VCST Internal Memo

Title: Assessment of ETP-078 AOA Level Polarization Sensitivity Measurements for the VIIRS F2 VisNIR Bands
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References

[1] VCST_TECH_REPORT_14_012, 'Summary of Preliminary Analysis of FP-11 Polarization Sensitivity Data,' Jeff McIntire, January 28, 2014.
[2] 'VIIRS AOA Polarization Sensitivity Results,' Eugene Waluschka, February 13, 2013.
[3] 'JPSS J1: Initial Look at AOA Polarization Characterization Data,' Raytheon, October 11, 2012.
[4] VIIRS PRD Rev C, 'Joint Polar-orbiting Satellite System (JPSS) Visible Infrared Imaging Radiometer Suite (VIIRS) Performance Requirements Document (PRD).'
[5] VCST_TECH_MEMO_14_002, 'Assessment of FP-11 Polarization Sensitivity for the VIIRS F2 VisNIR Bands,' Jeff McIntire, March 13, 2014.
[6] Mathematical Methods in the Physical Sciences, Mary L. Boas, John Wiley & Sons, 1985.

1. Introduction

Measurements of the VIIRS F2 sensor polarization sensitivity for the VisNIR bands were made on the Aft Optics Assembly (AOA) during ETP-078. Preliminary Analysis was reported in [1-3]. This work will provide an overview of the test setup and objectives, analysis methodology, and results.

2. Objective

The objective of the ETP-078 test was to determine the sensitivity of the VIIRS instrument to input linearly polarized light. There are two specifications which relate to the polarization sensitivity of VIIRS [4]:

> **V_PRD-12624** – The VIIRS Sensor linear polarization sensitivity of the VIS and NIR bands shall be less than or equal to the values indicated in Table 1 for scan angles less than 45 degrees off Nadir.
>
> **V_PRD-12667** – The VIIRS Sensor linear polarization sensitivity shall be measured within a characterization uncertainty of 0.5% (one sigma) for scan angles less than 55.84 degrees off Nadir.

Only the first specification will be addressed in this memo.

2. Test Equipment

The test setup for ETP-078 consisted of an integrating sphere, polarizers, a shaping filter, and various baffling. A general schematic of the test setup is shown in Figure 1 indicating the placement of the filters and polarizers relative to the optical path.

An integrating sphere was used as a source for ETP-078 testing. The integrating sphere used had a 30 cm diameter.

Three different polarizers were used during testing: BVO777, BVONIR, and MOXTEK. The BVO777 and BVONIR sheet polarizers were discussed in [5]. The MOXTEK polarizer is a wire – grid polarizer. These polarizers were mounted on a rotary stage which could be cycled between 0 and 360 degrees. A second fixed polarizer of each type was used in conjunction with the first to measure the polarizer efficiency.

The Sonoma filter is a long wave blocking filter with very low transmission above about 650 nm (shown in [5]).

3. Test Configuration

Four test configurations were used during ETP-078 testing: BVO777 with the Sonoma filter, BVO777 without the Sonoma filter, BVONIR without the Sonoma filter, and MOXTEK without the Sonoma filter. Dark, efficiency, and polarization sensitivity tests were performed for each configuration, except for testing with the MOXTEK polarizer (only polarization sensitivity testing was conducted).

First, a dark test was performed to determine a stray light pedestal to remove from the response. The rotating polarizer was then cycled through 25 different angles from 0 to 360 degrees in 15 degree increments for tests.

Next, a second fixed polarizer (the same type as the rotating polarizer) was inserted into the path between the rotating polarizer and VIIRS. The rotating polarizer was then cycled through 25 different angles from 0 to 360 degrees in 15 degree increments.

Lastly, the polarization sensitivity of VIIRS instrument was measured for all four configurations. The BVO777 and BVONIR configurations were measured four times and the MOXTEK configuration was measured twice. However, the source drifted for some data sets; as a result, these data were not used. The configuration with the Sonoma filter were used to measure the sensitivity of bands M1 – M3, while the sensitivity for bands I1 – I2 and M4 – M7 was measured without the Sonoma filter. However, useful data was collected for some bands in both configurations (with and without the Sonoma filter).

4. Methodology

A standard Fourier analysis was used to determine the polarization sensitivity of the VIIRS instrument [5,6]. The Fourier expansion is written as

$$dn = \frac{1}{2} c_0 + \sum_n c_n \cos(n\alpha) + \sum_n d_n \sin(n\alpha), \qquad (1)$$

where the Fourier coefficients are defined by the following:

$$c_n = \frac{1}{\pi} \int_{-\pi}^{\pi} \cos(n\theta)\, dn(\theta)\, \partial\theta, \qquad (2)$$

and

$$d_n = \frac{1}{\pi} \int_{-\pi}^{\pi} \sin(n\theta)\, dn(\theta)\, \partial\theta. \qquad (3)$$

In this work, only the zeroth through fourth order Fourier coefficients were calculated (for the polarizer efficiency tests, only the zeroth and second order terms were calculated). Eq. (1) can be rewritten as

$$dn = \frac{1}{2} c_0 \left[1 + \sum_{n=1}^{4} a_n \cos (n\alpha - \delta_n) \right], \qquad (4)$$

where the linear polarization sensitivity of the instrument (n=2) is defined as

$$a_n = \frac{\sqrt{c_n^2 + d_n^2}}{\frac{1}{2} c_0 \sqrt{DoLP}} \qquad (5)$$

and the phase angle is defined as

$$\delta_n = \tan^{-1}\left(\frac{d_n}{c_n} \right). \qquad (6)$$

The degree of linear polarization (DoLP) of the input light is defined as

$$DoLP = \frac{\sqrt{c_2^2 + d_2^2}}{\frac{1}{2} c_0}, \qquad (7)$$

determined from the cross polarizer efficiency testing.

5. Analysis

The data received was already pre-processed into background subtracted dn. This ETP-078 data is listed in Table 2 (including the type of test and configuration). Inside the data packets were measurements corresponding to discrete polarizer sheet angles, cycled from 0 to 360 degrees in 15 degree increments. This set of 25 measurements was then used to determine the Fourier coefficients in Eqs. (2) – (3), and finally the linear polarization sensitivity and phase from Eqs. (5) and (6). First, the dark data was analyzed for stray light, and the pedestal was removed from the remaining data. Then, the cross polarizer efficiency test was analyzed; then the efficiency correction defined by Eq. (7) was used in the final polarization sensitivity calculation. Note that no stray light pedestal or efficiency correction was determined for the MOXTEK configuration; the stray light pedestal from the BVONIR configuration was used and no efficiency correction was applied.

6. Results

Cross polarizer test data was analyzed for the BVO777 and BVONIR configurations and the DoLP for each configuration was determined. The efficiency was calculated for each band and detector; the results for the BVO777 with (black) and without (red) the Sonoma filter along with the BVONIR (blue) are shown in Figure 2. For each band, the detectors are plotted on the horizontal axis. Note that there is reasonable agreement between the BVO777 measurements for most detectors in M1 – M3; the signal is much lower for these bands without the Sonoma filter, and so the efficiency is less well determined, especially for band M1. Also, the Sonoma filter blocks only part of the in-band I1 radiance; as a result, the efficiencies for the different configurations are not consistent. For the remaining bands, the signal with the Sonoma filter was too low to reliably determine the DoLP. In addition, the BVONIR polarizer results are all in the range of 60 – 80 %, whereas the efficiencies reported in [5] were all above 95 %. This is due to the fact that the second fixed polarizer was offset from the optical axis; the BVONIR sheet polarizes by scattering the unwanted light component away and scatter is not symmetric. As the polarizer rotates, the scattered light intensity varies and this has the appearance of a polarized signal. In addition, in some cases efficiencies of greater than 100 % were observed with the BVO777 polarizer (which is unphysical); this must be regarded as uncertainty in the measurement.

The polarization sensitivity was derived for all VisNIR bands and detectors. Figure 3 plots the measured dn for band M4 data from TC11 using the BVO777 polarizer without the Sonoma filter. The lines indicate the calculated Fourier series using the zeroth through fourth order terms; the Fourier series reproduces the observed behavior very well. Note that the amplitude and phase of the Fourier series varies with detector. Figure 4 shows the zeroth through fourth order Fourier coefficients for M4 versus detector. The zeroth and second order terms are dominant, but the first, third, and fourth order terms are non-negligible. The results shown in Figures 3 and 4 are indicative of all VisNIR bands. Figure 5 compares the second order term a_2 across AOA test configurations. The different test configurations generally agree on the overall magnitude and detector dependence. Offline analysis indicates that the DoLP for the BVO777 changes significantly across the I2, M1, and M7 bandpasses, whereas the BVONIR DoLP is more constant (see [5]).

The AOA polarization factors (a_2) are compared for all bands and detectors in Figure 6 to the values determined from FP-11, HAM side A, scan angle -8 degrees [5] for the BVO777 configurations. In general, the results are in agreement. Note that the signal was near saturation for the sensor level test in bands I2 and M7, so no results were reported for this assessment. For some detectors, AOA test data shows bands M1, M2, and M4 are non-compliant with the specification (up to ~ 4.8 % for M1, ~3.5 % for M2, and ~3.4 % for M4 based on BVO777 results). Also, note that there is considerable variation with detector (greater than 2.5 % for M4).

The corresponding AOA polarization phases (δ_2) are compared for all bands and detectors in Figure 7 to the values determined from FP-11, HAM side A, scan angle -8 degrees [5] for the BVO777 configurations. In general, there is good agreement between the AOA and sensor level measurements, except for the reddest bands. Here the AOA measurements were measured with a different focal plane orientation, so the AOA phases were modified for the comparison ($\delta_{2\text{-new}} = n\pi - \delta_2$ where n = 1 or 3 was used to get the phase between 0 and 2π). Note that the phase determination becomes difficult when a_2 is small, as a small change in the c_2 or d_2 causes a large change in δ_2 when c_2/d_2 approaches 0 or 1; this was particularly true for bands I2 and M7 in the BVO777 configuration.

7. Summary

ETP-078 polarization sensitivity testing was performed under at the AOA level for the VIIRS F2 sensor. Analysis showed the following:

- Linear polarization sensitivity for bands M1, M2, and M4 was observed to be higher than the specified limit (as high as ~4.8 % for M1, ~3.5 % for M2, and ~3.4 % for M4 based on BVO777 results.
- Large detector to detector and scan angle differences were observed within bands (up to ~2.5 % in M4). This is likely the result of angle of incidence changes on the filter assembly.
- Comparisons between test configurations in general agreed (using the BVO777 and BVONIR polarizer sheet as well as the wire – grid MOXTEK polarizer).
- AOA test results are consistent with sensor level testing results for the polarization factor and phase in term of magnitude and detector – to – detector variation.

Table 1: Specified maximum polarization sensitivity [4]

Band	Sensitivity [%]
I2, M1, M7	3
I1, M2, M3, M4, M5, M6	2.5

Table 2: data used in the ETP-078 test analysis

Test type	Configuration			
	BVO777 w/ Sonoma	BVO777	BVONIR	MOXTEK
Dark	TC1	TC2	TC3	
Efficiency	TC4, TC31	TC5, TC32	TC6, TC33	
Polarization Sensitivity	TC10, TC47, TC57	TC11, TC28, TC48, TC58	TC9, TC49, TC59	TC100, TC101

Figure 1: Schematic of the polarization sensitivity test setup

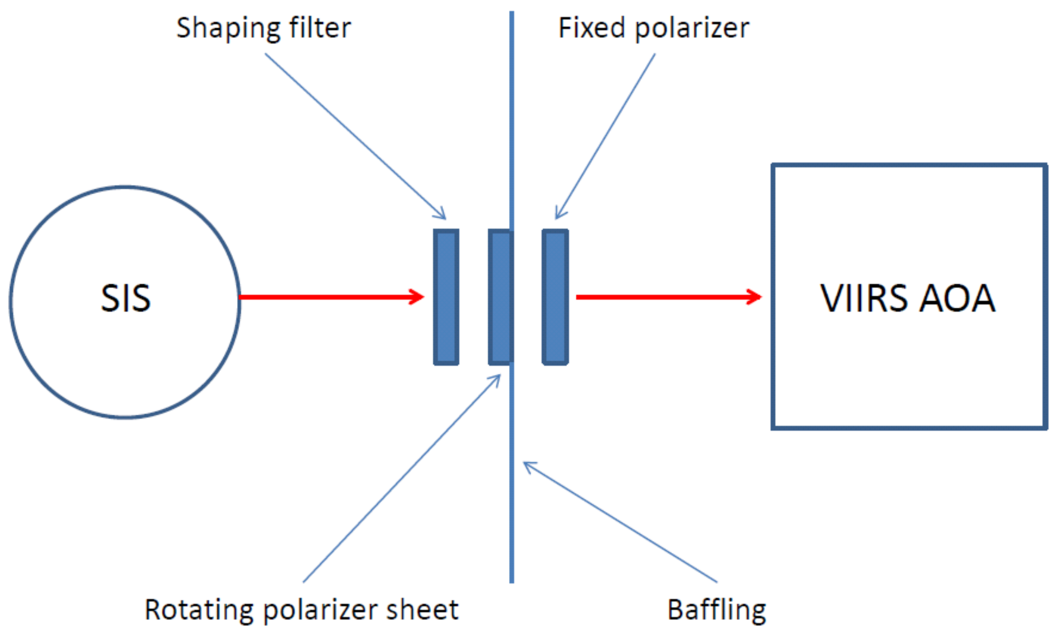

Figure 2: Polarizer efficiencies determined from ETP-078 testing

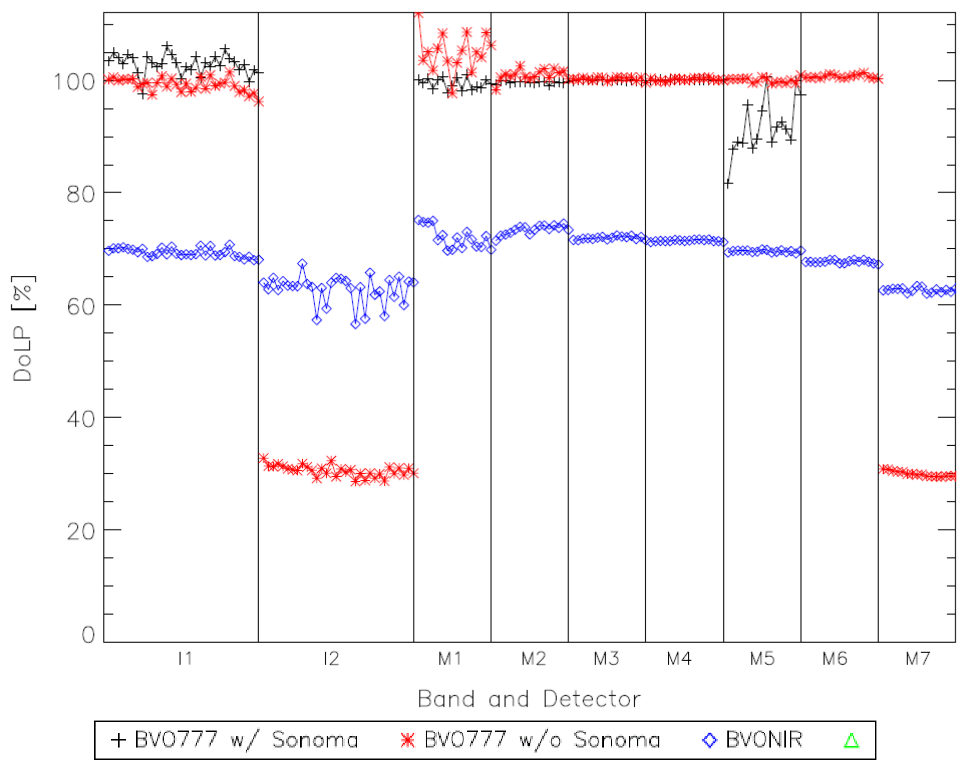

Figure 3: dn as a function of polarizer angle for M4 using BVO777 without the Sonoma filter

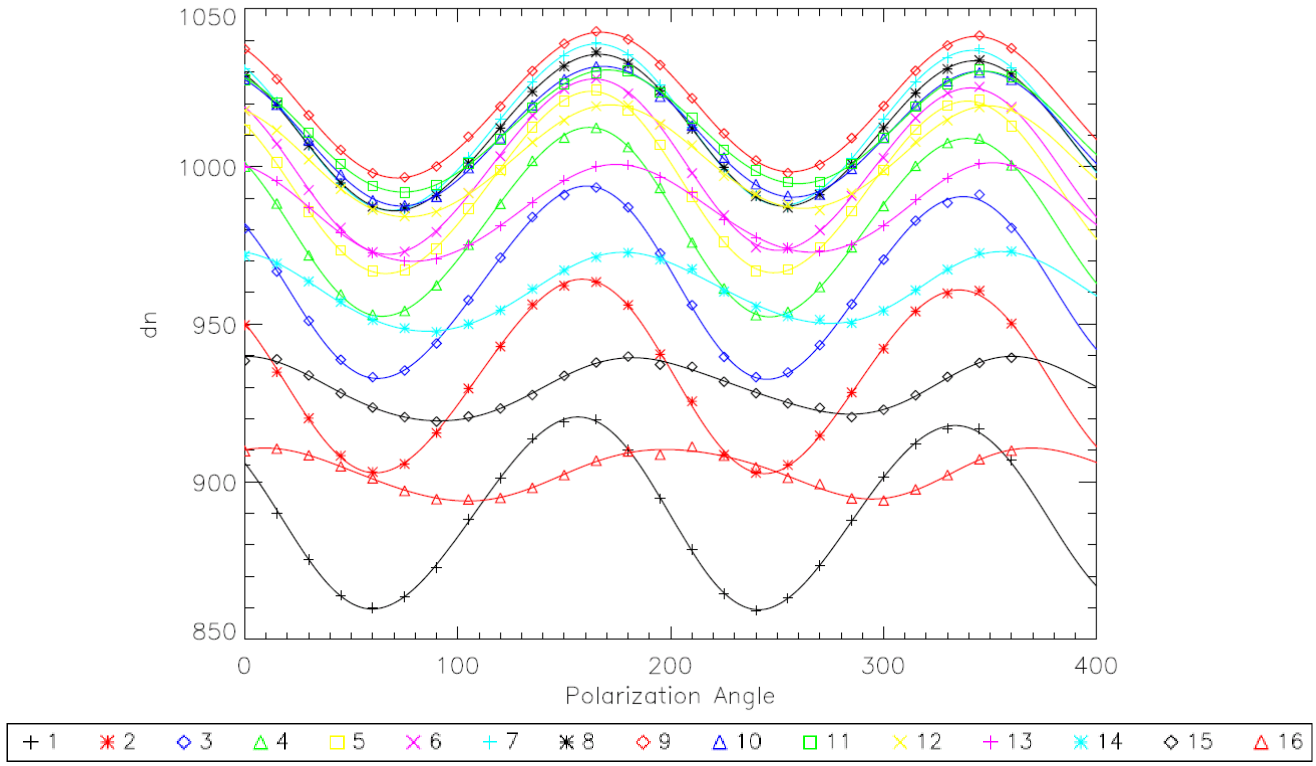

Figure 4: Fourier coefficients for M4 using BVO777 without the Sonoma filter

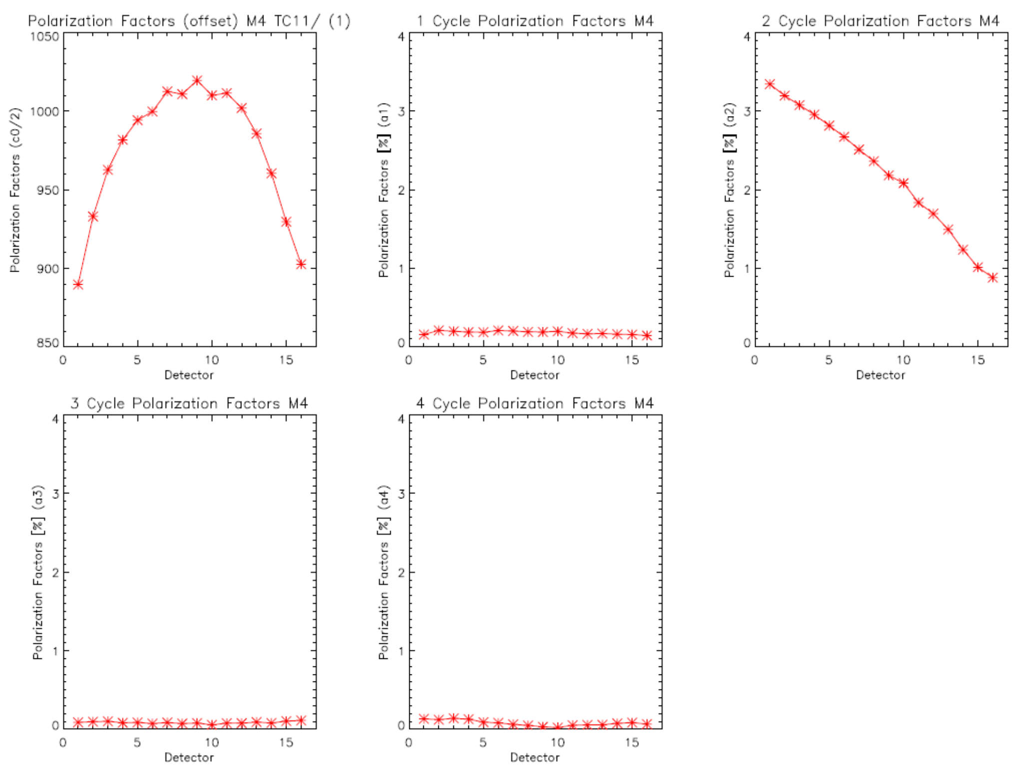

Figure 5: Polarization factor a_2 in [%] across AOA test configurations

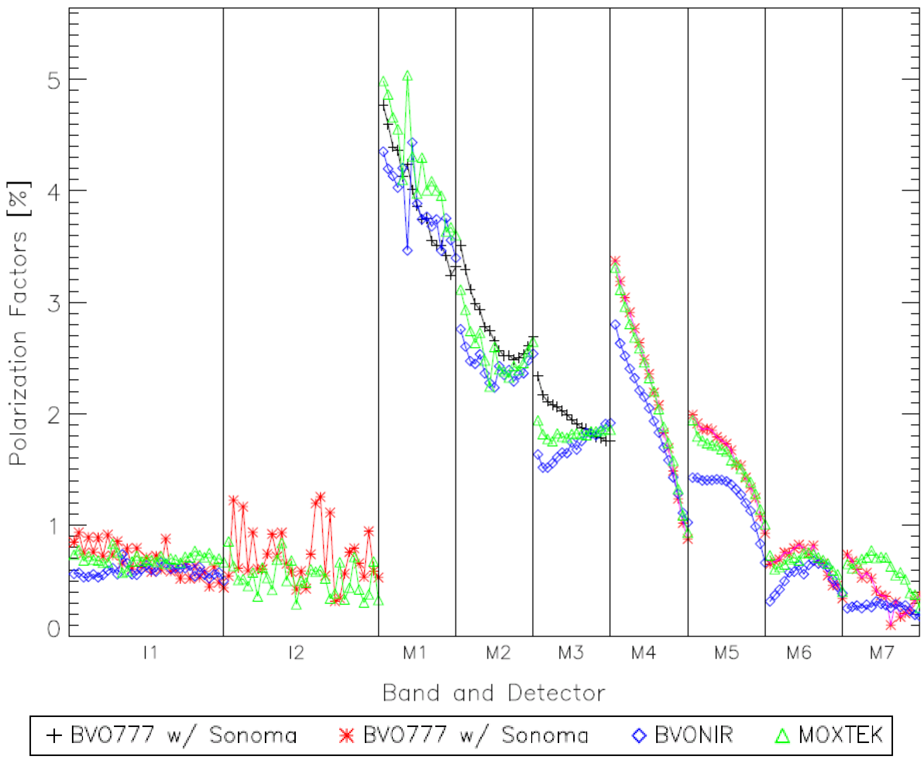

Figure 6: Polarization factor a_2 in [%] for BVO777 test configurations from AOA and sensor level tests

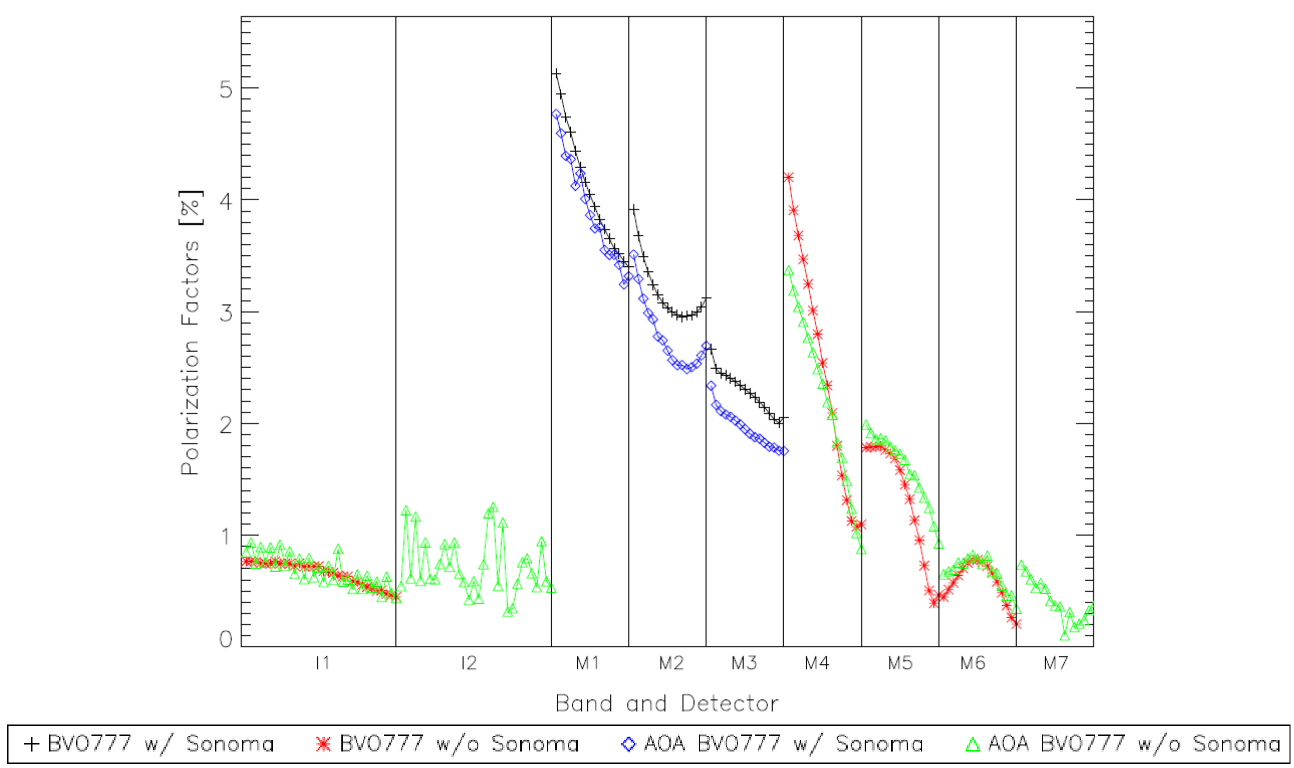

Figure 7: Polarization phase δ_2 in [radians] for BVO777 test configurations from AOA and sensor level tests