focus shift of each filter is equal the focus shift of a 5.500 mm thick plano/plano fused silica substrate at a wavelength of 633 nm (refractive index of 1.457) plus the shift of two fused silica CCD windows (with refractive index n_{fs} and thick nesses of 8.382 and 2.540 mm respectively).

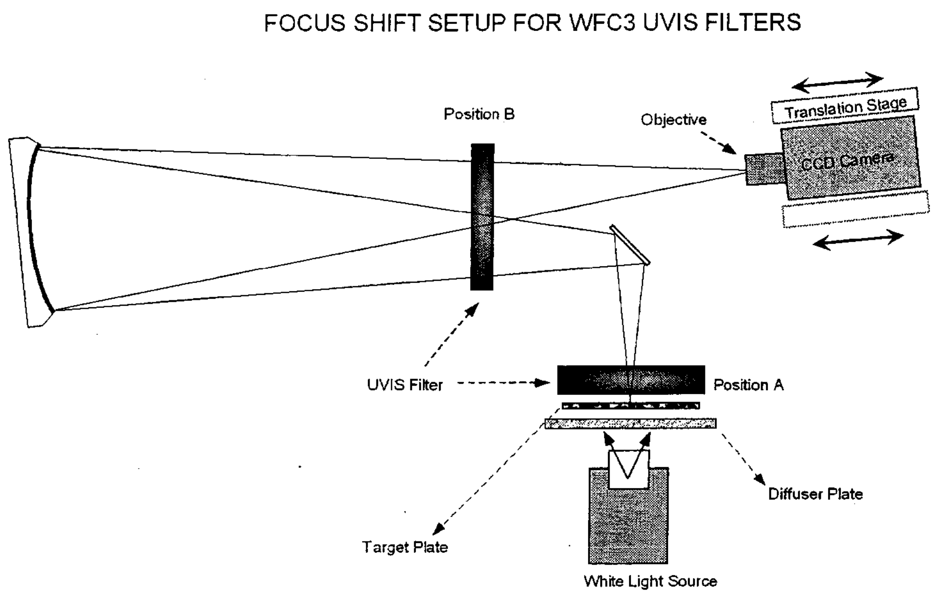


Figure-3, The focus shift setup for the UVIS filters

4. Transmitted Wavefront Measurements

The transmitted wavefront measurement for the UVIS filters is accomplished using the Broadband Achromatic Twyman-Green (BAT) [1] interferometer instrument, which was developed at JPL for the WF/PC-2 (figure-2). A high intensity white light source is directed to an order sorting filter wheel. The desired filter is selected to meet the required spectral range for the filter testing. The light beam then enters a monochromatar chamber (diffraction gating and collimating optics). The light beam bounce through a small steering mirror and a collimating spherical F/20 mirror. The beam is then divided into two light paths through a coated fused silica beam splitter.

The first interferometer light path goes through a filter holder and will be reflected back off a flat mirror. The second interferometer light path goes through a fused silica compensator window, a filter holder and will also be reflected off a flat mirror. The reflections from both legs of the interferometer are transmitted through the beam splitter and the compensator respectively. The two beams are combined at the beam splitter and reflected off the spherical mirror. Fringes are then collected at the CCD camera. A high frame rate, UV enhanced lumagin coated CCD camera is used to avoid the need for vibration isolation table.

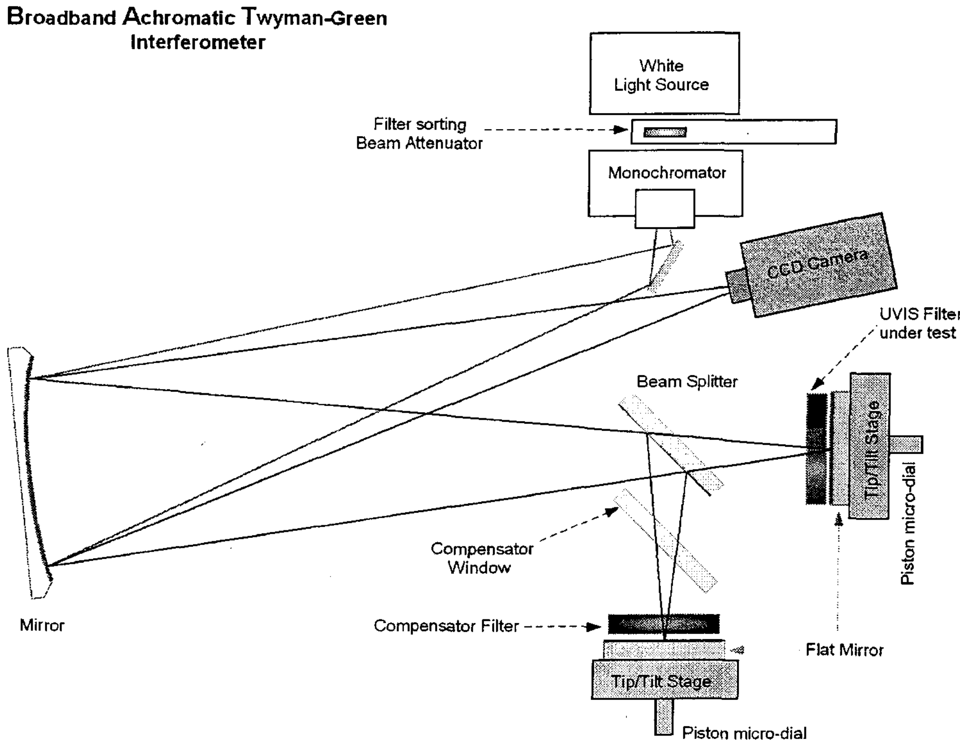


Figure-4, Broadband Achromatic Twyman-Green (BAT) Interferometer setup for the transmitted wavefront measurements of the UVIS filters

The CCD camera is attached to a frame grabber and the image of the fringes is transferred to a computer. Using "QuickFringe" (commercial software), The program will digitize the stored fringe data automatically and performs the analysis to provide the required transmitted wavefront error for the filter.

Acknowledgements

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